IDENTIFYING ALTERNATIVE APPROACHES TO FIRE AND HAZARD PROTECTION AT PROCTER & GAMBLE

LEADING COMMUNITY RISK REDUCTION

BY: Ray A. Webber
The Procter & Gamble Company
Cincinnati, Ohio

An applied research project submitted to the National Fire Academy
as part of the Executive Fire Officer Program

December 2004

CERTIFICATION STATEMENT

I hereby certify that this paper constitutes my own product, that where the language of others is set forth, quotation marks so indicate, and that appropriate credit is given where I have used the language, ideas, expressions, or writings of another.

Signed: ______________________________

ABSTRACT

This research identified alternative strategies to fire and hazard protection at Procter & Gamble (P&G) facilities. The problem was that traditional prescriptive fire protection codes and standards often did not apply to specialized research and development fire protection risks. The purpose of this project was to develop alternative methods to manage these specialized risks when traditional codes and standards did not apply.

This project utilized action research to apply information about available fire protection methodologies to P&G's fire protection program. Also, evaluative research was used to determine which fire protection methodologies studied were best suited to the company. This was accomplished by (a) identifying the available alternative risk management methodologies and how other industries applied them, (b) identifying the limitations of these risk management methods, (c) determining what methods were best suited to P&G's fire protection program, and (d) determining if the methodologies studied could be applied to non fire risks.

The primary procedure used in this research was a review of material relating to different risk management methodologies. This was coupled with a survey to assess what different risk management methodologies were being used by other firms and their experiences with them.

The results indicated that there were a number of different fire protection and risk management methodologies. However many of them were quite complicated and time consuming. Portions of The Society of Fire Protection Engineer's (SFPE) performance based method, the most applicable of those studies, were included in a model fire protection guideline.

The recommendations from this research were to (a) adopt a company-wide performance based fire protection guideline, (b) provide performance based fire protection methodology training to the site fire protection leaders, (c) establish corporate risk tolerance criteria, and (d) further research the concept of computer fire modeling.

TABLE OF CONTENTS

INTRODUCTION

Procter & Gamble's (P&G's) fire protection program is based on experienced gained in its operations throughout the world. The program is operated under the concept that each facility is unique and should have an individual program designed to provide adequate fire protection without unwarranted spending. At each site, one person is given overall responsibility for fire protection and is known as the site fire protection leader or more often, the site fire chief. The site fire protection leader must implement and execute effective strategies to protect the people, profits, and property of P&G from fire, explosion, and other calamities. In a plant or production facility, this role is relatively straight forward, as process and facility changes are infrequent and mostly limited in scope. The role of the fire protection leader at one of P&G's many research and development facilities however, can be much more challenging.

Site fire protection leaders at these research and development facilities must manage fire risks which are transient, un-researched, and often times only vaguely mentioned in codes and corporate fire protection guidance. The problem is that traditional prescriptive fire protection codes and standards often do not apply to the specialized research and development risks at P&G facilities.

The purpose of this research is to develop alternative methods to manage risks at P&G facilities when prescriptive codes and standards do not apply. Action and evaluative research methodologies will be used to answer the following research questions:

1. When prescriptive codes and standards do not apply, what methods are available to determine how best to protect a given fire risk and how are other firms dealing with similar circumstances?

2. What are the limitations and challenges associated with using such non prescriptive risk management methods?

3. What method or combination of risk management methods provides the best means to assess and manage fire risk at P&G facilities?

4. Should non prescriptive risk management methods be used to address non-fire risks at P&G facilities?

BACKGROUND AND SIGNIFICANCE

The Procter & Gamble Company was established in 1837 in Cincinnati, Ohio as a small family operated soap and candle company. Today, P&G markets nearly 300 products to more than five billion consumers in 140 countries around the globe and employs nearly 100,000 people in 80 countries. P&G's brands include: Tide, Folgers, Olay, Charmin, Iams, Pantene, Pringles, Swiffer, and Mr. Clean (P&G, 2003).

The company maintains its general offices and world headquarters in Cincinnati, Ohio as well as its original manufacturing plant. Also located in Cincinnati are five of the company's major research and development facilities: Ivorydale Technical Center, Winton Hill Business Center, Health Care Research Center, Miami Valley Laboratories, and Sharon Woods Technical Center. These facilities conduct research and development operations for all five of the company's global business units: Baby, Feminine & Family Care, Fabric & Home Care, Beauty Care, Health Care, and Food & Beverage.

The mission of each of these business units at P&G research and development facilities is to respond to the constant demands of the world's consumers for new ideas and products. The company's purpose is to provide branded products and services of superior quality and value that improve the lives of the world's consumers. Innovation in the realm of consumer goods often times requires non-standard approaches, and what P&G calls "Holistic Innovation" (G.L. Cloyd, personal communication, n.d.). Leading edge innovation and development often brings with it unique fire protection risks and concerns. Site fire protection leaders at P&G research and development facilities must manage a wide range of standard fire protection hazards such as flammable liquids, rack storage, electronic and paper data storage, as well as unique risks such as toxic gasses and materials, paper making machines and paper converting lines, high value equipment such as electron microscopes, and one of a kind process equipment.

Like many other companies, P&G maintains a rather comprehensive set of guidelines on how to protect fire protection risks common to it's facilities. The "P&G Fire Protection Manual" establishes a consistent system of protecting plant processes and facilities world wide. Sections of this manual give the user information on how to protect everything from rack storage of "non-woven" polyester film to computer guided automated track vehicles (P&G, 2001). While this manual is very useful in a plant or manufacturing setting, it has many limitations in a research and development setting.

The P&G Fire Protection Manual specifies protection strategies based on fire tests of materials and accepted strategies of common manufacturing methods. Protection strategies are based on data from a variety of sources including full scale fire tests and loss history (P&G, 2001). What about materials that are under development that have not been burn tested or that are constantly undergoing formulation changes? How are these materials protected? Or, how does one protect a system that is highly flexible, and has the ability to make significant changes in material composition from day to day? Often times the research and development arena serves as a proving ground for "full scale" fire protection strategies. That is, if a research and development process is scaled up to plant level, fire protection strategies can be based on what was done to protect the risk when it was smaller in scale.

This situation creates a considerable amount of uncertainty on how best to protect many of the fire protection risks at P&Gs R&D facilities. This is compounded by the fact that each project must bear the cost for any protection specific to their process risk. Conservative fire protection strategies or "overprotection" can often times add considerable cost to a project. Moreover, protection strategies based on codes and standards rather than the actual fire risk can lead to a false sense of security (Alderman & Harding, 2001). Additionally, codes are usually written to apply to a typical situation or configuration (Barry, 2004).

The identification of alternative fire and hazard protection methods is an idea at the very core of the United States Fire Administration's (USFA's) Community Risk Reduction process. "This is what community risk reduction is all about--a community assessing its fire risks and hazards, and then developing and implementing specific intervention strategies to address those risks and hazards" (National Fire Academy [NFA], 2003, p. 0-18).

Just like any municipal community, an industrial community or facility has a set of its own unique risks. P&G site fire protection leaders are tasked with the identification and management of these and other life safety risks as part of a broad company-wide risk management program. The P&G fire protection programs are working models of the USFA's second operational objective: "2,500 communities will have a comprehensive multi-hazard risk reduction plan led by or including the local fire service" (USFA, 2004, ¶ 1).

LITERATURE REVIEW

An obvious starting point within the scope of this research is to identify the various methods used to determine how best to protect fire and other hazards when traditional prescriptive codes and standards do not apply. Based on the author's own experience, prescriptive fire codes and standards do not always apply at P&G especially when considering some of the complex, unique research and development hazards. Custer and Mecham (1997) echo this in stating that the prescriptive approach may not always meet the needs or expectations of building owners. They go on to say that this is especially true for more complex buildings or processes as well as those with those with the high life or property loss potential. Moreover, "in many industrial situations, prescriptive codes and standards can have questionable feasibility, cost effectiveness and risk reduction benefit" (Barry, 2002, p. 5).

