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Review of

Sprinkler Hydraulics

By Russell P. Fleming, P.E.

It is unusual to be given an opportunity to review a second edition of a book that includes, among the changes from the first edition, comments on your original book review 17 years earlier. This is the situation with the new second edition of Harold Wass's *Sprinkler Hydraulics*. In his introduction to the new edition, written shortly before his death in 1999, Mr. Wass noted that my original review was generally favorable, but included a caveat to the effect that it was written from an insurance authority's point of view. He indicated that this gave him pause, since he considered himself to be objective. The result of his deliberation was a conclusion that the insurance industry's bias is one of the more benign, noting that even fire protection consultants may have a bias, a bias toward complexity.

Actually, the book may not technically be a true second edition since it has a new expanded title: *Sprinkler Hydraulics and What It's All About*. The book is updated to include a number of changes in the *NFPA 13* sprinkler rules that have taken place since the original book was published in 1983 by IRM Insurance, where Mr. Wass was a longtime employee. There are a number of references to the latest changes in the 1999 edition of the sprinkler standard, which incorporates sprinkler design criteria formerly found within *NFPA 231* and *231C* for high-piled storage. The book also has a new publisher: the Society of Fire Protection Engineers.

by Harold S. Wass, Jr.

What remains the same is the ability of the book to take the mystery out of hydraulic calculations. Harold Wass wrote in a conversational style and basically tried to help the reader understand how water flows through piping. The book starts with brief discussions of the mathematics involved and the units of measurements, moves on to some of the advances in sprinkler technology, and then settles on the subject of hydraulic calculations. Sprinkler discharge, K-factors, design areas, friction loss formulae, equivalent lengths of fittings, and all the other elements one would expect are included. One might argue that they are all addressed in *NFPA 13* as well, but this book provides a context for many of the rules of the standard. Sample sets of calculations are provided for tree systems, with and without velocity pressures, and for a system under a sloped roof. The special flow characteristics of loops and grids are analyzed. Appendices are also especially useful. One provides friction loss tables for Schedule 40 steel pipe using a C-factor of 120, but modification factors are included for other C-factors,

piping materials, and a number of special listed piping products.

Sprinkler Hydraulics is Harold Wass's legacy, his gift to the fire protection community. It is one of a very few texts dealing with the subject of hydraulic calculations for sprinkler systems and remains the best available.

Russell P. Fleming is with the National Fire Sprinkler Association.

For ordering information, or for an online version of this article, go to www.sfpe.org.

SCIENCE and FIRE PROTECTION Engineering

Recently, the SFPE Board of Directors decided to discontinue SFPE's role as the Secretariat for the International Association for Fire Safety Science (IAFSS). For those who do not know the IAFSS (www.iafss.org), it is an international organization to promote the dissemination of fire research and science. It does this through triannual symposia, the next (7th) to be held in Worcester, MA, in 2002. The IAFSS has a world-wide membership of about 300 with officers scattered about the globe. The IAFSS will find another source of administrative services, but I was moved by this event to raise some issues to the fire protection community on the role of science. Since the IAFSS embodies the scientific pursuit of the knowledge for fire safety and the SFPE embodies the use of engineering tools to design and analyze fire safety, we need to realize how important they are to each other.

As a mechanical engineer by initial training, I have had the opportunity to view other engineering professional organizations, such as the ASME, and realize that SFPE has a long way to grow. The traditional engineering professions are grounded in core curricula, using textbooks that have basic funda-

mental information approved by the scientific community. Fire protection engineering is not at the same state. It needs the input of science, and it needs the propagation of fundamental principles within its applications to development and design. These features are represented by *The SFPE Handbook of Fire Protection Engineering, 2nd edition*. (I note not much different from the first edition.) If one examines the contents, one will see that about 30 percent of the authors are scientists who are not members of SFPE. The scientific grounding of the subject is being developed outside of the profession. This has happened in other engineering disciplines, but they are probably too old to have an active memory of the origin of the science. Most of the other disciplines have grown due to technological advances that have sparked industrial development and a market for profit. Safety does not have the same incentives.

Fire safety is bound in regulations. Knowledge of the rules makes fire protection more of a legal exercise than engineering. Many wish to change that through the acceptance of performance codes for fire safety. But examine that process: (1) We needed credible sci-

ence that could be readily used, and (2) We needed recognition of the science. I think the *SFPE Handbook* went a long way to establish that recognition and its credibility. That science, which found its way into the *Handbook*, came about from a concerted U.S. government-funded program in the 1970s that established a worldwide dialogue. The 1980s saw this drop off and the 1990s saw it sustained by those applying science rather than developing it. Indeed, the IAFSS would very eagerly move to have symposia every 2 years, but many feel that there is not enough new research to warrant that frequency.

I think it's time that members of the fire engineering profession realize the importance of science and its shortage in the field. The science eventually needs to be developed within the profession. Ways must be found to enlist the intellect of scientists to contribute once again to fire research and its science. Fire safety is a federal government responsibility, since no individual or entity has the means to fully appreciate fire hazard and risk. I urge the SFPE and its membership to recognize the need to enlist scientists and to work to establish the adequate funding sources to make the profession grow to maturity.

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CORRECTIONS

In the Fall 2000 issue, Joe Cappuccio's name was misspelled, and Andrew Bowman was not listed as being a professional engineer.

AUTOMATIC SPRINKLER SYSTEM RELIABILITY

By Edward K. Budnick, P.E.

INTRODUCTION

When automatic fire sprinkler systems, or any fire protection safety features, are included in a fire protection design package, it is assumed that, if needed, they will perform as expected. One measure of expected performance is a system's reliability. Reliability is generally reported as probabilistic, i.e., the percent success rate for a given number of systems over a fixed time period. Put more simply, the reliability (i.e., probability of success) is expressed as

$$P(\text{success}) = \frac{\text{number of successes}}{\text{total number of incidents}} \quad (1)$$

Several published studies provide reliability estimates for automatic sprinkler systems. These estimates indicate that, historically, sprinkler systems have been highly reliable. However, there are biases and limitations in the data and the analyses that restrict their usefulness. Most of the published studies do not attempt to address these limitations or any other elements of uncertainty in the estimates. Also, most of the studies are more than ten years old and, therefore, do not include more current sprinkler technologies in the databases.

Simple statistical methods are available to more accurately estimate automatic sprinkler system reliability and the uncertainty associated with such estimates. Some of these methods can handle "sparse" databases, i.e., small data sets from a few systems or from a single system over a relatively short period of time. These methods and the resulting predictions are of value to manufacturers (in developing new sprinkler technologies and identifying possible failure modes), the user (in optimizing Inspection, Testing, and Maintenance (ITM) costs and insuring

a high level of operational reliability), and the designer (in performing probabilistic-based risk analyses for new design projects). Accurate estimates of reliability are necessary inputs to risk-based analyses where failure rates and redundancy considerations must be evaluated.

This article provides a brief summary of published sprinkler reliability studies. An attempt is made to address uncertainties in the reported failure rates in a systematic manner. Rather than report the results as a single estimate of sprinkler reliability, statistical methods are used to average the individual estimates within specified confidence limits. The value of this simple analysis lies in the limit estimates. While calculating the "average" value among several available data sources does not in itself improve the quality of the estimate, the simple calculation of the range of possible estimates at least allows the user to perform limited sensitivity analyses. Such analyses provide input to risk-based assessments for existing or proposed fire safety designs.

An illustration of the use of selected statistical methods to evaluate reliability for small or "sparse" data sets is also provided. As an example, limited ITM data for several existing sprinkler systems are analyzed. The results demonstrate the potential usefulness of small or limited data sets in estimating the reliability of a specific automatic sprinkler system as well as the effects of

changing ITM frequency on those estimates. These methods can be helpful in evaluating the reliability of newer sprinkler technologies with relatively short field experience.

RELIABILITY CONCEPTS

A detailed discussion of reliability engineering is outside the scope of this article. Modarres¹ provides a more complete review of the subject. Brief descriptions of selected elements of reliability are listed below to orient the reader to the value and limitations associated with published data on automatic sprinkler system reliability.

Reliability is normally defined as an estimate of the probability that a system or component will function as designed over a designated time period. There are two components to overall reliability. *Operational reliability* is a measure of the probability that a system or component will operate as intended when called upon. It is directly affected by the types and frequency of testing and maintenance performed on the system.

Performance reliability (i.e., capability) is a measure of the adequacy of the system, once it has operated, to successfully perform its intended function. For a sprinkler system, *operational reliability* accounts for the "readiness" of the system components, while *performance reliability* addresses the "capability" of the system to perform satisfactorily under specific

fire exposures. The capability of the system is related to the scope and adequacy of the engineering design standards (e.g., *NFPA 13*) and the level of compliance of the system and its components with the standards.

Two other important concepts are *failed-safe* and *failed-dangerous*. When a sprinkler system fails safe, it operates when no fire event has occurred. An accidental discharge of a sprinkler is an example of a failed-safe condition. A failed-dangerous condition occurs when a system does not function when needed, e.g., a sprinkler fails to open, or the water supply is unavailable.

Studies that rely on fire incident data to estimate automatic sprinkler system reliability mix both *operational* and *performance* reliability elements. They also typically do not include failed-safe incidents in the analysis. On the other hand, studies that rely on testing and maintenance data are, for the most part, providing estimates of *operational reliability*.

PUBLISHED STUDIES

Several studies have been published that report estimates of automatic sprinkler system “reliability.” For the most part, these studies provide estimates based on review of actual fire incidents where automatic sprinklers were present. As a group, they vary significantly in terms of reporting periods, the types of occupancies, and the level of detail regarding the types of fire incidents and sprinkler system design. Nevertheless, such studies are routinely referenced and provide some basis for estimating sprinkler system reliability.

Table 1 provides a summary of the reported reliability estimates. The three occupancy categories reflect occupancy type variations in the reported estimates. Several studies provided reliability estimates for “commercial” occupancies. These are grouped accordingly in the table. The estimates grouped under the “general” occupancy category were from studies that grouped commercial, residential, and institutional occupancies into a single database.

The estimates indicate relatively high reliability for automatic fire sprinkler systems. However, significant variation

exists among the various studies. The reported reliability estimates range from 81.3 percent to 99.5 percent. These differences may be attributable to any number of variations in the protocols or the databases used by each study. For example, the relatively low value of 81.3 percent² as well as the somewhat higher value of 87.6 percent reported by Kook³ appear to reflect biases in the databases. In both studies, the number of incidents was relatively small. And, while most of the suppression systems in the databases were sprinkler systems, apparently other types of suppression systems were also included. In addition, the high-end estimates of 99.5 percent reported by Maybee⁴ and Marryat⁵ reflect sprinkler system performance in occupancies where inspection, testing, and maintenance were rigorous and exceeded customary requirements for ITM activities. If these studies were excluded from the group, the range of reliability estimates for the remaining studies is from 86 percent to 97.9 percent, which still represents a significant range.

An additional limitation in the reported sprinkler reliability estimates is that most of the sprinkler systems were more than 15 years old. Therefore, while the reliability estimates provide reasonable information for conventional spray sprinkler tech-

nology, it may not be appropriate to rely on these estimates to evaluate the reliability of newer technologies such as quick response, residential, and ESFR sprinklers without addressing additional factors.