Before exploring the concepts of prescriptive and performance based fire protection methodologies, it is beneficial to define and clarify these concepts. Prescriptive fire protection involves protecting a given risk in accordance with specific guidance or requirements. "Often times, there is little or no room for deviation from a published standard" (Alderman & Harding, 2001, p. 1). For example, P&G fire protection standard No. 602 sets requirements for automatic sprinkler systems installed in company buildings. One requirement is that all interior and exterior hose connections must be capable of delivering 500 gallons per minute (gpm) (P&G, 2003). This and many other prescriptive approaches tend to be based on regulations, and industry practice borne out of past fire incidents (Alderman & Harding, 2001).

Barry (2002) states that performance based fire protection is a "quantitative, probabilistic measure of fire protection success based on functional performance requirements" (p. 5). Barry (2002) goes on to say that these performance requirements are derived from specific fire scenarios and risk tolerance criteria. The Society of Fire Protection Engineers (SFPE) defines performance based design as "An engineering approach to fire protection based on fire safety goals and objectives, analysis of fire scenarios, and quantitative assessment of design alternatives using engineering tools and methodologies" (SFPE, 2000, p. 9). The term "performance based design" has become widely used moniker to identify scenario based methods of quantitative fire hazard analysis. In this context, desired outcomes are expressed in terms of specific goals, objectives, and performance criteria (NFPA, 2003).

The author contacted a colleague for an interview to discuss this subject of alternatives to prescriptive fire protection. Bryan Stemen is a fire protection engineer for The Smithsonian Institution in Washington, DC. Mr. Stemen (personal communication, September 6, 2004) indicates that one of the most widely used methods has been developed by the SFPE and is outlined in their publication *The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings.* This particular methodology has enjoyed relatively wide-spread acceptance with consultants and fire protection engineers alike according to Mr. Stemen. In fact, the SFPE methodology was used to analyze the fire and life safety systems during the recent renovation at the Smithsonian's Arts and Industries building on the National Mall in Washington DC. In this instance, the SFPE method allowed renovations to preserve the historic fabric of the building and still meet the code intended fire and life safety goals (Bowman, 2000). The SFPE methodology consists of a nine step process and is outlined in appendix A.

A process similar to the SFPE method is call Risk Informed, Performance Based Fire Protection, and appears to have been developed mostly by Thomas F. Barry, the director of risk-based services for HSB Professional Loss Control in Kingston, TN. The basic methodology behind Risk Informed Performance based fire protection is known as quantitative risk assessment. This process is very similar to what the nuclear power industry calls probabilistic risk assessment and can be used to assess a wide variety of risks (Barry, 2002).

Although they appear similar, there are some important differences between Barry's Risk Informed, Performance Based Method, and the SFPE's performance based fire protection methodology. Barry describes his system as being "probabilistic" while he describes the SFPE method to be "deterministic" (Barry, 2002). Andersson (n.d.) indicates that in 1997 the British Standard Institution outlined a draft framework for engineering approaches to fire safety design in buildings. The three categories of approaches are 1) deterministic, 2) probabilistic, and 3) comparative. Andersson (n.d.) goes on to clarify what is meant by deterministic and probabilistic methodologies. In a deterministic study, the object is to show that on the basis of initial assumptions, which are usually "reasonable worst cases" a defined set of conditions will not occur. In a probabilistic study however, "criteria are set such that the probability of a certain event is acceptably low" (Andersson, n.d., p. 3).

Barry's Risk Informed methodology as well as the SFPE method are both performance based systems which make use of various established engineering models. Both of these models include methods such as failure modes effects analysis (FMEA), hazard indicies, hazard operability studies, preliminary hazard analysis (PHA's), consequence analysis, reliability analysis, event tree analysis, and fault tree analysis (Custer & Mecham, 1997). Custer and Mecham (1997) give a brief explanation of each of these systems but find FMEA analysis particularly useful. FMEA analysis is used to systematically study failure modes on individual components in a system. This analysis tool can also identify the results of each of these failures on the system or on other components of the system (Custer & Mecham, 1997).

Fault trees and event trees are other tools that appear to have some use in the fire protection engineering field. Clemens (2002) defines a fault tree as "A graphic model of the pathways within a system that can lead to a foreseeable, undesirable loss event" (¶ 5). In other words, fault trees can be used to build a model of all possible combinations of events which could lead to one particular undesirable outcome. Clemens also tells us that they can be used to determine numerical probabilities of the particular undesired occurrence.

Fire protection engineers often use event tree analysis as part of a process for determining a protection strategy for a given fire risk. Event trees are used to characterize the way in which a fire might spread from ignition source through a building. The fire protection engineer then uses this information to develop a plausible fire scenario or "design fire curve" (Custer & Mecham, 1997).

Another tool available to the fire protection professional is the fire safety concepts tree. NFPA standard No. 550--"Guide to the Fire Safety Concepts Tree" describes the framework, and applications of this tool. The fire safety concepts tree provides an overall structure to analyze the impact of fire safety strategies and can identify outages and areas of redundancy in fire protection strategies. It is intended to be used as a decision support tool and "should be accompanied by the application of sound fire protection engineering principles" (NFPA, 2002, p. 2-2). It shows the relationships between fire protection and damage control strategies through a series of decision or logic gates. It provides a simple visual representation of the total concept of fire safety found in codes and standards (NFPA, 2002). An example of the fire safety concepts tree can be found in Appendix C.

In March of 2004, 10 CFR 58.10 was enacted. This federal regulation promulgated by the Nuclear Regulatory Commission (NRC) allowed nuclear reactor operators to voluntarily adopt NFPA 805 "Performance Based Standard for Fire Protection for Light Water Electric Generating Plants". NFPA 805 serves as an alternative approach to "existing deterministic prescriptive fire protection requirements" (NRC, 2004, ¶ 8). This rule came about because nuclear power industry professionals felt that the NRC's deterministic fire protection approach was too "prescriptive" and represented an unnecessary regulatory burden. This can be substantiated by the fact that since 1979, the NRC had issued over 900 exemptions from its then current fire protection requirements (NRC, 2004).

The literature reviewed affected this research project in that the author was able to conclude that there is no one single accepted methodology of performance based fire protection (Custer & Mecham, 1997). However, the literature available revealed that the most widely used methodology appeared to be that of the SFPE. Barry's Risk Informed method although very similar to the SFPE methodology was simply not referenced as much as the SFPE methodology. Some of the other engineering principles discussed such as fault trees, event trees, FMEA analysis, etc., can be used on their own, but are commonly used as components of both Barry's and the SFPE's method. This led the author to include both Barry's and the SFPE's methodologies in the survey forwarded to other fire protection professionals to complete this research.

From the literature reviewed, the author can clearly answer research question number four "Should non-perscriptive risk management methods be used to address non-fire risks at P&G facilities?" In short, the findings of the literature review indicate that some of these methods are already being used at P&G, especially for chemical process hazards. The United States Occupational Safety and Health Administration's (OSHA's) Process Safety Management of Highly Hazardous Chemicals Standard (1996) is intended to prevent or minimize the consequences of releases of toxic, reactive, flammable, or explosive chemicals. The primary means by which it accomplishes this is by establishing a "systematic approach to evaluating the whole process". OSHA calls this approach a "process Hazards Analysis" or PHA.

OSHA recognizes that this can be rather a generic term since the selection of a PHA methodology or technique will be dependent on a number of factors. A single technique is not specified.

In order to fulfill the OSHA process safety requirements as well as their own corporate safety objectives, the Procter & Gamble Company published Health Safety & Environmental Standard number CBA4492 "Process Safety Practice" (2004). This standard provides the user guidance as to when to use a PHA and what particular PHA method is best used for given situations. The goal of this standard is to identify how a process or utility system might be involved in a process incident, the impact that incident may create, and ways to prevent the incident. P&G states that the PHA uses qualitative and/or quantitative methods to analyze potential failures or human errors. This analysis can include such areas as process design, operating procedures, maintenance and management systems. P&G's Process Safety Practice makes mention of various PHA methods including What If/Checklist method, Hazard Operability (HAZOP) method, and FMEA. P&G's Process Safety Practice also recognizes that fault tree analysis, and event tree analysis are useful as supplemental tools to a full scale PHA, especially to estimate event probability.

Other industries are using components of Barry's methodology to manage non fire risks. The American Petroleum Institute (API) initiated a risk based inspection methodology in order to optimize inspections of process piping and vessels containing hazardous materials. This was done because not all chemical containers or piping at a facility represent the same likelihood or consequence of failure. By analyzing the consequence and likelihood of failure for each component, one can prioritize inspection activities (Dugan, 2001).

Alderman and Harding (2001) recognize that the petrochemical industry is not alone in its use of risk based inspection methodologies. Gas and electrical utility companies use risk based inspection to determine "what when and how to maintain systems" (Alderman & Harding, 2001, p. 23). Similarly, Alderman & Harding find that the Gas Research Institute has developed similar risk management tools to manage pipeline inspection and maintenance activities. They also indicate that this same method can be used to derive an inspection testing and maintenance plan for fire protection systems in large office or industrial complexes.

Research question number two attempts to identify the limitations and challenges associated with using non prescriptive risk management methods such as those described above. In his interview, Stemen (personal communication, September 6, 2004) indicates that there are several well known problems with performance based codes and fire protection methods in general. He states that the hazard evaluation process with performance based systems is often cumbersome, and potentially complex. This is compounded by the fact that engineering costs associated with performance based designs often outweigh the perceived savings of using non prescriptive design methodologies in the first place. Stemen also points out that there is often an assumed base of administrative controls present in most performance based methodologies, such as 24 hour security surveillance, or lack of combustible storage in a hallway. Documentation of these assumptions, he says, is often lost, or otherwise forgotten about. Hence, key pieces of a performance based design can be omitted over time--reducing the level of fire protection.

Mr. Stemen also spoke to the potential problems with performance based codes versus general performance based fire protection methods. He states that there are a number of different opinions in the fire protection community regarding just what model code set to use--NFPA or the International Code Council (ICC). He cautions against using more than one "path" of codes, for example using both NFPA standards and ICC codes in the construction of a building. This can be problematic because each code family tends to refer to itself. That is, NFPA standards will reference other NFPA standards and ICC Codes will refer to other ICC Codes.

Stemen's observations regarding the challenges of performance based methodologies and codes are echoed in much of the literature available on the subject. Problems with using performance based codes include schedule conflicts, resulting from longer design reviews, and increased design costs. Moreover, many fire departments and other authorities having jurisdiction may be unfamiliar with or have limited experience dealing with performance based codes and methodologies (Koffel, 2003). Koffel (2003) also points out that with the exception of NFPA's "Life Safety Code" performance based codes are quite new in the United States. Custer and Mecham (1997) reiterate these concerns and identify several others when speaking of performance based fire protection engineering methods. They indicate the perceived disadvantages of performance based fire protection methodologies are as follows:

1. Authorities Having Jurisdiction (AHJ's) may be unfamiliar with this methodology.

2. It requires more engineering time for analysis calculation and design documentation.

3. It may cost more up front.

4. There may be concerns regarding the qualifications of the designer or reviewer.

5. A change in the occupancy may change the fire protection needs which necessitates clear documentation of the design including any key assumptions.

The SFPE recognizes that problems arise in performance based fire protection engineering due to a general lack of research and relevant data in the fire protection engineering field. In the SFPE "Research Agenda for Fire Protection Engineering" (2002), the SFPE cites several examples. One of the biggest challenges is that current predictions of fire phenomena leave quite a bit to be desired. These predictions are often based on rules of thumb and extrapolation from small scale testing. The SFPE (2002) notes that while these methods are based on a large body of experience, the margin between predictions and actual behavior is often unknown. Also, the applicability of these predictive methods to new fire hazards and technologies is unknown and should not be assumed.

The SFPE (2002) goes on to illustrate that there are other unknowns including predictions regarding fire development, heat release rates, and detector response. Even minimum flow rates needed to achieve fire suppression from sprinkler systems are unknown in all but a limited number of cases.

Stemen's comments and observations, as well as the information found in many of the references influenced this research project. The descriptions of the limitations of certain fire protection methodologies were included as response options in the survey. These descriptions provided the author with survey question responses that respondents may have been likely to select.

PROCEDURES

The purpose of this applied research project was to identify alternative methods of risk management that could be used in a general framework by P&G fire protection personnel when traditional codes and standards did not apply. The procedures used to accomplish this purpose included the following:

1. A survey distributed to fire protection professionals to determine the methods they use when prescriptive codes and standards do not apply to a given risk.

2. An interview with Bryan Stemen, a fire protection engineer with The Smithsonian Institution in Washington, DC.

3. A review of literature pertaining to performance based fire protection.

After reviewing a portion of the literature and speaking with Mr. Stemen, the author developed the survey so that it included appropriate terminology and choices. This survey was developed on web-based service called "Survey Monkey" which can be found at http://www.surveymonkey.com. After the survey was completed, it was forwarded via e-mail with an embedded web link to a sample group on November 1, 2004. The process used for selecting the sample group was to identify a collection of fire protection professionals that (a) had access to e-mail and whose e-mail address was easily obtainable, (b) was diverse, and (c) was likely to return the survey with valid responses. Based on the author's own experience in the fire protection field, he identified several sources from which to construct a survey group. These sources included:

1. The St. Bernard/Winton Place Community Awareness and Emergency Response (CAER) Group membership list.

2. The SFPE Design Performance Task Group.

3. The SFPE Engineering Practices Task Group.

4. The SFPE Performance Based Fire Safety Design Task Group.

5. NFPA Industrial Fire Protection Section executive board members.

Individuals who received the survey were colleagues of the author and included Mark Bowman a risk engineer with GE Global Asset Protection Services (GE GAPS). GE GAPS is the risk engineering firm for P&G in North America. Mr. Bowman then forwarded the survey via e-mail to a number of his clients and colleagues. Other individuals receiving the survey were fire protection professionals from the U.S. Department of Energy complex, and various colleges and universities.

The author was not able to determine exactly how many persons actually received the survey as numerous e-mails containing the survey link were returned as "undeliverable". Also, Mr. Bowman forwarded the survey to several other persons. It is not known how many of these individuals received or completed the survey. In all, 18 persons completed the survey before it was "closed" electronically on December 1, 2004. The original survey questions and results were transferred from the web-based instrument into a word document and appears in appendix D. The survey was used to determine the following:

1. The primary focus of work performed at the respondent's facility.

2. The fire protection risks at the respondent's facility.

3. Risk management methods used by the respondents.

4. Whether or not the respondent used performance based fire protection methods.

5. Whether or not the respondent used performance based risk management methods for non fire risks.

6. The limitations associated with the use of performance based methods.

7. Whether or not the respondent's organization had established formal risk tolerance levels.

The author conducted a phone interview with Bryan Stemen on September 6, 2004. The intent of the interview was to inquire about Mr. Stemen's experience with using performance based fire protection engineering methods, as well as the experiences of some of Mr. Stemen's colleagues. Mr. Stemen's comments and observations were helpful to the author in determining likely and appropriate survey responses.