LIMITED UNCERTAINTY ANALYSIS

Estimates of reliability are required input to fire risk assessments. The applicability and accuracy of such estimates are perpetuated through the risk analysis and directly reflected in the performance outcomes. The estimates compiled in Table 1 demonstrate variability in sprinkler system reliability among different studies. Unless the parameters of a particular study match those of interest, reliance on the estimate of reliability from a single study can incorrectly alter the results of a risk assessment.

Relatively simple statistical methods are employed here to provide both “estimates” of sprinkler system reliability and measures of “uncertainty” associated with the reported estimates. Uncertainty is reported as confidence intervals, i.e., the upper and lower bounds associated with the reliability estimate.

The estimates of reliability are simple calculations of the “mean” of the values reported in Table 1. The confidence intervals are calculated based

TABLE 1. Selected Automatic Sprinkler Reliability Studies (percent)

Occupancy	Reference	Reliability Value (of success)
Commercial	Milne ⁶	96.6/97.6/89.2
	NFPA ⁷	90.8-98.2
	Miller ⁷	86
	Maybee ⁴	99.5
	Kook ³	87.6
	Taylor ²	81.3
	Linder ⁹	96
General	Miller ⁸	95.8
	Miller ⁸	94.8
	Powers ¹⁰	96.2
	Richardson ¹¹	96
	Finucane et al. ¹²	96.9-97.9
	Marryat ⁵	99.5

on the degree of certainty required. There are many factors that are involved in selecting a degree of certainty. In its simplest form, it is a measure of the likelihood that the actual mean value falls within the confidence intervals. Assuming normal distribution, the higher the accuracy desired, the wider the confidence intervals (and the higher the required certainty).

Mean reliability estimates and 95 percent confidence limits were calculated for each of the occupancy categories represented in the data sources. Similar estimates were calculated for a category referred to as “combined,” which is simply combined estimates for both the commercial and general categories. The 95 percent confidence limits were selected as representative of confidence limits typically used for quality assurance estimates for manufactured machine parts. Other confidence limits are routinely used, depending on the required certainty associated with a particular product or system. Table 2 provides a summary of the results of this analysis.

This relatively simple effort at estimating variance in reported data improves the statistical certainty of the reported reliability estimates. For example, for the three occupancy categories presented in Table 2, the “mean” reliability estimates range from 93.1 to 96.0 percent, a relatively small range, and much smaller than the range associated with the raw reliability estimates in Table 1. Greater confidence in the estimates is also provided by reporting a range of estimates using upper and lower confidence limits. This information reduces the uncertainty in estimating the impact of sprinkler system reliability in risk-based design evaluations.

ANALYSIS OF SMALL DATA SETS

Field performance data for new sprinkler technologies are limited. Therefore, in order to estimate the reliability of these systems or components, methods must be used that can handle small data sets. The results from a pilot study¹³ of several existing automatic sprinkler systems are used to demonstrate the usefulness of such analyses.

Table 2. Reliability Estimates for Sprinkler Systems

	Commercial	General	Combined
Lower confidence limit (95%)	88.1	93.9	92.2
Mean (%)	93.1	96.0	94.6
Upper confidence limit (95%)	98.1	98.1	97.1
Number of referenced studies	9	7	16

Note: Combined = Commercial and General

Selection of the Pilot Study System(s)

An important step in the pilot study was the selection of the sprinkler systems and collection of the data to be studied. This was accomplished by reviewing existing sprinkler system ITM data, in addition to available system drawings and documentation. Detailed ITM records were obtained for a 66-month period for several sprinkler systems in the same complex of buildings.

Development of System and Component ITM Database

The second element of the study was the development of a database. The raw ITM data collected for the sprinkler systems were reviewed and an appropriate database scheme developed. The data obtained from the ITM reports were placed in a spreadsheet database in the statistical package.¹⁴ This statistical package offers the ability to serve as a database and a statistical tool for analysis.

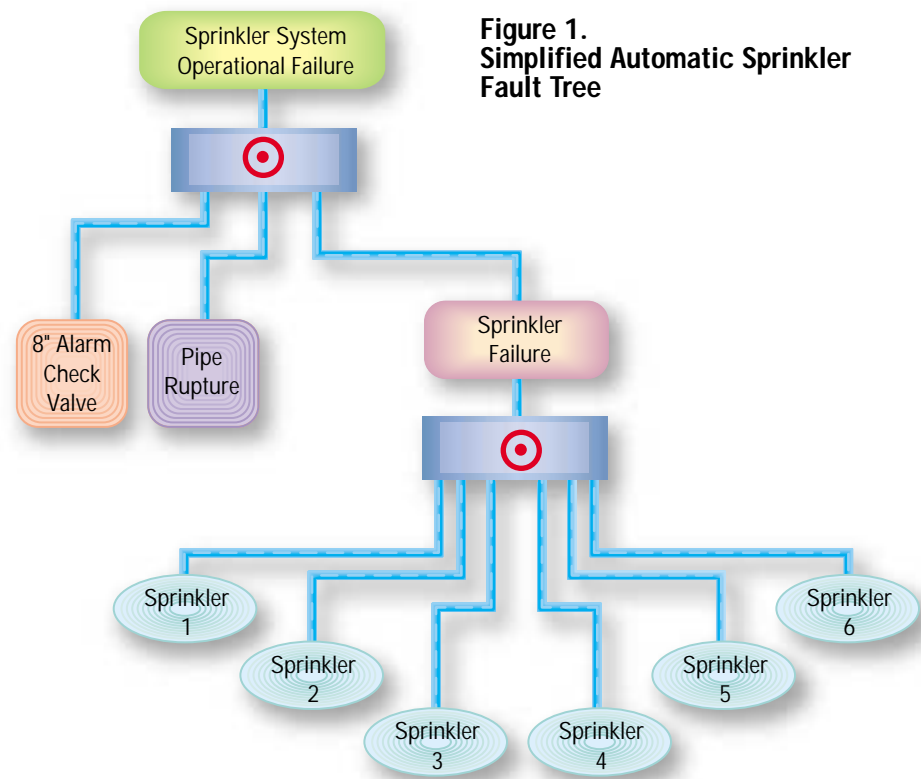


Figure 1. Simplified Automatic Sprinkler Fault Tree

The database spreadsheet set up each inspection form as an individual case. The ITM results were entered for each component in each system identified by the test record. The results for all component tests were either "pass" or "fail."

Development of System Fault Trees

Once component failure rates were developed, system schematics were used to develop fault trees for individual systems. Figure 1 provides a summarized version of the fault tree design. The fault tree structures were programmed into spreadsheets. The spreadsheet programs allowed failure probability and reliability information to be propagated through the systems using the fault tree models, resulting in an overall system reliability estimate.

Once the baseline system reliability information was obtained, further analysis was performed to examine testing and inspection intervals and how altering these intervals affected the system's reliability. The use of fault trees provided information that offers insight into testing and inspection frequencies and established a means to track system performance.

Fault trees were constructed for each sprinkler system. For the fault tree models, the system's boundaries were defined as the base of the system riser to the sprinkler grid. Defining the

system with boundaries at the riser and sprinkler grid assumed that the water supply was 100 percent reliable.

Component Failure Rates

The model used to develop component failure rates was the Exponential Model for Life Testing (EMLT).¹³ The EMLT model defines the estimate of the mean life (μ) of a component as

$$\mu = \frac{T_r}{r} \quad (2)$$

where

T_r = accumulated time on test, and

r = number of component fires.

The confidence interval about the mean is given by

$$\frac{2T_r}{X_{\alpha/2}^2} < \mu < \frac{2T_r}{X_{1-\alpha/2}^2} \quad (3)$$

where $X_{\alpha/2}^2$ is dependent on the degrees of freedom (DF) and found in statistical tables, and
DF = 2(r).

The 95 percent confidence interval about the estimated mean was calculated for each component failure rate. The individual system components' failure rates are provided in Table 3 along with the industry reported failure rates for similar components.

Reliability Estimates

Table 4 provides the reliability estimates and associated uncertainty of the system fault tree model calculations. The analysis was performed using the existing ITM frequencies, checking manual valve positions, and sprinkler and pipe inspections conducted each month. The existing frequency tests all other system components quarterly. The system fault tree models were then used to estimate the reliability of the sprinkler system if the monthly inspections were extended to quarterly frequencies. In addition to the actual component failure data, industry component failure data for similar components were used in the fault trees. The reported confidence intervals were also propagated to allow for comparison.

The uncertainty intervals reported for the system reliability estimates reflect the propagation of the 95 percent confidence interval about the mean component failure rates through the fault tree models. This was accomplished by quantifying the component failure rate distributions as fuzzy sets and using interval arithmetic in the fault tree model. Singer¹⁶ presents the theory and methodology for this quantification and propagation.

The mean reliability estimates illustrate the reduction in system reliability that occurs when ITM frequencies are

Table 3. Component Failure Rates

Component	Number of Components in Database	Total Hours in System	Pilot Systems ITM Data 95% Confidence Interval Failure Rate (failures/hour)	Industry Failure Rate (failures/hour)
PIV	10	480,480	0	N/A
ACV	10	480,480	0	¹ 4.0 x 10 ⁻⁶
OSY	172	8,264,256	7.5x10 ⁻⁸ < 3.6x10 ⁻⁷ < 8.7x10 ⁻⁷	¹ 4.0 x 10 ⁻⁶
Main Drain	10	480,480	0	4.0 x 10 ⁻⁶
Inspector's Test	10	480,480	2.3x10 ⁻⁶ < 8.3x10 ⁻⁶ < 1.8x10 ⁻⁵	4.0 x 10 ⁻⁶
Flow Alarm	10	480,480	5.8x10 ⁻⁶ < 1.5x10 ⁻⁵ < 2.7x10 ⁻⁵	² 4.6 x 10 ⁻⁸
Motor Gong	10	480,480	4.1x10 ⁻⁵ < 2.5x10 ⁻⁵ < 1.3x10 ⁻⁵	² 2.0 x 10 ⁻⁶
Fire Department Connection	10	480,480	0	N/A
Piping (gasket failure)	10	480,480	5.0x10 ⁻⁷ < 4.0x10 ⁻⁶ < 1.2x10 ⁻⁵	¹ 1.0 x 10 ⁻⁶

Note: 1 from Finucane and Pickney¹²
2 from WASH-1400¹⁵

Table 4. Sprinkler System Reliability Estimates and 95% Confidence Limits for Six Existing Sprinkler Systems¹³

System	System Reliability at Current Component Testing Frequency ¹	System Reliability Using Industry Component Failure Rate Data and Current Testing Frequency	System Reliability for All ITM at 3-Month Frequency Using Pilot Component Failure Rate Data	System Reliability for All ITM at 3-Month Frequency Using Industry Component Failure Rate Data
System 1	0.949<0.993<0.999	0.864<0.984<0.997	0.854<0.978<0.998	0.684<0.971<0.996
System 2	0.949<0.993<0.999	0.840<0.971<0.994	0.854<0.978<0.998	0.665<0.963<0.993
System 3	0.949<0.993<0.999	0.864<0.984<0.997	0.854<0.978<0.998	0.684<0.971<0.996
System 4	0.949<0.993<0.999	0.864<0.984<0.997	0.854<0.978<0.998	0.684<0.971<0.996
System 5	0.949<0.993<0.999	0.864<0.984<0.997	0.854<0.978<0.998	0.684<0.971<0.996
System 6	0.948<0.993<0.999	0.856<0.981<0.996	0.852<0.978<0.997	0.665<0.963<0.993

Note:¹ Monthly tests of manual valves, sprinklers, and piping; quarterly frequency for other components.

reduced. Not only does system reliability decrease with reduced ITM frequencies, but also the uncertainty associated in the lower reliability direction of the uncertainty interval becomes larger. This is an element of system reliability analysis that is often overlooked but greatly affects the interpretation of the results and clearly demonstrates the limitations of a given database. As the database is expanded, uncertainty associated with the reliability estimates will be reduced.