Finally, the author completed a review of applicable literature using material from within P&G including procedures, "Current Best Approaches", and other industry standard fire protection reference material. Most of P&G's material is in electronic format and although available to every employee of the company, would not be easily accessible to members of the general public. The author also used search databases through the Public Library of Cincinnati and Hamilton County to obtain much of the printed references. These search databases included OCLC First Search, EBSCOhost, and Wilson Web--Advanced Search. The on-line search engines "Google" and "Yahoo" were also used and returned an unexpected number of relevant sources.

During the course of the research, the author encountered several limitations which are worthy of mention. First, the number of surveys returned was far fewer than expected. This may be attributed to several different causes. First, many of the e-mail addresses obtained by the author were invalid. Second, there appears to be a limited number of persons in the United States responsible for facility based fire protection who are not consultants or part of the insurance industry. This assumption may have merit considering that there are only four chapters of NFPA's Industrial Fire Protection section--The Southern Ohio Chapter, of which the author was a member was dissolved in 2001 (B. Hufstedder to R. Burnside, personal communication, June 2001).

Another limitation that appears counterintuitive is the large volume of literature available on the subject of performance based engineering techniques. Due to the sheer volume of material available, it was difficult and time consuming to extract key facts relevant to the scope of this applied research project (ARP). Moreover, much of this literature is highly technical and based heavily in statistics, and probability. The author, not having an engineering nor advanced mathematical background, found much of this material cumbersome and difficult to explain.

RESULTS

A proposed guideline for performance based fire protection at P&G is shown in appendix E and represents the result of this research.

Answers to Research Questions

Research Question 1. When prescriptive codes and standards do not apply to certain risks, there are several options available to the fire protection professional. The literature reviewed indicated that there are two generally accepted methodologies that can be used by the fire protection professional (a) Barry's "Risk Informed, Performance Based" method and (b) the SFPE's Engineering Guide to Performance Based Fire Protection Analysis and Design of Buildings. These two methodologies incorporate numerous other techniques such as fault tree analysis, event tree analysis, and failure and effects mode analysis. Barry (2002) states that his methodology involves the use of risk assessment tools such as event trees, and fault trees in conjunction with traditional fire protection engineering methods and fire modeling tools.

The survey instrument distributed to fire protection professionals was used to answer the second portion of research question number one "How are other firms dealing with similar circumstances?" The majority of respondents to the questionnaire (31 percent) indicated that they were employed primarily as fire protection consultants. Other respondents indicated their specific industry was manufacturing (18 percent), environmental restoration (12.5 percent), education (12.5 percent), and insurance (6 percent). 12.5 percent of the respondents indicated they were employed in "other" industries.

Fire protection hazards faced by survey respondents were diverse. Answers to this question were not "mutually exclusive" meaning the respondent could chose as many responses as applied to their particular situation. The majority of respondents (72.2 percent) indicated that flammable liquids posed a fire protection concern for the facilities or processes they were protecting. High value equipment/contents (61.1 percent), research and development processes (55.6 percent), and heavy combustible loads (55.6 percent) represented other common responses.

Nearly all of the respondents (93.8 percent) indicated that when prescriptive codes and standards did not apply, they simply relied on judgment based on experience and operating history. 56.2 percent of respondents indicated they used Barry's Risk Informed methodology, while 43.8 percent indicated they used general qualitative analysis and PHA's. 18.8 percent of survey respondents indicated that they used the SFPE performance based method.

When survey respondents were asked whether or not they used performance based methodologies to protect non fire risks at their facilities 43 percent indicated they did not, and 37 percent indicated that they did use these techniques. 18.8 percent of respondents responded that they did not know whether these techniques were used to protect non fire risks.

When asked what challenges and limitations they encountered when using performance based risk management methods the majority of respondents (46.7 percent) indicated that they simply did not use performance based methods at all. Lack of material and testing data (40 percent), time consuming methods (33.3 percent), complicated methodology (26.7 percent), cost (13.3 percent), and not being acceptable to the AHJ (13.3 percent) were the other answers given by those completing the survey.

The final question asked respondents if their organization had established formal fire protection or industrial safety risk tolerance levels. 66.7 percent of respondents indicated they had, while 33.3 percent indicated they had not. No respondents indicated that they did not know if their organization had established risk tolerance levels.

Some of the results led this author to believe that several survey respondents may not have completely understood the concepts, or terminology included. This is evidenced by the fact that 56.2 percent of respondents indicated they use the Risk Informed methodology, while only 37 percent indicated they use performance based methods at all. Since the Risk Informed methodology is an example of a performance based technique, then one would expect that at least 56.2 percent of respondents would indicate they use performance based techniques.

Research Question 2. There are several limitations and difficulties associated with using performance based fire protection methodologies as indicated by the literature, the interview with Bryan Stemen, and the survey. These problems include:

1. Lack of data on a variety of subjects, which leads to inaccurate modeling.
2. Lack of overall acceptance/understanding of performance based methods by AHJ and other fire protection professionals.
3. Methods can be complicated.
4. Up front engineering cost.

The survey responses appear to coincide with information found in the literature. Barry (2002) states that probabilistic risk management methods are rarely used because there is a general lack of appropriate risk assessment tools. He also indicates that another drawback of this methodology is the unavailability of specific risk tolerance criteria that are acceptable to society.

Performance based methodologies are largely data driven. That is, accurate information is needed in order to make sound decisions. The lack of data or uncertainty can be problematic for performance based methodologies. There are several sources of uncertainty in performance based methods including (a) uncertainty about terminology, definitions, and problem statements, (b) the science and engineering being used, (c) the risk perceptions, attitudes, and values (Custer & Mecham, 1997). Custer and Mecham (1997) also say that uncertainty is particularly problematic in the area of computer fire modeling. Can the room of ignition be predicted? Will other variables influence the time to flashover? Does data exist for the fuel being burned in the model? To add to this problem, there are few references that deal with how to handle uncertainty from a statistical or probabilistic standpoint (Custer & Mecham, 1997). These variables and uncertainties are examples of what Stemen calls "assumptions" and must be managed carefully throughout the life of the design.

Research Question 3. Based on the information found in the literature review, the surveys, and interviews, the author concluded that the best methodology to assess and manage fire risks at P&G facilities is a mix of prescriptive and performance based fire protection. Quantitative risk analysis methodologies and techniques are not a "stand alone" solution to the analysis and protection of fire and other industrial risks and cannot by themselves unequivocally derive an appropriate risk management strategy. Rather they are intended to be used as decision support tools, as a supplement to good personal judgment. "Like any tools they can be used to good advantage by skilled practitioners, or they can be used to create havoc in the hands of the unskilled" (Palisade Corporation, 1996, ¶ 10). This coincides with Mr. Stemen's interview comments that performance based methodologies are best used in a "graded" approach as part of an overall solution with the use of prescriptive codes. Stemen's suggestions are validated by the SFPE (2000) when they state that their methodology can be used in conjunction with prescriptive and performance based codes. Although this author recommends a proposed procedure for performance based fire protection, modeled after the SFPE method, it is not intended to stand alone. Based on the results of this research, it is best used in conjunction with prescriptive tools and good judgment.

Research Question 4. Non prescriptive or "performance based" risk management methodologies are already being used at P&G facilities, albeit in limited areas. From the company resources consulted, process safety appears to be the only industrial health and safety discipline that uses any of the performance based tools such as fault trees, event trees, and failure modes effects analysis. These tools are employed to analyze hazards posed by chemical processes and provide safeguards to prevent them (P&G, 2004). The survey results as well as some of the literature referenced indicates that performance based methodologies may have applications for non fire risks, however it is important to understand their limitations.

The survey results indicated that most respondents reported limitations or drawbacks with performance based methodologies. Nonetheless, 37.5 percent of the respondents use performance based risk management methodologies for non fire risks at their facilities. The risks identified by the respondents were mostly nuclear and chemical hazards and a variety of methodologies were used to manage them including PHA's, FMEA's, and hazard analysis. One respondent recognized that often times these methodologies do not identify all risks associated with a given process and that often times pilot scale mock ups are used to identify actual process risks.

The literature reviewed generally agreed with the survey responses in this area however it was not as specific. Barry (2002) states that the steps in his risk informed methodology are patterned after qualitative risk analysis (QRA) steps developed by the Center for Chemical Process Safety as well as the American Institute of Chemical Engineers. QRA methodology has been accepted by U.S. chemical and oil industries and is now being used in numerous other applications. However, Barry does not specify what these other applications are. Similar statements are made by the SFPE (2000) regarding their performance based methodology. They state that their engineering guide is a framework for performance based engineering for buildings and can be applied to other applications under the guise of an engineer.

DISCUSSION

Appendix E of this applied research proposal represents a performance based fire protection methodology for use at P&G facilities. It reflects many of the SFPE performance based method components while omitting those steps which would add little value to P&G fire protection risks. It takes into account the need for simplicity and ease of use by P&G fire protection and risk management personnel. This proposed methodology is intended to be used as a supplement to an already existing framework of fire risk assessment; not in a stand alone fashion.

The survey results as well as the literature reviewed indicate that there is no one single correct methodology to use when prescriptive codes and standards do not apply. Custer and

Mecham (1997) attribute this to a number of factors including the complexity or the simplicity of the methodology, the lack of data, the lack of credible analysis and design tools, and the relationship of the some methodologies to specific regulations. Survey respondents also indicated that these same concerns when using performance based methods, as well as indicating that these methods tend to be time consuming. Despite these drawbacks, the author concludes that performance based methodologies can be useful to P&G risk management personnel when used as part of what Stemen (personal communication, September 6, 2004) defines as a "graded approach" to fire protection.

Stemen indicated in his interview that performance based methods can be used as part of an overall system even in conjunction with prescriptive based codes. The SFPE methodology can be used in conjunction with either prescriptive or performance based codes or as a stand alone engineering tool. It addresses a number of fire protection concerns and also allows for some design flexibility (SFPE, 2000). Barry's risk informed method uses the same general framework as the SFPE method, however it addresses the element of likelihood or probability much more comprehensively. At their core however, both of these methods are simply quantitative risk assessments that have been tailored to fire protection (Barry & Stone, 2004).

Hence, performance based approaches have been used to manage risks other than fire protection for quite some time (SFPE, 2000). Like many other industries, P&G's process safety program uses elements of quantitative risk analysis and performance based design. However, P&G recognizes that several of these methods including event trees and fault trees are quite complex and generally beyond the capabilities of most internal risk management organizations (P&G, 2004). Organizationally, P&G is not capable of performing "in-house" calculations for each and every fire protection design consideration or risk assessment. The Risk Management and Engineering Services departments are not staffed for these types of activities. Currently, PHA's, process safety studies, and other in-depth engineering tasks are subcontracted to engineering firms because they are complex and time consuming.

The author concludes that the SFPE performance based method stands a better chance of being implemented into P&G fire protection programs, than does Barry's Risk Informed Performance Based structure. Barry's method is quite comprehensive and is being used to protect our nation's nuclear power facilities from fire (NRC, 2004). However, Barry's method appears to have many of the same complexities identified by the P&G process safety standard. With this being said, it is important to remember that nearly all of the methodologies examined employ the use of some sort of fire or hazard modeling. The complexity of these models varies greatly and is simply dependent on the number of variables and the level of detail desired (Alderman & Harding, 2001). Based on the author's experience it is unlikely that Barry's method as a whole, would receive much use or acceptance at P&G simply because of its complexities.

Numerous sources including Custer and Mecham (1997), and Barry and Stone (2004) show that establishing risk tolerances or loss criteria is one of the basic steps of any performance based fire protection methodology. Currently, P&G does not have any formal risk tolerances established for fire protection, only a broad goal of "protecting people profits, and property" (P&G, 2001). Therefore, the use of any performance based method would certainly require the establishment of risk tolerances at some level in the organization.

The author speculates that establishing fire protection risk tolerances may well be attractive to the company in light of recent changes to the corporate insurance policy. The company must now pay the first $5,000,000 of any fire loss (C. Francis, personal communication, September 29, 2004). In other words, P&G now has a five million dollar fire insurance deductible. This is a vast increase from the $250,000 deductible which was in place until late 2001 (P&G, 2001).

If the author's proposed methodology were implemented, it would have several organizational implications. First, fire protection leaders would have to be trained how to use the methodology as well as how to apply it correctly. P&G fire protection programs are very much prescriptive based and fire protection leaders are accustomed to prescriptive approaches. If performance based methodologies are to be used properly, persons using these tools would need training specific to their application. Second, in order to use performance based methods as they were intended, the company must establish risk tolerance criteria at some level in the organization. While such an undertaking would certainly not pose a threat to the company, it would require a significant amount of research and additional workload.

RECOMMENDATONS

P&G fire protection leaders should adopt a standard framework for determining fire protection requirements when prescriptive codes and requirements don't apply. Appendix E represents a draft performance based fire protection methodology that should be used as part of what Stemen (personal communication, September 6, 2004) calls a graded approach--a mix of prescriptive and performance based methodologies. The author purposes that this draft be distributed to the Cincinnati based P&G site fire protection leaders for evaluation and comments. These individuals have a diverse background in fire protection and will be invaluable in further refining the proposed corporate performance based fire protection methodology.

A training program should be developed so fire protection leaders understand the performance based methodology and how to apply it correctly. The author proposes that this may be best handled by contacting a fire protection engineering consultant with a background in training or curriculum development.

The utilization of this or any proposed performance based fire protection methodology is heavily dependent on the establishment of risk tolerance levels. Therefore, the Procter & Gamble Company should consider the development and implementation of formal fire protection risk tolerances. The most logical way to implement these risk tolerance levels would be via the P&G corporate insurance division. This organization develops, and administers the company's fire protection program and serves as a risk engineering resource to site fire protection leaders. Management supported, fire protection risk tolerances can assist fire protection leaders in eliminating ambiguity in determining acceptable loss levels.

Finally, the author proposes further research or investigation into the subject of computer aided fire modeling programs. Computer fire modeling is rarely if ever used at the Cincinnati based P&G facilities. Anecdotal evidence suggests that site fire protection leaders know little of the capabilities of these very powerful tools. This certainly serves as a research opportunity for future readers. Although not specifically mentioned in the literature review, many sources indicate that computer fire models often play an important part in performance based fire protection methodologies. More research should be done to determine what different types of models are available, their specific applications, and their overall usefulness to the site fire protection leaders.

One more point of potential interest to future readers and researchers is the exploration of the limitations encountered with the survey. Why were so few surveys returned? The author theorizes that this is due to a general decline in the number of persons who have full time responsibility for fire protection at a private facility. This phenomenon was originally noted by the author as he witnessed the decline in membership and the eventual dissolution of the Southern Ohio Industrial Fire Protection Association--the original NFPA Industrial Fire Protection section chapter. Furthermore, this theory is supported by the fact that the majority of survey respondents appear to be consultants. Is this perceived phenomenon cause for concern, or is it an indication that industry has made tremendous strides in fire protection and no longer requires in house fire protection resources?

REFERENCES

Alderman, J., & Harding, M. (2001, Fall). Proactive vs. prescriptive fire protection for the offshore industry. *Fire Protection Engineering*, 23-27.