The results of this effort suggest that meaningful reliability estimates can be obtained for sprinkler systems with limited data. This capability is helpful in addressing specific types of systems (including those using newer technologies) or systems exposed to similar environments. Based on the results of such analysis, ITM frequencies or system components can be tailored to achieve a desired reliability based on the specific system in question rather than general industry values.

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Edward K. Budnick, P.E., is with Hughes Associates.

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MICROBIOLOGICALLY INFLUENCED CORROSION IN FIRE SPRINKLER SYSTEMS

By Bruce H. Clarke

INTRODUCTION

Numerous reports in the past decade have described the rapid development of pinhole-sized leaks and highly obstructive interior growth developments in sprinkler system piping, fittings, and supply tanks. Some occurrences have been reported after less than one year of system service.¹ In many of these cases, the cause has been found to be microbiologically influenced corrosion (MIC).

MIC in fire sprinkler systems has grown from an obscure topic of regional discussions in the early 1990s to one now generating widespread concern, speculation, and debate throughout several countries. Unfortunately the building owner, fire protection engineer, and contractor faced with addressing this problem still have relatively few universally accepted practices within our industry to reference. In fact, many calls for help are still answered with theoretical treatment solutions and, in some cases, inaccuracies. And while most fire protection professionals have now heard of this problem, proper diagnosis and treatment are still not fully understood.

MIC DEFINED

Corrosion occurs in many forms and can be defined from many scientific viewpoints. Microbiologically influenced corrosion is one type. For the fire protection discipline, it can specifically be defined as:

An electrochemical corrosion process that is concentrated and accelerated by the activity of specific bacteria within a fire sprinkler system, which results in the premature failure of metallic system components.

This definition fully captures both cause and effect. But a more detailed review is required to fully clarify the true nature of MIC and the complexities in addressing this problem.

Electrochemical Corrosion Process

Metallic materials can degrade and fail from various causes including corrosion. In general, corrosion can be defined as the “wearing away of material.” As in other forms of corrosion, with MIC the “wearing away” or removal of material occurs through a series of *electrochemical* interactions. Thus both an “electrical” and a “chemical” component are required for MIC. The electrical component occurs through electron transfer.² This is basi-

cally the removal of pipe wall material one electron at a time. Electrons are stripped away from pipe material atoms through various forms of oxidation which are dependent on the bacteria involved. The chemical component is the result of the bacterial metabolic process that occurs. This creates various organic and mineral acids which chemically decompose metallic surfaces from direct contact.³ The section on THE MIC PROCESS will describe this in more detail.

Concentrated and Accelerated

The MIC process is both *concentrated* and *accelerated* in comparison to typical corrosion seen in sprinkler systems. All metallic systems normally begin to corrode from the instant moisture meets metal. This is called general or uniform corrosion.

With general corrosion, a thin layer of oxidation occurs relatively evenly throughout the entire pipe wall surface. This type of corrosion is typically not treated nor a significant concern in fire sprinkler systems. This is because it does not significantly change a pipe's interior surface roughness (i.e., “C-factor”), and the rate of decay is naturally self-limiting. A typical corrosion rate in sprinkler pipe is highly dependent on

water quality but is usually negligible at under 1.0 mil/year. With MIC, this relatively slow corrosion rate is abnormally accelerated up to 10 mils/year. Put in perspective, schedule 40 pipe has a wall thickness of approximately 20 mils.

When microbiologically influenced corrosion occurs, general corrosion also becomes concentrated, or localized, into high-activity pockets or cells. This causes pitting, which can drastically change a previously smooth interior pipe wall surface and its associated "C-factor."

Activity of Specific Bacteria

As defined, MIC is from the activity of *specific* bacteria. Various bacteria are present in all ecosystems. Sprinkler systems also normally have many kinds, but only a relatively small number have the potential to cause rapid system destruction. Only a few *specific* bacteria *concentrate* and *accelerate* the general corrosion process. Thus a high "general" bacteria count is meaningless. It is important to understand that the bacteria associated with MIC do not produce a new corrosion process but, as stated, simply concentrate and

accelerate general corrosion which is already occurring.³ Microbiology influences, not induces, corrosion.

How are these "specific" bacteria defined? MIC-related bacteria are primarily classified by oxygen tolerance: being *aerobic* or *anaerobic*. *Aerobic* bacteria require oxygen to flourish and reproduce. *Anaerobic* bacteria are those that do not require oxygen to flourish and reproduce.¹ And, while most species only flourish with one atmosphere and find the other toxic, facultative bacteria can survive in both aerobic and anaerobic environments. All three types play a role in the relatively complex and random interactions that can occur in microbiologically influenced corrosion.⁴

In defining bacteria further, classification is not absolute and can become relatively confusing. The most commonly used method of categorizing bacteria associated with MIC further is by metabolism. These labels are basically definitions of what each bacteria

type eats (or metabolizes) and excretes as a byproduct. As these terms imply, where plants use photosynthesis (i.e., light) to develop energy, bacteria use chemosynthesis (i.e., eating/breathing various chemicals or minerals).

However, use of these metabolic tags are not universally replicated and can be somewhat confusing. A single bacteria type may fall under more than one metabolic definition. Some of the commonly referenced categories include Sulfur-Reducing Bacteria, Metal-Reducing Bacteria, Acid-Producing Bacteria, Iron-Depositing Bacteria, Low-Nutrient Bacteria, Iron-Related Bacteria, Iron-Reducing Bacteria, Iron-Oxidizing Bacteria, Sulfate-Oxidizing Bacteria, Slime-Forming Bacteria, Sulfate-Reducing Bacteria, and Iron Bacteria.^{1,2,4}

Finally, all bacteria can be classified by their scientific name under phylum, class, order, family, genus, or species.⁵ For example, one type of sulfate-reducing bacteria is anaerobic and metabolizes sulphate to sulphide. The sulfate-reducing bacteria group includes the genera *Desulfovibrio*, *Desulfobacter*, and *Desulfomaculum*.² All are of the phylum *Thioprotheutes*, which interestingly translates from Greek to "sulfur-breathers."

Within a Fire Sprinkler System

The specific source of MIC is consciously omitted from the captioned definition. Bacteria is only indicated to be *within the fire sprinkler system*.

Typically, a sprinkler system's water supply is incorrectly considered to be the only source for bacteria. Although there currently are no conclusive relational studies in the fire protection industry, there are growing beliefs this is not the only source of bacterial infection. Besides all water sources, bacteria capable of causing MIC are potentially present in all soil, air, and cutting oils. Thus the manufacture, shipping, storage, and flushing of system materials should be addressed in all MIC investigations.



Obstructive growth from MIC

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MIC does not only occur in water-filled systems. Dry pipe systems are also susceptible.¹ In fact, evidence shows that dry systems may be more susceptible to damage than fully wet systems due to the humidified atmosphere that is created after a first trip test. This could create the right atmospheric moisture content for some bacterial types to thrive.



Above Top: Interior pitting and roughness created by MIC.
Bottom: Exterior pinhole.

Premature Failure

The ultimate effect of MIC is the *premature failure* of metallic components. This failure can take two forms. First is the failure of a system to hold water (i.e., leakage requiring component replacement). This is most often seen in the development of the pinhole-sized leaks often referenced as a primary MIC infection indicator. This is also typically the only concern in many treatment investigations.

Second, and more concerning, is the failure of a system to achieve its designed purpose: that of fire control. Several systems with MIC have been found with sprinkler drops completely plugged with the debris generated as a byproduct of the MIC process (called biofilm or biosludge). Sprinkler system feed mains have also been found with up to 60% obstruction from biological growth.⁶ This could present an obvious hydraulic concern as many sprinkler systems today will not provide fire control with just a 15%-20% flow reduction due to design.

What is considered *premature*? With regard to system function, at any time a system is "in service" and fails to operate as designed, it has

experienced "premature failure." If a system is operational and properly maintained, it is *always* expected to work as intended. This is the foundation for the public's trust we build upon in selling the value of sprinklers. Unfortunately, like the recent Omega sprinkler which was recalled after it did not perform as expected in *every* instance, the effects of MIC could conceivably be the next large public relations problem our industry will have to address.

What constitutes premature with regard to the integrity of specific system components must also be discussed. Long-term warranties are not typical with system components, but with proper maintenance, a sprinkler system is typically expected to last for a minimum of 30-60 years before major repairs are required.

Metallic System Components

The word *components* and not simply "pipe" is used as the captioned point-of-failure. While pipe is the typically seen failure point, there are increasing reports that sprinkler orifice caps, control valves, fittings, and supply tanks are also being damaged. Only *metallic* components are susceptible to MIC, while plastic materials are not directly susceptible.

Plastic components are, however, subject to bacterial debris blockage from upstream bacterial activity in metallic components. The term *metallic* is also chosen over steel. With the exception of a possibly very select few steel alloys, virtually *all* metallic materials currently in use today are susceptible to biological corrosion.

THE MIC PROCESS

The corrosion process can be very complex with many variable interactions at a cellular level between aerobic, anaerobic, and facultative bacteria. However, several steps in the process are somewhat universal: ^{1, 2, 3, 4}



Above: Interior biofilm buildup with clearly seen corrosion cell tubercle shell.

Left: Interior biofilm growth and exterior pinhole leak – at approximate two o'clock point on pipe wall.

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1. Bacteria enter the system, attach to metallic components, and begin to rapidly colonize and reproduce.
2. Aerobic colonies metabolize nutrients from the water and/or the metal surfaces they are attached to, and subsequently excrete a polymer film byproduct that bonds together to form crustaceous nodules called tubercles.
3. Tubercles and associated biofilms create microenvironments on the metallic material surface (under the tubercles).
4. The underdeposit area (i.e., under the tubercles) becomes oxygen-depleted (i.e., anaerobic and anodic) in relation to the surrounding system water or air (which remains aerobic and cathodic).
5. Underdeposit anaerobic bacteria metabolize pipe wall materials and excrete an acidic byproduct. Relative acidity and alkalinity levels within the tubercle shells are reduced to an approximate 2-4 pH, which chemically attacks the metallic component surface.

The described corrosion process can continue indefinitely until the aerobic and anaerobic bacteria in the system are killed. The tubercles created from colonization must also be broken down to destroy the underdeposit microenvironment. This is because even without bacteria in the underdeposit of a corrosion cell, the process can still continue indefinitely as the corrosion chain in its final phases is no longer reliant on their activity.

CURRENT TREATMENT REFERENCES

Currently, the fire protection industry has a very limited amount of usable references supported by scientific data. However, several allied groups can provide excellent information on data from other industries.

The National Association of Corrosion Engineers (NACE) has many published studies and overviews about MIC detection and treatment. The American Society for Testing and Materials (ASTM) offers several publications on proper bacterial testing practices.

The American Water Works Association offers standards describing the proper management of the somewhat hazardous chemicals typically used in injection devices attached to sprinkler systems for microbial control. Depending on how a facility's water is supplied, this may be a very important reference to maintain compliance with the nationally mandated Safe Water Drinking Act. The B300 series of publications specifically address disinfection chemicals (such as hypochlorites commonly used in treatment), and the B500 series of documents specifically addresses scale and corrosion control chemicals (such as the phosphates commonly used in treatment).

The National Fire Protection Association (NFPA) fire codes also address MIC. But these references are still very limited. The most impacting to our industry thus far was a section added to the 1999 edition of *NFPA 13: Standard for the Installation of Sprinkler Systems*. Section 9-1.5 covering water supply treatment states:

In areas with water supplies known to have contributed to microbiologically influenced corrosion (MIC) of sprinkler system piping, water supplies shall be tested and appropriately treated prior to filling or testing of metallic piping systems.

While this has generated a flood of needed curiosity, it does little to address the resulting questions about proper treatment. First, there is no explanation as to what is considered an area "known to have contributed to microbiologically influenced corrosion." Data indicates data thus far on confirmed cases have been widely inconsistent, varying within city blocks and even within building complexes fed off common loops. If one case is found in a given municipal area, is the entire community served by the same water supply now considered a "biological activity area?"

It also requires that building owners be fully familiar with the sources of their fire protection water. This can be very difficult as many municipalities switch between and blend multiple sources such as canals, various wells, rivers, lakes, and reservoirs. It also

does not address the fact that contamination can come from sources other than the water supply, as already discussed.

Finally, this section indicates that sprinkler systems "shall be tested and appropriately treated prior to filling." The "who," "how," and "when" are still in debate by those addressing this issue. *Who* is truly qualified to make the determination of *when* a failure is the result of MIC and if a biocidal treatment program will prevent all future failures? And *how* is a system best tested (i.e., most accurately and cost-effectively) to confirm MIC? Almost anything requiring laboratory work can be overtested... at a price. These are questions where answers are still evolving.

National Fire Code 25: Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems, 1998 Edition, Section 10 and Appendix 10 discuss MIC treatment and detection in some detail. *NFPA 25* also provides other inspection requirements that can be useful. These include:

Section 7-3.4.1 stating "...system piping and fittings shall be inspected quarterly for external conditions (e.g., missing or damaged paint or coatings, rust, and corrosion."

Section 7-3.6 stating "...the dependability of the water supply shall be ensured by regular inspection and maintenance, whether furnished by a municipal source, on-site storage tanks, a fire pump, or private underground piping systems."

TREATMENT

The analysis required to properly select a course of action to address MIC is typically outside of the scope of work that most sprinkler contractors and engineers are competent to directly provide. Thus, until treatment methods become universally proven and standardized, the most critical step in proper mitigation begins with the selection of a qualified corrosion control consultant.

With the wrong choice, a building owner could spend a large amount of

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money on a problem that will likely recur. And a poor treatment choice could actually accelerate the corrosion rate and affected area beyond that experienced before treatment.

The company chosen to determine treatment must have a detailed knowledge not only of microbial corrosion control but also of metallurgy and sprinkler system dynamics. Fire sprinkler systems have flow characteristics and concerns that are much different from most common industrial process systems where MIC is typically addressed.

Most other industries deal with MIC in systems containing fluids that are either always static or always flowing. And unlike sprinkler systems, dynamic systems have flow rates that are relatively constant, making prescribed chemical dose rates constant. A constant flow rate does not occur in sprinkler systems. Variable differences are seen with system drains and refills, inspectors testing, and main drain tests. The dose rate for each of these flows must be considered to ensure the chemical injection rate is always effective. Most other industrial systems also have multiple points where biocidal chemicals can be injected. Sprinkler system water can realistically only be treated at system risers, back flow apparatus, or suction tanks.

Finally, as previously stated, it is critical to understand that premature system failure can be a function of both bacterial infection and a water quality that is incompatible with components. In fact, in the majority of premature system failure cases, water chemistry is likely to also be a major factor. A high bacterial count does not always indicate MIC will occur, and conversely, a low bacterial count does not discount that MIC has occurred in the past in a given system and will not occur in the near future.

Analysis

In systems suspected of already being infected, the first step is to have all possible water supply sources (tank, city mains, ponds, rivers, etc.) and the interior of each system tested for bacterial levels and activity. While

this detection is not difficult with current technology, analysis of these results is somewhat complex. And, as previously stated, in determining treatment, bacterial detection is worthless without factoring in water quality.

The laboratory used for analysis should be capable of giving conclusive details of water supply mineral and chemical levels, pipe wall deposit compositions, and type-specific bacterial counts. Multiple tests are used in these analyses from simple bacterial incubation with visual inspection to sulfur print or DNA testing. Obviously, not all tests are required nor are necessarily needed. Current preferred analysis methods run the spectrum, depending on the consultant chosen. Costs for such testing can also vary widely.

In new systems, if MIC-causing bacteria *could* be present, all sources should be tested. It is critical that susceptibility be determined *before* any systems are filled or tested in any way. This is because if water tests are positive, a chemical injection system must be installed and used immediately after completion – including in hydrostatic testing and preliminary fills.

Once a system is filled with infected water, treatment can become exponentially more complex as any future treatment from a chemical injection system must now be effective in remote and stagnate system legs. In bacteria-positive areas, several additional water quality tests should be completed throughout the first year of service to ensure contamination has not occurred from any other sources.

Mitigation in Affected Systems

When MIC is confirmed in operational systems, the building owner is first faced with a fundamental question. Can the system be salvaged (i.e., cleaned) or does it have to be replaced? Currently, this decision is not supported by documented best practices in our industry.

Who is qualified to determine if a system can be cleaned or must be replaced? Pipe cleaning is typically an option when corrosion (i.e., pitting) is not excessive. However, *excessive* is a

relative term. To answer this question, the resulting after-cleaning quality of the pipe must be considered – both for future longevity and system hydraulics. The resulting frictional loss from numerous pits after cleaning could affect system performance. This, of course, is typically outside of the scope-of-work of most corrosion control consultants. Who is actually qualified is currently interpreted in many ways. When replacement materials are chosen that are different than those of the original system, this also must be accounted for in hydraulics analysis of the post-treated system.

Chemical Injection

Once system components have been cleaned or replaced and sterilized, a chemical injection system must be installed to prevent recurrence. Once installed, this system will be required to be operational continuously. As with any other mechanical system, this will require continuous system preventive maintenance.

When such a system is chosen, the applicable AHJ should be consulted. In addition to frictional loss concerns mentioned from changes in pipe surface roughness, increased back flow prevention hardware may be required. This could mean a 10 psi (0.7 bar) or more pressure drop to sprinkler systems in addition to that created by pitting if cleaning is chosen. In new system design, added alarm system contacts must also be planned to monitor injection system chemical levels, operational status, and trouble signals. Many pre-engineered systems available today have readily available contact points for these signals. As with detection, the perceived “best choice” depends on the person choosing and is highly variable.

Several commercially available chemical injection systems have been specifically designed for installation on fire protection systems. Some simply use existing hardware and chemicals modified from MIC treatment in other utilities, such as cooling towers. None of the systems currently available are believed to be UL-listed or FM-approved specifically for use as a

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sprinkler system components. And while most appear to be effective when properly installed and maintained, reliability and effectiveness have not been time-proven when compared with most industrial system benchmarks. Past references should always be investigated with any choice.

Most injection systems currently available are designed to work with specific chemicals. These selected chemicals and dose rates are critical. Some bacteria can develop chemical resistance over time if doses are not strong enough and bacteria are not quickly killed. A small number of MIC-related bacteria (such as the genera *Bacillus* and *Clostridium*) also have the ability to convert to a spore state when they encounter adverse conditions which are not lethal.^{3,4} Spores are impervious to chemical penetration and thus can then survive biocidal treatments indefinitely. And while subsequent treatments may then slow or stop their activity, they will reappear when/if treatments are stopped and resume colonization. With a weak chemical attack, bacteria may also become resistant to the chemicals chosen.

As with most other parts of the treatment system, the choice of chemical depends on the consultant. These generally include penetrants and biocides to break up the tubercles which protect underdeposit colonies, a biocide to kill the bacteria in the colonies, and a corrosion inhibitor to protect the interior system surface.

Unlike most other industrial systems treated for microbiologically influenced corrosion, several chemical interactions must be considered. First, sprinkler systems are typically located directly over people. Chemicals used must therefore be nontoxic in contemplation of accidental discharge. Second, system designs typically place water discharge (such as from inspector's test ports) into foliage or biologically sensitive drains. Most municipal waste water treatment plants (to which typical drains ultimately flow) require bacterial activity to decompose waste. Too

large a quantity of biocides in municipal drains could be a problem.

In conclusion, a complete toxicity review with the highest possible biocidal chemical concentration must be completed. As much as possible, these chemicals should be noncombustible, colorless, odorless, and nontoxic. These must also be nondeteriorating to rubbers and polymers such as those used on pipe couplings and sprinkler o-rings. Chemical storage should also be reviewed, as several currently used can degrade rapidly with heat and may create relatively toxic vapors.

Some of the more common chemicals currently in use specifically for microbial control in sprinkler systems include quaternary ammonium compounds, organo-sulfur compounds, bromines, carbamates, isothiazalone, phosphates, and chlorines. Sodium silicate is effectively used in bulk quantities by several municipalities as an inhibitor but this should be avoided for individual systems due to the potential sprinkler head plugging overdosing can cause.

FUTURE ACTIVITY

The National Fire Sprinkler Association formed an "MIC Task Group" in 1996 to address these associated issues. Their work continues, and they currently have the only known Internet-accessible Web site for reporting suspected MIC cases. The National Association of Corrosion Engineers (NACE) recently formed a task group specifically to investigate MIC fire sprinkler systems – a problem they have been addressing for years in other industries. And NFPA recently formed an "MIC Task Group" as an extension of the *NFPA 13* New Technology Task Group. This group is working to develop a report containing specific recommendations for the prevention and treatment of MIC. It is planned for inclusion in the next edition of *NFPA 13*.

Studies by many universities, government, and private industry groups will also continue to research microbial control in other industries as they

have for the past several decades. This should continue to provide improved treatment options in our industry. Some currently being investigated include *in situ* steam sterilization and gas fumigation as possible alternatives to chemical cleaning and sterilization. Other studies are looking at using engineered bacteria to control corrosion-causing bacteria through various interactive means. And studies into the development of bacterial-resistant materials such as chemically impregnated steel or plastic-coated pipes also hold promise. This may include work with biostat coatings. These are films, paints, and coatings that do not kill organisms but simply inhibit their growth or attachment to metallic components.

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Which Sprinkler to CHOOSE?