Andersson, Lotta. (n.d.). *Probabilistic risk assessments of fire safety design alternatives.* Retrieved September 30, 2004 from http://www.safetynet.de

Barry, T.F. (2002). *Risk informed, performance based industrial fire protection.* Knoxville, TN: Tennessee Valley Publishing.

Barry, T.F., & Stone, T. (2004, October). Risk informed fire protection: Moving beyond the educated guess. *Professional Safety*, 58-61.

Bowman, A. (2000, Fall). Performance based analysis of an historic museum. *Fire Protection Engineering*, 36-43.

Clemens, P. (2002). *Fault tree analysis* (4th ed.). A training presentation for the Jacobs Engineering Corporation. Retrieved October 10 from http://www.sverdup.com/safety

Custer, R., & Mecham, B. (1997). *Introduction to performance based fire safety.* Boston: Society of Fire Protection Engineers.

Dugan, K.W. (2001, Spring). Practical applications of risk based methodologies. *Fire Protection Engineering*, 5-15.

Koffel, W.E. (2003, Summer). A roundtable discussion regarding the international practice of fire protection engineering. *Fire Protection Engineering*, 7-14.

National Fire Academy. (2003). *Leading community risk reduction student manual.* Emmitsburg, MD: United States Fire Administration.

National Fire Protection Association. (2002). *NFPA 550 guide to the fire safety concepts tree.* Quincy, MA: Author.

______. (2003). Overview of performance based design. In F.W. Mowrer (Ed.), *Fire protection handbook* (pp. 3-197-3-205). Quincy, MA: Author.

Nuclear Regulatory Commission (2004). *Voluntary fire protection requirements for light water reactors; Adoption of NFPA 805 as a risk-informed, pPerformance-based alternative*. 10 CFR 58.48. Retrieved October 3 from http://www.nrc.gov

Occupational Safety and Health Administration. (1996). *Process safety management of highly hazardous chemicals*. 29 CFR 1910.119.

Palisade Corporation. (1996). *Guide to using @ Risk; Risk analysis and simulation add-in for Microsoft Excel or Lotus 1-2-3.* Newfield, NY: Author.

Procter & Gamble. (2001). *Fire Protection Program.* (Fire Protection Manual Standard No. 103). Cincinnati, OH: Author.

______. (2003, July). *Sprinkler system design considerations.* Fire protection manual standard 602. Cincinnati, OH: Author.

______. (2004, February). *Process safety practice*. Process safety manual standard no. 492. Cincinnati, OH: Author.

______. *Facts about P&G 2003-2004 worldwide.* Retrieved November 10, 2004 from http://www.pg.com

Society of Fire Protection Engineers. (2002). *A research agenda for fire protection engineering.* Retrieved October 6, 2004 from http://www.sfpe.org

______. (2000). *SFPE engineering guide to performance based fire protection analysis and design of buildings.* Quincy, MA: Author.

United States Fire Administration. (2004). *USFA 5-year operational objectives.* Retrieved November 30, 2004 from http://www.usfa.fema.gov

Appendix A
The SFPE Performance Based Fire Protection Analysis and Conceptual Design Methodology Outline

I. Define the project scope (identify and document the following)
   i. Constraints on the design and project schedule
   ii. Stakeholders associated with the project
   iii. The proposed building construction and features desired by the owner/tenant
   iv. Occupant and building characteristics
   v. The intended use and occupancy of the building
   vi. Applicable codes and regulations

II. Identifying goals (identify and document goals such as)
   i. Levels of protection
   ii. Similar items

III. Define Stakeholder and design objectives (design goals that have been quantified into engineering terms) These may include the following:
   i. Mitigating the consequences of a fire (in $$, loss of life or other terms)
   ii. Maximum allowable conditions such as extend of fire spread temp. and spread of combustion products

IV. Developing Performance Criteria (a further refinement of design objectives)

V. Developing design fire scenarios

VI. Developing Trial Designs (these include the following:)
   i. Proposed fire protection systems
   ii. Construction features
   iii. Operations

VII. Evaluating the trial designs (each trial design is evaluated using each design fire scenario)
   i. Only trial designs that meet the performance criteria can be considered as final design proposals

VIII. Selecting the final design (can be based on a variety of factors including:)
   i. Financial considerations
   ii. timeliness of instillation
   iii. system and material availability
   iv. ease of installation, maintenance, and use

IX. Prepare design documentation

Appendix B
Risk Informed Performance Based Fire Protection Methodology

I. Define program objectives

II. Define risk tolerance levels*

III. Develop a loss scenario

IV. Evaluate the likelihood of the initiating event*

V. Exposure profile modeling

VI. Determine the fire protection system success probability

VII. Risk estimation and comparison with risk tolerance*

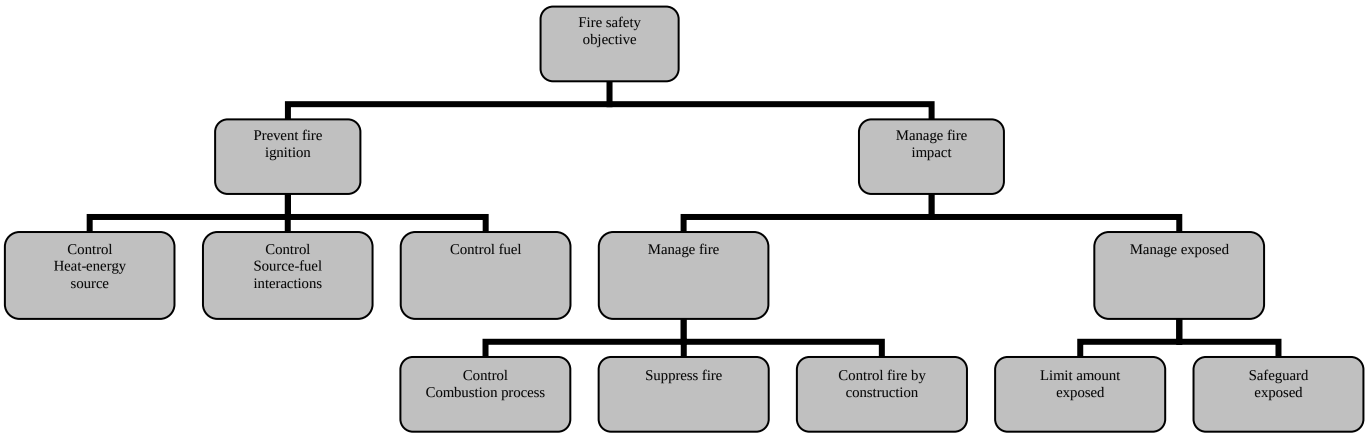
VIII. Cost benefit analysis of risk reduction alternatives*

* Not developed in the SFPE Performance Based Approach (Barry, 2002)