By Kenneth E. Isman, P.E.

Once it has been decided that a building is going to be sprinklered, one of the fundamental decisions that needs to be made is which type of sprinkler to choose. From 1955 to 1981, the choice was relatively simple. There were only two types of sprinklers, the conventional sprinkler (sometimes called the old-style sprinkler) and the spray sprinkler. In North America, the spray sprinkler was the sprinkler of choice except for fur storage vaults, piers, and wharves. In these special areas, fire tests had



shown some advantage to using conventional sprinklers. Outside North America, much of the world continued to use conventional sprinklers, only allowing spray sprinklers to be used when pressed by some American firm doing business overseas, and then usually only under a noncombustible ceiling.

As the spray sprinkler received more and more attention in North America, it became the “standard” sprinkler referenced by *NFPA 13*. So many spray sprinklers were installed after 1955 that the sprinkler actually became referred to as the Standard Spray Sprinkler. The letters SSP (for Standard Spray Pendent) and SSU (for Standard Spray Upright) were stamped on the sprinkler for easier identification. Such a high percentage of spray sprinklers were installed that the fire protection industry considered the term “sprinkler” and the term “Standard Spray Sprinkler” to be synonymous.

In 1981, a revolution (or evolution, depending on how you look at it) in sprinkler technology occurred. The fire protection industry decided that it might be better off developing a specific type of sprinkler for a specific occupancy. Rather than rely on the spray sprinkler’s “one-size-fits-most” approach to developing water droplets of different sizes and velocities and spray patterns that distribute water to fight most fires, the Residential Sprinkler was developed to combat the types of fires found specifically in residential occupancies while making the most efficient use of the water through development of specific droplet sizes and distribution of the water. The recognition that a sprinkler could be developed for a specific type of occupancy opened a floodgate of new types of sprinklers that have the capability of fighting fires more efficiently than the spray sprinkler, or of achieving different design goals than the spray sprinkler, in the occupancy for which they were designed.

ORGANIZING THE TECHNOLOGY

In order to see how these new sprinklers fit into the “big picture” of

fire protection, some organization needs to be given to the different types of sprinklers. There are three different parts of the sprinkler that can be varied to get different performance from the sprinkler: the activation mechanism (link), the deflector, and the orifice.

NFPA 13 defines two different types of activation mechanisms, Fast Response and Standard Response. A Fast Response sprinkler is defined as one having a Response Time Index (RTI) of 90 (ft-s)^{1/2} [50 (m-s)^{1/2}] or less. A Standard Response sprinkler is defined as one having an RTI of 145 (ft-s)^{1/2} [80 (m-s)^{1/2}] or more. The RTI of a sprinkler is a quantitative method of measuring the sensitivity of the link to any given fire and is a function of the link material’s thermal capacity, mass, and surface area. The method by which the link is attached to the rest of the sprinkler and the conductivity of this connection are also taken into account in the calculation of RTI.

Note that a “no man’s land” exists between the RTI values for Fast Response and Standard Response. The committees responsible for writing this definition wanted a clear distinction between the Fast Response and Standard Response sprinklers. In theory, a sprinkler with an RTI between 90 and 145 (ft-s)^{1/2} [50 and 80 (m-s)^{1/2}] could be developed and given the term Special Response sprinkler, but no strategic advantage can be seen for such a device, and its presence does not seem necessary at this time.

The rest of this article will focus on the different deflectors that are currently being installed on sprinklers and the effect of the different orifice sizes. These two variables are independent. Note that a spray sprinkler can have an orifice size of K=11.2 (K_M=160) and that a large drop sprinkler can also have an orifice with K=11.2 (K_M=160). This does not make the sprinklers the same. Even though the orifice is the same size, the deflectors on the sprinklers are very different and can produce very different size water droplets and different areas of water distribution.

Over the last 15 years, sprinkler ori-

fice sizes have been growing larger and larger. There are several factors driving the use of larger orifice sprinklers, of which the most important is the ability to achieve higher flows than smaller orifice sprinklers at the same pressure. Another way of expressing this concept is the ability to achieve flows necessary for fire control at lower pressures than what is generally required from a smaller orifice sprinkler. As the fires get more challenging (aerosols, flammable liquids, high-piled storage of plastics), the amount of water we need to get from the sprinkler to control the fire increases. As the flow increases, so does the pressure necessary to push that water out of the sprinkler. The relationship between the flow and the pressure at an orifice can be expressed by the formula

$$Q = K (P)^{1/2} \quad (1)$$

where:

Q = flow in gpm or l/min

K = measure of the ease of getting water out of the orifice, related to size and shape of the orifice in units of gpm per (psi)^{1/2} or K_M in units of l/min per (bar)^{1/2}

P = pressure in psi or bar

Table 1 shows the relative necessity of having sprinklers with bigger orifices. The table shows how much pressure is necessary to achieve a density of 0.85 gpm/ft² (35 mm/min) (necessary for protection of certain high-piled plastic storage) over a coverage area of 100 ft² (9.3 m²). In order to achieve this density over this area, a flow of 85 gpm (300 l/min) would be necessary from the sprinkler. Using the formula above, the Table was developed to show the pressures necessary from each of the different orifice size spray sprinklers.

Table 1 shows a number of interesting concepts. It is clear that the larger orifice sprinklers are necessary. If an engineer wanted to get 85 gpm (300 l/min) from a sprinkler with a K=5.6 (K_M=80), a pressure of 230 psi (16 bar) would need to be applied at that sprinkler – clearly not a practical fire protection solution. But with a K=14

Table 1 - Pressures to Achieve 85 gpm from Various Orifice Size Spray Sprinklers

Nominal Size inches (mm)	Name	K (K _M) gpm/(psi) ^{1/2} [l/min-(bar) ^{1/2}]	Flow gpm (l/min)	Pressure psi (bar)
1/2 (13)	Standard	5.6 (80)	85 (300)	230 (16)
17/32 (13.5)	Large	8.0 (110)	85 (300)	113 (7.7)
5/8 (16)	Extra Large	11.2 (160)	85 (300)	58 (3.9)
3/4 (19)	Very Extra Large	14.0 (200)	85 (300)	37 (2.5)
		16.8 (235)	85 (300)	26 (1.8)

(K_M=200) spray sprinkler, the flow of 85 gpm (300 l/min) can be achieved with only 37 psi (2.5 bar).

The Table also shows the nominal orifice size. Prior to 1996, this was how sprinklers were described by *NFPA 13*. However, in light of the fact that nothing on the sprinkler can actually be measured to these dimensions, and because metric conversions were getting more difficult, this method of identifying orifice sizes was abandoned in 1996.

The Table also shows the orifice names used in *NFPA 13*. Prior to 1999, the name helped to define the orifice size. However, in developing the 1999 edition of *NFPA 13*, the committee needed to come up with a name for an orifice larger than "Very Extra Large." The committee had a hard time developing a suitable name. In the meantime, the committee was also aware that even larger orifice sprinklers were coming in the future. In the end, the committee decided to abandon the concept of using sprinkler names and describe sprinklers by their K-factors.

In writing the 1999 edition of *NFPA 13*, the committee also decided to standardize the K-factors that were being used to describe orifice sizes. In the past, manufacturers were allowed to pick any K-factor from a range. This led to the situation where some sprinklers had K-factors of 5.75 (K_M=82) while others had K-factors of 5.4 (K_M=77), yet these were supposed to be the same orifice size sprinklers. With the 1999 edition of *NFPA 13*, the manufacturers will have to change their literature and possibly even their sprinklers.

The published K-factors will have to be consistent with those used in Table 1. The listing and approval laboratories will work out with the manufacturers what the allowable tolerance from that K-factor will be.

The most variable of all of the things that can be changed on a sprinkler is the deflector. Once the water comes out of the sprinkler, the deflector breaks the water up into different size droplets and distributes those droplets in a predetermined pattern. In some occupancies, large water droplets are needed to penetrate high-velocity fire plumes. In other occupancies, lots of little droplets are necessary so that the heat from the fire can be absorbed. In some occupancies, the water needs to be thrown straight down at the floor. In other occupancies, the water needs to be distributed to the side of the sprinkler as well as below it.

There are currently at least eight different kinds of deflectors being put on sprinklers. Figure 1 shows how all of the different types of sprinklers can be categorized by the type of deflector.

Conventional Sprinklers – As discussed above, these sprinklers are primarily used outside of North America. Approximately half of the discharge from these sprinklers is up towards the ceiling while the other half is down towards the floor.

Residential Sprinklers – These deflectors are designed to produce many small and medium-sized water droplets. Large droplets are not necessary because residential fires do not tend to develop high-velocity vertical

fire plumes. However, residential fires do produce a great deal of heat, which is absorbed by the small water droplets. Medium-sized droplets do penetrate the outer edges of the fire plume to pre-wet adjacent combustibles, making it harder for the fire to spread. This sprinkler maximizes the efficiency of absorbing heat from a fire and, therefore, can operate at lower flows than Spray Sprinklers. However, the NFPA committees responsible for various residential occupancies have expressed concern about allowing listed flows to get too low. In a decision to take effect soon, the manufacturers will not be allowed to list sprinklers at densities less than 0.1 gpm/ft² (4.1 mm/min) for *NFPA 13* applications or less than 0.05 gpm/ft² (2.0 mm/min) for *NFPA 13D* or *NFPA 13R* applications. If order for the residential sprinkler to be successful, it needs to open before the fire gets very large. To do this, a fast response link is put on the sprinkler. However, this should not be confused with a Quick Response Sprinkler. As covered later in this article, a Quick Response Sprinkler has a very specific spray pattern. While the residential sprinkler is Fast Response, it is not Quick Response.

Spray Sprinklers – Still the most popular type of sprinkler, the Spray Sprinkler discharges 100% of its water down towards the floor in an umbrella-shaped discharge pattern. The deflector is designed to produce water droplets in three specific size ranges. Small droplets help absorb the heat from the fire and maintain cool ceiling temperatures. Medium-sized droplets penetrate the edges of the fire plume to pre-wet adjacent surfaces making it more difficult for the fire to spread. Large-sized droplets penetrate the fire plume to get to the surface of the burning fuel to control or suppress the fire. There are at least four different types of Spray Sprinklers as represented by the four boxes on the bottom level of the Figure. All of the green boxes in Figure 1 are considered types of Spray Sprinklers.