Appendix C
The NFPA Fire Safety Concepts Tree

Top gates with selected lower tiered gates

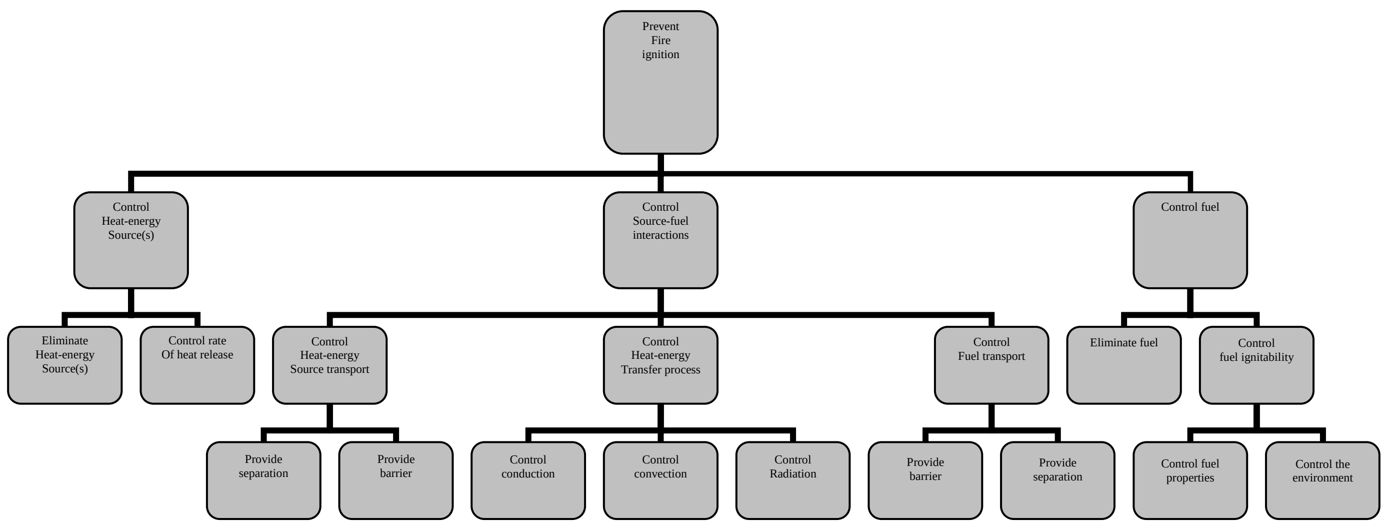
Note: "And" & "Or" decision gates not shown because of scaling.



Appendix C
The NFPA Fire Safety Concepts Tree

Prevent fire ignition branch shown

Note: "And" & "Or" decision gates not shown because of scaling.



Appendix D
Survey Results

Please select the choice that best describes the primary focus of work at your facility.

	Response Total
Manufacturing	3
R&D	0
Environmental restoration	2
Warehousing	0
Petro chemical	0
Public utilities	0
Military/defense	0
Insurance	1
Consulting	5
Healthcare	1
Wholesale/retail	0
Education	2
Transportation	0
Construction/Real estate/Design	0
Laboratory/analytical facility	0
Other (please specify)	2
Aerospace	
Test jet engines	
Total Respondents	16
(skipped this question)	2

What specialized or unique fire protection risks are you responsible for protecting? (select all that apply)

	Response Total
Flammable liquids	13
R&D processes or materials	10
High value equipment/contents	11
Clean room	6
Radiation/radioactive sources	8
One of a kind equipment/contents	9
Sensitive electronics	6

Appendix D
Survey Results

Explosives	4
Heavy combustible loads	10
Other (please specify)	4
Aircraft operations	
None	
Radioactive materials, pyrophoric wastes, carbon filter beds, relocatable structures, waste processing facilities	
Support building & jet engine test stands	
Total Respondents	18
(skipped this question)	0

If traditional prescriptive codes do not apply what method do you use to determine how best to protect a given fire risk? (select all that apply)

	Response Total
SFPE performance based method	3
Judgement based on experience/operating history	15
Risk informed method	9
General qualitative risk analysis	7
Process Hazard Analysis (PHA)	7
Other (please specify)	1
GM Fire prevention policy	
Total Respondents	16
(skipped this question)	2

Do you use any non perscriptive or "performance based" methods to protect non fire risks at your facility?

	Response Total
Yes	6
No	7
Don't know	3

Appendix D
Survey Results

Total Respondents	16
(skipped this question)	2

If you answered yes to question #4 please describe any non fire risks and the methods used to determine how best to manage them

NFPA ESS
Crew training--FMEA, Hazard Analysis
Emergency response Baseline needs assessment
Quantitative & qualitative release-cloud methodologies
System safety review
Engineering judgement based on experience
N/A
PHAs

Total Respondents	8
(skipped this question)	10

What challenges or limitations have you experienced when using "performance based" or non perscriptive risk management methods. (select all that apply)

	Response Total
I do not use performance based methods	7
Methods are complicated	4
Cost	2
Methods are time consuming	5
Lack of material and testing data	6
They are not acceptable to the authority having jurisdiction	2
Other (please specify)	0

Total Respondents	15
(skipped this question)	3

Appendix D
Survey Results

Has your organization established formal fire protection or industrial safety risk tolerance levels?

	Response Total
Yes	10
No	5
Don't know	0
Total Respondents	15
(skipped this question)	3

Your company or organization name (optional)

Total Respondents	11
(skipped this question)	7

Appendix E
Proposed P&G Fire Protection Standard

P&G	**Fire Protection Standard** **Alternative Fire Protection Methodology**	**Number: TBD** **Page: 1** **Date: December 2004** **Function: Fire Protection**

INTENT

This standard is intended to provide the user with a standardized methodology to develop fire protection strategies when prescriptive codes and guides do not apply. It is based on the SFPE "Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings". When traditional codes and standards do not apply to a given situation, the fire protection leader or GBU resource can use this methodology as a process to guide fire protection decisions.

APPLICATION:

I. Define the scope of the project:

Identify the project scope in terms of the boundaries of the system or design. It is best to drive the project boundaries down to their lowest level, such as a specific fire protection system component. Project scope can be larger (such as fire protection for an entire PRL) however, this adds to the complexity of this process.

Project boundaries and scope must also consider budget and schedule

II. Identify the fire safety goals

What fire protection goals are important to the project, the customers, the site, and the company? These goals are best determined through a meeting with the project operators, managers, or other stakeholders. The goals may be best articulated in an "intent" or "objective" statement.

In general, there are four fundamental fire safety goals. They are:

1. Provide life safety for building occupants and firefighters
2. Protect the continuity of operations or elements that affect company profits. For R&D facilities, this could include "speed to market"
3. Protect the physical assets of the company
4. Limit the environmental impact of any fire

III. Define acceptable loss or level of risk

This can be considered a more detailed explanation of the stake-holder goals. This is often stated in terms of the level of risk or loss that is acceptable. These risk levels must be translated into more specific fire protection terms. These terms serve as design objectives from which performance criteria (the next step in this process) can be developed. For example, if a stakeholder indicated that they waited to confine flame damage to the compartment of origin, the fire protection leader may state this as "preventing flashover in the room of origin".

The acceptable loss levels must meet all four of the fundamental fire safety goals in the previous step (step II)

IV. Develop and define performance criteria

The fire protection leader must now select performance criteria that will satisfy the acceptable loss and risk levels stated in the previous step. Performance criteria may include temperatures of materials, gas temperatures, smoke concentration, human response including the time to egress. More than one performance criteria may be necessary to satisfy the acceptable level of risk. Typically, these performance criteria take the form of damage indicators. Also note, that some performance criteria may be set by performance based codes.

Examples of performance indicators may include statements such as:

Visibility greater than 23'
Upper layer temperature no greater than 400 deg. F.
HCl concentration no greater than 5 ppm
Particulate concentration no greater than .5 g/m^3

Table B-3 in the SFPE guide provides an excellent example of how fire protection goals are eventually transformed into performance criteria. In other words, how step I is transformed into step IV.

Note that it is impossible to achieve a completely risk free environment. As the level of risk decreases, the cost associated with achieving those decreased levels rises.

V. Develop fire scenarios

A fire scenario represents one of a set of fire conditions that may be threatening to a building or its occupants and its contents. The description must address the state of the building or area of concern, its contents, and occupants at the time of the fire.

For a possible fire scenario, numerous factors might affect fire development. These may include: form of ignition source, type of fuel, location of fire, how the compartment affects the fire, initial status of doors or windows (open or closed), HVAC status, type of construction, manual suppression.

An example of a fire scenario is as follows:

> A worker is carrying a box with four one gallon glass of acetone into a PRL. The worker trips, dropping the box and breaking the glass on all of the acetone jugs. Before the spill can be cleaned up, the vapors find an ignition source from a nearby paper parent roll unwind stand. The vapor ignites, and since the liquid is above its fire point it continues to burn on the floor around the PRL equipment and paper parent roll. The fire easily ignites the parent roll, as well as combustible insulation on the interior wall. All PRL workers are familiar with the area and evacuation procedures, but do not attempt extinguishment with portable fire extinguishers in the area. Some workers do not evacuate immediately but stay only long enough to perform emergency shutdown procedures on process equipment.

Stakeholders must "buy into" or accept the fire scenario.

The fire protection leader should not attempt to consider all fire scenarios as this is nearly impossible. Instead, he or she should focus on several of the most critical scenarios including the worst credible, the worst possible, and the worst expected fires. The significant aspects of these fires should be quantified. If data does not exist (i.e., heat release rates of products, response time of sprinklers, etc.) then the fire protection leader should examine only the most significant aspects of the fire.

The fire protection leader must be careful to not select a design fire scenario that is highly improbable and too conservative otherwise a very expensive solution may be prescribed.

Similarly, a design fire developed using a non-conservative approach may put building occupants and processes at undue risk. Design fires should not be a description of how the majority of real fires in a building behave. Rather, they are sued to develop and test a trial design and therefore should present a conservative approach.

Developing the design fire can be a complex exercise for the fire protection leader. He or she should include enough detail to derive accurate predictions but must eliminate data that does not contribute to the results desired. Computer fire modeling can be very helpful in this situation, however the user must be familiar with the application.

VI. Identify possible fire protection designs

The design fire scenario developed in the previous step will be used to test proposed fire protection designs. This can be as simple as selecting features similar to prescriptive based designs, but with enhanced capabilities or features. The fire protection leader identifies potential fire protection design(s) which may satisfy the performance indicators and risk tolerances.

NFPA 550 (The Fire Safety Concepts Tree) can assist with the identification of general approaches and methods for achieving a given design objectives. Each fire protection leader should have access to the NFPA codes via the fire protection home page.

There are numerous options for trial designs but generally come from the following categories:

- Limiting or preventing fire initiation and development
- Controlling the spread of smoke
- Fire detection and notification
- Fire suppression
- Protecting egress routes or shelter areas for occupants
- Passive fire protection

These categories are explained in detail in chapter 9 of the SFPE performance based design handbook.

VII. Evaluate proposed fire protection designs

In this step, the trial fire protection design will be evaluated using the fire scenario(s) selected in step V. When the design is matched up against the scenario the performance criteria (step IV) is used to determine if the risk tolerances are exceeded (step III). For example, would the sprinkler system (proposed design) react quickly enough (design criteria) to prevent the egress path from becoming untenable (design criteria) in order to prevent injury in the compartment of origin (risk tolerance)?

When determining if a trial design meets specific performance criteria, the following factors should be considered:

Effectiveness--Does the design meet the established performance criteria? (Effectiveness is the combination of reliability and availability)

Reliability--Will the design or system function as intended? For example, will the sprinkler system discharge sufficient water to control the fire without excessive fire spread?

Availability--Is the system capable of performing a required function at a given instant in time? For example, the system might be unavailable during unplanned maintenance.

System cost--instillation, IT&M, maximum acceptable fire damage
In this step, the fire protection leader analyzes the expected performance of the fire protection system against one or more design fire scenarios. Where multiple design fire scenarios have been developed, they should be considered independently.

Computer fire models are a very effective tool in this step.

For a trial design to be successful, each performance criteria must be met in each of the design fires. Careful consideration should be given to known variations and unknown effects. Several methods exist for accounting for uncertainties in engineering design and include safety factors, uncertainty analysis, sensitivity analysis, comparative analysis, and analysis margin techniques. If the fire protection leader is not able to perform these techniques, he or she must build conservatism into design fire scenarios and performance criteria

VIII. Prepare documentation

Proper documentation is essential to this process and should include the following:

- Project scope--extent of the project including assumptions relative to the design
- Goals and objectives--The fire safety goals and objectives agreed upon by the stakeholders
- Performance criteria--All performance criteria developed, including uncertainty or safety factors built in
- Fire Scenarios--Each fire scenario should be discussed, the basis used to select the fire, and expected conditions and assumptions
- Fire protection design--The final fire protection design. How does it meet the performance criteria?
- Evaluation--description of the design tools used, uncertainty or safety factors, reasons for rejection of any trial designs (where appropriate)
- Critical assumptions--Include all assumptions that must be maintained throughout the lifecycle of the system or hazard in order for the design to function properly.
- Critical features--Design parameters that must be maintained throughout the lifecycle in order for the system to function properly
- References--Include references that are critical for operation and maintenance of the system or any sensitive information that may not easily be retrieved (i.e., product fire test data)
- As built drawings--Of the fire protection system(s) and the risk being protected.

This documentation must be maintained throughout the lifecycle of the system or risk

REFERENCES:

The SFPE handbook of Fire Protection Engineering, 3rd edition

The SFPE Engineering Guide to Performance Based Fire Protection Analysis and Design of Buildings

P&G	**Fire Protection Standard** **Alternative Fire Protection Methodology**	**Number: TBD** **Page: 1** **Date: December 2004** **Function: Fire Protection**

FIRE PROTECTION CHECKSHEET
For alternative methods of fire protection

I. Project Scope

Physical location:	
Fire department capability: (use fire department evaluation--FP std # 1302)	
Utilities: Potable water, FP water, electric, steam, fuel gas, chilled water, lab gasses	
Historical preservation concerns:	
Security schemes: Matrix/one-key systems, surveillance,	
Business interruption/continuity concerns:	
Applicable regulations:	

II. Fire Safety Goals

State the fire safety goals	

Acceptable loss

What is the loss(s) deemed "acceptable" by the fire protection leader and other stake-holders	

Performance criteria

Life safety criteria

Thermal effects: • Time/temperature. How long before a human is exposed to temperature "X" before injury occurs?	
Toxicity • What is the IDLH for expected fire gasses (CO, HCL, HCN, etc). How long before fire gasses reach the IDLH concentration?	
Visibility • How long before smoke obscures the vision of the occupants? Is visibility dependent on lighting even without smoke?	

Non-life safety criteria

Thermal effects: • How long before the following occur and at what temperatures--melting, charring, deformation, ignition.	
Fire spread • The spread of fire by progressive ignition. At what point will the fire spread to other objects in the area of concern? Ventilation and airflow can either increase or decrease this rate.	
Smoke damage • The damage threshold will depend on the sensitivity of the target. Many targets such as electronics are sensitive to corrosive products at low levels. How long and at what concentration of smoke before damage occurs?	
Fire barrier damage • How long before the fire would damage fire barriers and spread? How long before the fire would affect the structural elements	
Damage to exposures: • Are exposures a concern?	
Damage to the environment • At what point are combustion products considered harmful to the environment? • How much fire water runoff (ground or surface water contamination) is acceptable?	

Develop the design fires

Design fire(s) description:	
Estimate heat release and other products of combustion	Heat release rate can generally be represented by the following: The hear release increases proportionately to the square of the time since ignition

Describe potential trial fire protection designs

Evaluating trial fire protection designs

Based on the fire scenario, and the interaction of the trial design, determine a timeline for the following events:

- Ignition
- Fire detection
- Evacuation begins
- Evacuation ends
- Untenable conditions reached in room of origin
- Window failure
- Flashover in room of origin
- Fire spread beyond room of origin
- Manual suppression
- Failure of structural elements
- Fire extinguishment

The heat release rate of the design fire scenario curve is a key factor in determining the time of many of these events.

Fire protection design matrix

Fire scenario description	Trial design description	Performance indicators	Risk tolerance exceeded?