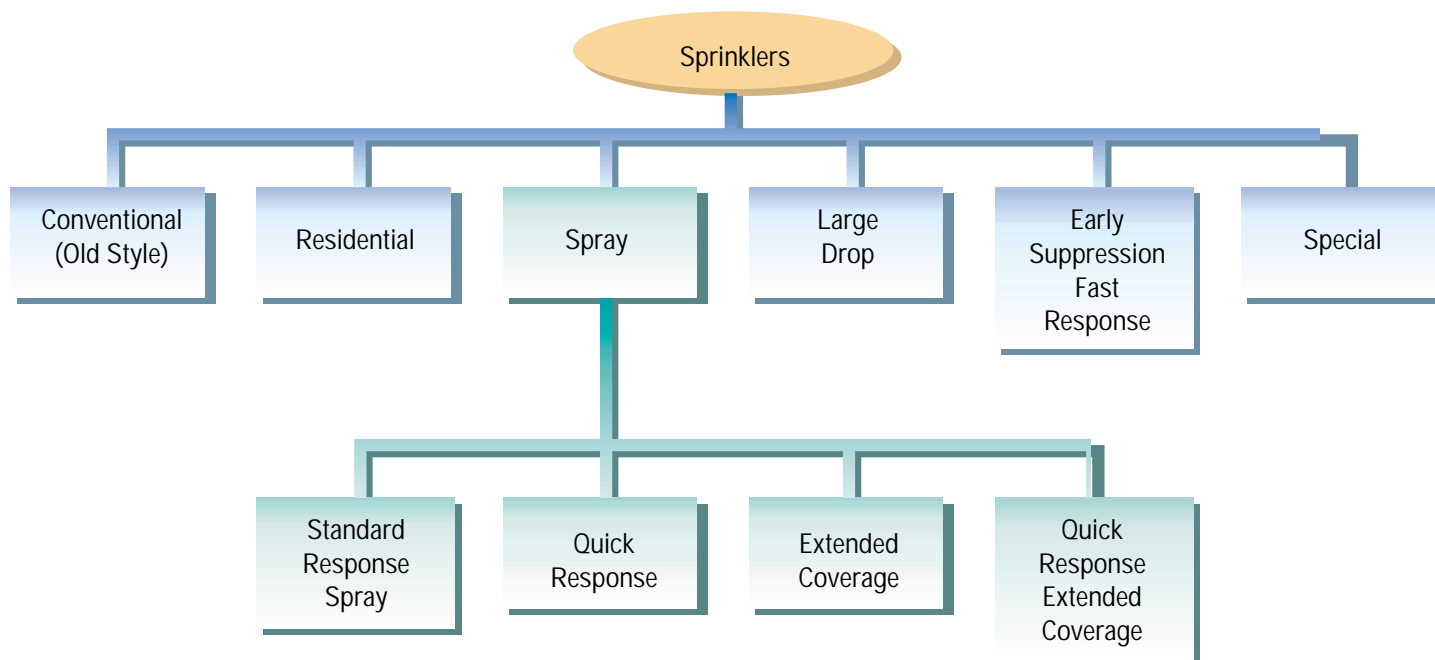


Figure 1 - Relationship of Different Sprinklers by Deflector

TYPES OF SPRAY SPRINKLERS

Standard Response Spray Sprinklers – More than 90% of the sprinklers installed from 1955 to 1981 in North America were this type of sprinkler. Today, they are still used extensively, but hold less than 75% of the market. These sprinklers produce the spray pattern and droplet sizes discussed above for Spray Sprinklers, are intended to be installed at the maximum distances and areas covered by *NFPA 13*, and are available in a variety of orifice sizes.

Quick Response Spray Sprinklers – These sprinklers are identical to the Standard Response Spray Sprinklers except for the actuating mechanism. As Fast Response Sprinklers, they react while the fire is smaller and can control the fire with fewer operating sprinklers, allowing for smaller water supplies, smaller pipe, and less water damage. These sprinklers are intended to be installed using the allowable distances and areas of *NFPA 13*.

Extended Coverage Sprinklers – These sprinklers produce the same umbrella-shaped distribution and three different sized water droplets as the Spray Sprinkler; however, they spread that spray pattern over a larger area. Extended Coverage Sprinklers are intended for use in areas larger than the distances and maximum areas of *NFPA 13*. The limitation on the

area of coverage for each individual sprinkler is contained in the special listing of the sprinkler, not *NFPA 13*. In order to obtain these listings, the manufacturer frequently needs to utilize greater flows and pressures than would normally be used under *NFPA 13*. In order to utilize these sprinklers, hydraulic calculations need to ensure that these higher flows and pressures are available. These sprinklers are not interchangeable, since some models may need higher pressures and flows to cover similar areas as other models. These sprinklers are considered Standard Response Sprinklers even though some of them employ a fast response link. They use faster response to compensate for the possible increased distance to a fire.

Quick Response Extended Coverage Sprinklers – Similar to the Extended Coverage Sprinkler, these sprinklers can cover more area than normally allowed by *NFPA 13*. In addition, the links are sensitive enough to be considered Quick Response even at the extended spacings. As with Extended Coverage Sprinklers, Quick Response Extended Coverage Sprinklers are not interchangeable due to differing flow and pressure requirements.

Large Drop Sprinklers – Developed specifically for high-challenge storage occupancies, these sprinklers produce a greater amount of large water droplets than spray sprinklers. The large droplets penetrate the fire plumes more easily and help control the fire.

Early Suppression Fast Response (ESFR) Sprinklers – The ESFR Sprinklers were developed to specifically suppress fires in high-challenge storage occupancies. In most cases, they can do so without the need of in-rack sprinklers. All of the other sprinklers discussed here are designed to control fires, but ESFR Sprinklers, if designed and installed properly, will suppress fires. The ESFR Sprinkler produces many large droplets and gives those droplets a high velocity as they travel down towards the floor. This, combined with the fast response element, helps them suppress fires while they are still small.

Special Sprinklers – There are many sprinklers that are being developed for use in specific applications that call for unusual spray patterns. The Attic Sprinkler is one example. The Attic Sprinkler has a deflector designed to discharge water down the typical

slope of an attic roof/ceiling. Other examples include window sprinklers and concealed space sprinklers and are discussed later in this article.

NEW SPRINKLERS ON THE MARKET

Now that the terminology has been explained, it will be easier to discuss the new types of sprinklers that are on the market and where they fit in to the "big picture."

One of the recent trends in new types of sprinklers has been the production of larger and larger orifice Spray Sprinklers. While the sprinkler with a K-factor of 16.8 ($K_M=235$) is currently the largest orifice spray sprinkler, it is only a matter of time before one with a K-factor of 22 ($K_M=315$) or 25 ($K_M=350$) is developed. One of the things that the NFPA committee was concerned about was the proliferation of different K-factors, so they limited the manufacturers to the following sizes: 16.8, 19.6, 22.4, 25.2, and 28.0. In metric units, these will be 235, 275, 315, 350, and 400. It should be noted that the sprinklers with a K-factor of 16.8 are being marketed as K=17. While 17 may be a "sexier" number to market the device, *NFPA 13* will require the use of K=16.8 in the hydraulic calculations.

There are currently two different ways that Spray Sprinklers are being listed for use. The first method is as a regular Spray Sprinkler. The sprinkler can be used with any of the area/density curves of *NFPA 13*, although to be used in storage occupancies, it needs to be listed as a "Storage Sprinkler." *NFPA 13* is trying to encourage the use of these larger-orifice sprinklers.

In the 1999 edition, a new section (5-4.1.2) was added for storage occupancies. This new section only allows K=5.6 ($K_M=80$) sprinklers to be used if the design density is 0.2 gpm/ft² (8.2 mm/min) or less. Similarly, K=8.0 ($K_M=110$) sprinklers will only be allowed if the design density is 0.34 gpm/ft² (13.9 mm/min) or less. Any storage commodity that needs a design density of more than 0.34 gpm/ft² (13.9 mm/min) will need to utilize a sprinkler with an orifice size of K=11.2 ($K_M=160$) or more.

The second method by which big orifice Spray Sprinklers are allowed to be used is through the Specific Application listing. *NFPA 13* allows sprinkler manufacturers to get special listings to protect certain size storage arrangements of certain commodities. The limitations as to what kind of commodities can be protected and how they can be stored are up to the manufacturer to define and become a part of the listing of the sprinkler. When sprinklers are used in conformance with the Specific Application listing, much of the sprinkler installation, hydraulic calculation, and water supply information needs to be found in the listing, not *NFPA 13*. The designer and plan reviewer need to be completely familiar with the Specific Application listing in order to get the sprinkler system installed correctly.

Another big trend in the sprinkler industry has been the development of different types of ESFR Sprinklers. The original ESFR Sprinkler was a pendent sprinkler with an orifice of K=14.0 ($K_M=200$). A few years after that, an upright sprinkler with a K=11.2 ($K_M=160$) was recognized as an ESFR Sprinkler for protection of storage in slightly smaller buildings than the K=14 ($K_M=200$). More recently, pendent ESFR Sprinklers were recognized with an orifice size of K=25.2 ($K_M=350$).

There are two methods in which to use the K=25.2 ($K_M=350$) ESFR Sprinkler. The first method is to use the rules of *NFPA 13*. The 1999 edition contains information on the protection of Class I-IV commodities as well as cartoned unexpanded plastic. Minimum pressures vary from 20 to 50 psi (1.4 to 3.4 bar) based on the storage height and the ceiling height in the building.

The second method under which the K=25.2 ($K_M=350$) ESFR Sprinklers can be used is through the Specific Application listing process. One manufacturer of an ESFR Sprinkler with a K=25.2 ($K_M=350$) has received a special listing for use with pressures lower than those required by *NFPA 13*. Use of this sprinkler is allowed due to the special listing; however, the listing is specific to one manufacturer, not all sprinklers with that orifice size.

Another development in the evolution of ESFR Sprinklers is the upright ESFR with a K=14.0 ($K_M=200$). Although not yet listed or approved, this sprinkler has undergone fire tests and shown impressive performance. As an upright sprinkler, the manufacturer knew that the pipe under the sprinkler would be an obstruction and designed the sprinkler to be much less susceptible to minor obstructions completely below the sprinkler. Hopefully, this sprinkler will pass the rest of its tests and join the ranks of acceptable ESFR Sprinklers.

The last trend that will be covered in terms of new products in this article will be the Special Sprinklers. New sprinklers are being developed for specific applications where performance can be optimized by taking advantage of the geometry of the space. As previously discussed, the Attic Sprinkler has been developed specifically for the typical sloped ceiling configuration of an attic.

Another special sprinkler that has been developed for a specific application is the Window Sprinkler. This sprinkler discharges water in a spray pattern against glass to give it improved fire resistance. The window sprinkler gives architects more flexibility in the products they choose, while maintaining the integrity of the fire compartment.

The last new type of sprinkler that this article will cover is the Concealed Space Sprinkler. Just listed in May 2000, this sprinkler will not be found in *NFPA 13*, but may be used in accordance with its special listing. The sprinkler is intended for use in flat concealed spaces between 12 and 32 inches (300 to 800 mm) in depth. Rather than throw its water down, like a spray sprinkler, this sprinkler is designed to discharge most of its water to the sides. The sprinkler is designed to operate at a density of 0.1 gpm/ft² (4 mm/min) over a design area of 1000 ft² (90 m²). Each individual sprinkler has a K-factor of 3.0 ($K_M=40$) and must discharge at a minimum of 10 psi (0.7 bar). The maximum allowable distance between sprinklers is 10 ft (3.1m) and the minimum allowable distance between sprinklers is 6 ft (1.8m).

One of the unique things about the Concealed Space Sprinkler is that it allows CPVC pipe to be installed in the concealed space with it. Prior to this, CPVC was not allowed in a concealed space that required sprinklers. Now, with special additional design rules covered in the manufacturer's data sheet, the sprinkler can protect the concealed space and the exposed CPVC pipe at the same time.

OLD DOG, NEW TRICKS

In addition to the development of new sprinklers, there is constantly ongoing research expanding our knowledge of what we can protect with existing sprinkler technology. In the 1996 edition of *NFPA 30 – Flammable and Combustible Liquids Code*, extensive use of new information about sprinklers was used to revise Chapter

4 and give definitive criteria on how to protect certain flammable and combustible liquid storage with spray sprinklers. In the 2000 edition of *NFPA 30*, even more information has been added to define even more commodities that can be protected with spray sprinklers (including some flammable liquids in plastic containers) and a few commodities that can be protected with ESFR Sprinklers.

In addition to flammable and combustible liquids, work has continued on expanding the list of commodities that can be protected with ESFR Sprinklers. Recent work has included the protection of rubber tires, roll paper, and higher racks of plastic commodities than could be protected a few years ago. It is clear that building owners enjoy the flexibility that ESFR Sprinklers give them, and they continue to press for research into additional arrangements that can be protected with these sprinklers.

Even the sidewall sprinkler is having its application expanded. A new exception to section 5-4.2 in *NFPA 13* allows the Sidewall Sprinkler to be used to protect below overhead doors. While many Authorities Having Jurisdiction allowed this application in the past, some did not because it technically violated the rule that sidewall sprinklers be no more than 6 inches (150 mm) down from the ceiling. While some extended coverage Sidewall Sprinklers had special listings allowing them to get as far as 18 inches (450 mm) down from the ceiling, this did not allow for protection under an overhead door. The sprinkler committee was sympathetic to the problem of how to protect under such an overhead door and revised the standard. It is anticipated that the sidewall sprinkler will be between 4 and 6 inches (100 to 150 mm) below the plane of the overhead door once it is in the open position.

Kenneth E. Isman, P.E. is with the National Fire Sprinkler Association.

REFERENCE

- 1 *NFPA 13, Standard for the Installation of Sprinkler Systems*. National Fire Protection Association, Quincy, MA, 1999.

For an online version of this article, go to www.sfpe.org.



PROJECT MANAGEMENT OF AN ESFR SPRINKLER INSTALLATION

By William Fletcher, P.E.

INTRODUCTION

The managing of a construction project in which Early Suppression Fast Response (ESFR) Sprinklers are to be used requires careful planning by the construction project team to ensure the system is designed and installed properly. This involves a coordinated effort by the various disciplines (fire protection, architectural, structural, mechanical, and electrical) in the conceptual design stage as well as during construction. This article discusses the various aspects involved in managing such a project to ensure a successful outcome.

SUPPRESSION MODE VS. CONTROL MODE

Suppression Mode, Fast Response Sprinklers were developed in the 1980s for use against severe fire challenges. These sprinklers were developed from the design concepts of two of their predecessors; the Large Drop and Residential Sprinklers. They are intended for use in certain occupancies in which fire suppression is possible. The term "suppression" relates to sprinkler system performance where the first few operating sprinklers provide sufficient water to the fire to reduce it to an acceptable level, if not extinguish it. Based on extensive testing, there can be no ESFR Sprinklers obstructed by

Above: ESFR sprinkler head in operation.

the building structure or equipment such as lights, ducts, cable trays, etc. In the case where objects such as ducts, conveyors, and walkways are unavoidable, the option of providing more sprinklers to compensate for them when they shield sprinkler water distribution is available. The obstruction of even one ESFR Sprinkler could result in the lack of fire suppression. The avoidance of obstructed sprinklers is one of the greatest challenges to overcome when ESFR systems are involved.

The Suppression Mode Sprinkler is different from the Standard Control Mode Sprinkler (these include standard



Fire Test at Factory Mutual Research Center

spray upright and pendent, Extra Large Orifice, and Large Drop type sprinklers). In full-scale fire testing involving control mode sprinklers, as many as 20 to 30 sprinklers can operate in order to achieve fire control. The control mode sprinkler prevents fire spread by slowly reducing its intensity and prewetting surrounding combustibles so they do not ignite. The performance of a control mode system is therefore not as susceptible to obstructions as ESFR systems.

CURRENT APPLICATIONS

ESFR Sprinklers are intended to protect a wide range of storage and are being installed throughout the United States and in many parts of the world. There are two major benefits for using ESFR Sprinklers in warehouse facilities. The primary reason is that ESFR sys-

tems eliminate the need for in-rack sprinklers for specific rack storage arrangements up to 40 ft (12.2 m) high in maximum 45 ft (13.7 m) high buildings. They also provide greater flexibility in warehousing operations since the cost of removing and reinstalling in-rack sprinklers, as the storage layout changes, is not a factor. ESFR systems are intended solely for warehouse storage occupancies and should not be used in buildings involving manufacturing occupancies.

ESFR – THE RIGHT CHOICE FOR YOUR APPLICATION?

One of the first things to consider is whether the use of ESFR Sprinklers are an appropriate choice for the hazard and building construction involved. This involves the gathering of data on the proposed storage and building con-

struction details. This information is more important when ESFR Sprinklers are being used than Standard Sprinklers since the ESFR system is relying on fire suppression in the incipient stage of a fire as opposed to the control mode concept previously discussed. There is, therefore, less tolerance for certain design and installation factors when ESFR Sprinklers are involved.

PROJECT MANAGEMENT

The project management aspects relating to fire protection in a building that will use ESFR Sprinklers are very important. There are many individuals involved with the construction of a building, and each has their own particular area of expertise. It is essential to bring these individuals together to review the proposed fire protection goals in the conceptual stages of planning. The proper design and installation of an ESFR system can be complicated, and everyone involved must work closely together prior to the onset of construction as well as during the construction process.

Periodic meetings should be held at the construction site with the Architect, Structural, Mechanical, and Electrical Engineers as well as the foremen representing the various trades. A building survey can then be done prior to each meeting to review the ESFR installation progress and identify any problems. In the fast-paced world of construction, the early identification of deficiencies involving the sprinkler installation is important in order to make the appropriate changes. For example, three experienced sprinkler fitters can complete the installation of the ceiling piping for a 120,000 ft² (11,000 m²) building (3 systems) in approximately three weeks. Frequent site visits are therefore necessary due to the fast pace of work involved. The key points involved in successfully managing an ESFR project include the following:

Storage Details

Extensive testing and analysis back ESFR application for various storage arrangements and commodities. It is therefore important to know the proposed storage type and racking config-

uration that will be used early in the design process. This will usually require some investigation and research. The commodity type, storage configuration, rack dimensions, etc., all need to be known in advance. The best source of this information is generally the building occupant (end-user). This information is also needed for the local jurisdiction to obtain any needed permits (high-pile permit, for example). Determining this information for a multitenant leased building, "Spec building" may not be possible since tenants for these types of buildings are usually signed up after the building construction and sprinkler installation are complete. It should be noted that not all storage types are compatible for use with an ESFR system. For example, when racking is used, the racks must have "open" shelves as opposed to "solid" shelving. The end-user (warehouse occupant) must also understand the importance of maintaining flue spaces within the racks. These spaces can become blocked in such applications as pick racks where boxes are packed tightly on wire shelving. Open-top, five-sided combustible containers cannot be used within racks since they can prevent water from running across the top of storage and down the flues and can also collect sprinkler water. The appropriate guidelines referenced for the project must therefore be carefully reviewed for a complete list of such restrictions depending on the proposed storage.

Roof Construction

Roof construction and roof height are some of the aspects of building design that must be closely coordinated. Some types of roof construction can present inherent problems with ESFR sprinklers being obstructed by structural members. A recurring challenge in designing ESFR sprinkler systems has been to design a layout which eliminates obstruction to distribution, satisfies guidelines for spacing between sprinklers on or between branch lines, and satisfies guidelines for maximum area of coverage per sprinkler. This has been a common problem with construction using open bar joists or steel trusses. The layout of



ESFR Sprinkler system with obstructed sprinklers due to electrical junction box and conduit located directly below sprinklers.



ESFR Sprinkler system with no obstructed sprinklers.

the sprinkler system must therefore be done in a concerted effort with the Structural Engineer's plans. A roof/ceiling slope up to and including 2 in/ft (17%) is acceptable. If the ceiling slope is in excess of 2 in/ft (17%), a suspended ceiling with an acceptable slope may be installed above the storage with sprinklers installed below the ceiling.

Design Specifications and Fire Sprinkler Plans

Specification of design criteria for the sprinkler system will include system hydraulic design, underground main layout, location of hydrants, and

sprinkler piping earthquake bracing (in specific geographic areas where needed). Since obstructions to sprinkler discharge will significantly affect the ability of the system to suppress the fire, all potential obstructions must be identified prior to the submittal of sprinkler shop drawings. In order to accomplish this, it would be desirable to have the fire sprinkler contractor on the design team at the project inception. Piping should not be fabricated or installed until all the necessary approvals are obtained via the plan review process.

The water supply to be used is also of critical importance. Quite often the larger building developments are locat-

ed on the "outskirts" of town where the water supply details are not completely known. In most cases, the water department should be contacted and a meeting should be held to determine the supply characteristics. For example, some areas can experience a drop in the available water pressure during certain times of day or night. A 24-hour monitoring device can be hooked up to a public hydrant to determine the minimum static pressure in such cases. Hydrant flow tests should be conducted well in advance of sprinkler design beginning. A common practice is to subtract 10% off the static and residual hydrant test pressures to account for future pressure fluctuations and growth in the area. Since ESFR systems require high operating pressures for the sprinklers, there is a good chance a booster pump will be needed for the public supply. In areas subject to a high frequency of earthquakes and/or areas with water supply reliability concerns, consideration should be given to the provision of a secondary, on-site water supply.

Installation of Equipment by Contractors

As the building construction progresses, it is likely that changes in the location of equipment that will be installed at or near the roof level will occur. This is prevalent during the tenant improvement stage of the project. Aside from building construction issues, the second most likely cause of obstruction to ESFR Sprinklers is due to equipment being added by contractors. This includes lights, ducts, heaters, cable trays, conduit, draft curtains, etc. The best way to deal with this is to involve the foreman from the various trades in all of the project meetings. Everyone must understand the obstruction rules and these guidelines should be presented in writing to all parties.

SUMMARY

The benefits of a properly designed and installed ESFR Sprinkler system are very attractive. Since they respond faster to a fire than standard sprinklers, fewer sprinklers will operate to minimize fire, smoke, and heat damage. ESFR protection eliminates the need

for in-rack sprinklers, in many cases, allowing users to handle material within racks more easily. The system provides greater storage flexibility than standard sprinklers since users can store a variety of products anywhere in the warehouse.

However, there are many questions that need to be asked in the conceptual design stage, such as whether the use of ESFR sprinklers are an appropriate choice for the hazard and building construction involved. There are many pitfalls that can be encountered during the design and subsequent installation of these systems. Careful project management is therefore essential to ensure all members of the construction project team understand the applicable guidelines. Finally, frequent site visits should be conducted to ensure the ESFR system is installed "obstruction free."


William Fletcher, P.E., is with FM Global.

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- FM Global Data Sheet 8-9 "Storage of Class 1-4 & Plastic Commodities"
- FM Global ESFR Technology, Facing Today's Challenges; Form P9202
- FM Global ESFR Installation Alert, Understand Before You Install; Form P9709
- FM Global Record Magazine, ESFR Around the World
- Factory Mutual Research Approval Guide 2000 - Fire Protection


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BOOKS

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Sprinkler Hydraulics and What It's All About, 2nd edition, by Harold S. Wass, Jr. Significantly expanded and updated to the 1999 edition of *NFPA 13*, this comprehensive reference on sprinkler hydraulics contains practical information on all aspects of hydraulic design including sprinkler discharge; friction losses; backflow prevention; relationships to water supply; examples of dead-end, loop, grid, and in-rack sprinkler designs and inspection; and reliability. Written in an easy-to-understand format by one of the industry's acknowledged experts on sprinkler hydraulics.

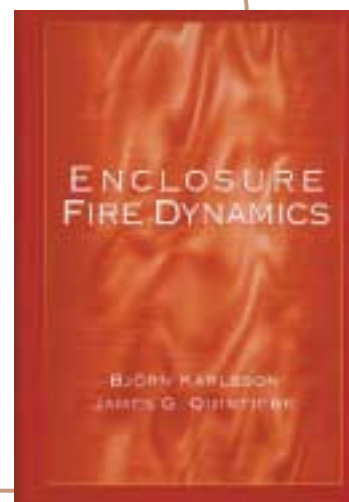
Price: SFPE Member, \$50.00;
Nonmember, \$60.00

Comprehensive Fireproof Building Design Methods is a translation of the Japanese Methodology for Building & Fire Performance Evaluation under Article 38 of the Building Standard Law of Japan. A publication of the International Forum for Fire Research, this document summarizes a comprehensive research effort by the Construction Ministry of Japan to develop rational design methods for attaining enhanced fireproof design in various building conditions. 400 pages.

Price: \$50.00

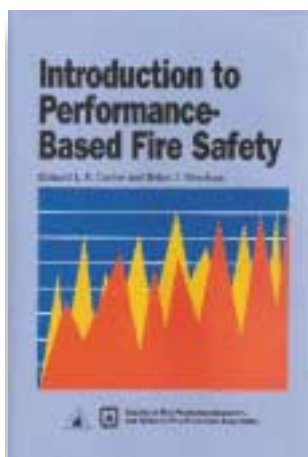
Enclosure Fire Dynamics, by Bjorn Karlsson and James G. Quintiere, 1999. This 300-page text has been developed to serve as a framework and reference for how to estimate the environmental consequences of a fire in an enclosure. It is based in part on the work in this area developed by Professor Magnusson, Lund University, and is expanded upon with new topics and information from authors. Ten chapters and three appendices cover such subjects as fire plumes and flame heights, pressure profiles and vent flows, heat transfer and computer modeling, as well as suggestions for educators.

Price: SFPE Member, \$59.95;
Nonmember, \$79.95



Design of Smoke Management Systems by J. H. Klotz, Ph.D., and J. A. Milke, Ph.D., 1992. Offers state-of-the-art information for anyone who has been challenged with the design of smoke management systems. Includes sections on the nature of smoke, its movement in buildings, and analysis methods for the design of smoke control systems with sample calculations. Published by ASHRAE. 225 pages.

Price: SFPE Member, \$56.00;
Nonmember, \$83.00



Introduction to Performance-Based Fire Safety, by Richard L. P. Custer and Brian J. Meacham, 1997. This 11-chapter, illustrated book presents the basic concepts of performance-based fire safety engineering and includes chapters on design vs. codes, fire dynamics and modeling, hazard analysis and risk assessment, performance criteria, human factors, and case studies illustrating the process. 260 pages. (Item No. F6-PBFS-97) AVAILABLE ONLY THROUGH NFPA (800) 344-3555 and outside the U.S. (508) 895-8300.

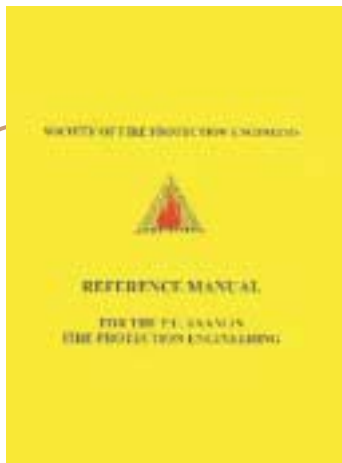
Price: SFPE Member, \$66.75; Nonmember, \$74.25

GUIDES GUIDES GUIDES



Engineering Guide – Assessing Flame Radiation to External Targets from Pool Fires by the SFPE Task Group on Engineering Practices, 1999. Summarizes accepted calculation methods for radiant heat transfer from pool fires to targets located outside of a flame. For each method, the data requirements, data sources, inherent assumptions, and limitations are summarized.

Price: SFPE Member, \$35.00; Nonmember, \$50.00

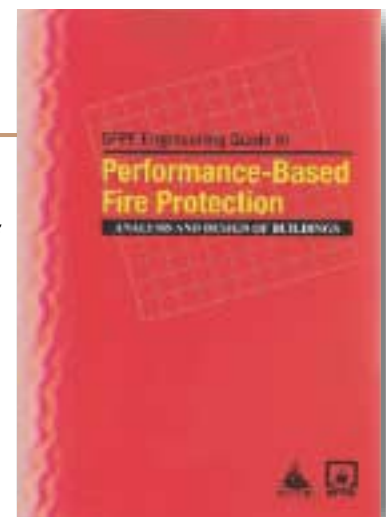


Reference Manual/Answer Manual for the P.E. Exam in Fire Protection Engineering, 1st edition, 1996. This study guide includes practical information on engineering licensing in the United States, problems and solutions on every technical subject in the PE exam syllabus, and detailed appendices including a reference list. 545 pages.

Price: SFPE Member, \$125.00; Nonmember, \$175.00

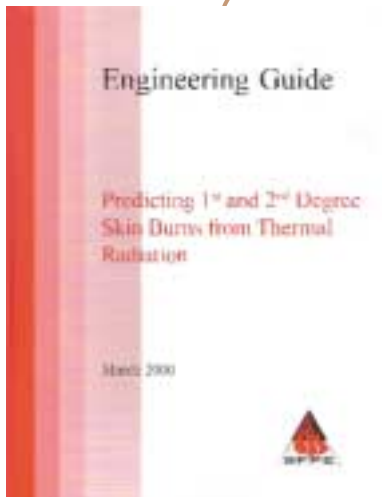
SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings by the SFPE Task Group on Performance-Based Analysis and Design, 2000. This guide outlines a process for carrying out these designs and is essential for anyone who will apply, approve, or be affected by performance-based codes and standards. Chapters cover such topics as defining your project scope and identifying goals, specifying stakeholders and design objectives, developing performance criteria, creating design fire scenarios and trial designs, evaluating trial designs, and documentation and specifications. Equip yourself for the coming era of performance-based codes with this unique guide!

Price: SFPE Member, \$46.75; Nonmember, \$52.00



Guide to the 1997 UBC Smoke-Control Provisions – An Illustrative Commentary by Douglas H. Evans, P.E., published by ICBO, 1999. This sixty-page interpretive guide provides the basics on smoke management systems as well as detailed information for implementing the smoke-control provisions in accordance with section 905 of the 1997 Uniform Building Code.

Price: SFPE Member, \$19.00; Nonmember, \$40.00



The SFPE Engineering Guide to Predicting 1st and 2nd Degree Skin Burns from Thermal Radiation summarizes accepted calculation methods for predicting pain, and first- and superficial second-degree burns from radiant heat transfer. Calculation methods are presented that range from simple algorithms to more detailed calculation methods. For each method, the data requirements, possible data sources, inherent assumptions, and limitations are presented. The guide also provides an overview of the physiology of the skin as it relates to thermal injury.

Price: SFPE Member, \$35.00; Nonmember, \$50.00

FIRE-T3: A Guide for Practicing Engineers by the SFPE Task Group on Documentation of Computer Models, 1995. A practical user's guide to FIRE-T3, a three-dimensional heat-transfer model applicable to analyzing heat transfer through fire barriers and structural elements. 82 pages.

Price: \$36.00



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B R A I N T E A S E R

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?

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

Solution to last issue's 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:

$$C = 2\pi r = 2 \times \pi \times 20,000 \text{ km} = 125,664 \text{ km}$$

With the addition of the 10-meter section, the circumference would become 125,674 km, which would correspond to a radius of 20,001.6 km. Therefore, the loop would rise 1.6 km above the top of the mountain.

C O R P O R A T E 1 0 0

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

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Changes to the PE Licensing Model Law Proposed



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

The National Society of Professional Engineers (NSPE) has developed a new model for the process by which engineers would become licensed as professional engineers.¹ NSPE cited their goal of having all engineers licensed as PEs and their belief that the current licensing procedures are inadequate for engineers working in a number of specialized areas of engineering as their reasons for developing the new model. According to NSPE, today only approximately 20% of all engineers are licensed as a PE.

Under the current model licensing law, there are four requirements for becoming licensed as a PE:

- Graduation from a four-year academic program accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology
- Passing the Fundamentals of Engineering Exam, which is also referred to as the "engineer-in-training" exam
- Four or more years of engineering experience
- Successful completion of the Principles and Practices of Engineering Exam, which is also called the "professional-engineering" exam.

As with many model rules, the requirements for becoming licensed may vary in some states from the requirements of the model law.

The new model proposed by NSPE would include two separate paths to licensure as a professional engineer. Under the first path, the first three steps would be similar to those under the current model law: engineers would be required to earn an Bachelor of Science degree from an engineering school, pass the Fundamentals of Engineering exam, and have four years of engineering experience. However, the final step to licensure would require a credentials and portfolio review, and if the engineer's credentials and portfolio are deemed acceptable, completion of a new "Professional Licensing Exam."

The proposed credentials and portfolio review is intended to judge whether an engineer has sufficient experience for licensure. Also, since the new proposed Professional Licensing Exam is nontechnical in nature, it is presumably intended to determine whether the engineer has sufficient understanding of the application of engineering principles.

Instead of testing technical subjects, the new Professional Licensing Exam would focus on ethics and codes and standards that are applicable to the engineer's area of practice. The proposed change in subject matter for the exam reflects that most of the problems faced by state licensing boards deal with professional ethics, such as when an engineer practices outside of his or her area of expertise, or how they promote themselves in advertising. As with the current Principles and Practices of Engineering Exam, under the new model, SFPE would define what should be covered in the Professional Licensing Exam for Fire Protection Engineering.

Under the second path of the new licensure model, engineers who received an advanced degree in engineering, such as a Master of Science or a Ph.D., would not be required to pass the Fundamentals of Engineering Exam. Additionally, for engineers with a master's degree, only three years of engineering experience would be required, and for those with a doctorate, only two years' experience would be required. Engineers with advanced degrees would also be required to undergo a credentials and portfolio review and pass the Professional Licensing Exam.

The next step for NSPE is to receive endorsements of their proposed model from other engineering societies, such as SFPE. If you have opinions on this new model, please do not hesitate to send them to engineering@sfpe.org.

¹ Anon. "NSPE Proposes Changes to Model Law for Licensing of Engineers," *Engineering Times*, Vol. 22, No. 10, National Society of Professional Engineers, Alexandria, VA, November, 2000.