A RESEARCH AGENDA FOR FIRE PROTECTION ENGINEERING

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Fire protection engineers are the link between fire research arid its application in the built environment. In this capacity, fire protection engineers have a unique perspective on where fire research is needed. The Society of Fire Protection Engineers held a workshop in 1999 to identify and prioritize the research needs of the fire protection engineering community. The participants in this workshop identified research needs in ***four*** *areas: (1) application of risk concepts, (2) fire phenomena, (3) human behavior in fire, and (4) data.*

INTRODUCTION

"Fire protection engineering" is the application of scientific and engineering principles to protect people and their environment from destructive fire. **As** the primary appliers of fire protection research, fire protection engineers form one of the principal links between researchers and the end users of fire protection technology.

Fire protection engineering utilizes fire prevention, passive and active fire protection measures, and evacuation strategies to provide the safety required by society at a reasonable cost. Other strategies such as fire safety education, training and fire service response are also used, although other professional groups such as the educational, environmental and legal communities are more active in these areas.

Every profession must strive to find better, more cost effective methods to achieve its goals, and fire protection engineering is no exception. However, there are limited resources available to finance fire related research, which makes it necessary to ensure that the research that is conducted will have the greatest impact. Fire protection engineers, as the primary appliers of fire protection technology, have an understanding of the areas where technology development is most needed.

On October 21 & *22,* 1999 the Society of Fire Protection Engineers hosted an international workshop to develop a research agenda for fire protection engineering. The 70 attendees came from around the world and from all segments of fire protection practice: consulting, insurance, education, research, manufacturing, enforcement, and facilities management. The purpose of the workshop was to identify research needs of the fire protection engineering community.

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* Much of **this** paper is excerpted from "A Research Agenda for Fire Protection Engineers" as published by the Society of Fire Protection Engineers. Readers are referred to the full report, which is available from http://www.sfpe.org/pbdfr.pdf, for further detail.

Why Research Is Needed

The innovation gained through research can be implemented to reduce direct and indirect fire related costs, improve life safety, improve international competitiveness and facilitate regulatory reform. Improvements are needed in many areas:

- **Improved Life Safety.** Fire death rates among the elderly and physically and mentally disadvantaged populations are disproportionately high. Changes are occurring in the demographics of the population that will exacerbate this problem. People are living longer, and the elderly will constitute a larger percentage of the population. Accessibility laws will lead to a greater integration of physically and mentally disadvantaged into the built environment. Additionally, fire injury rates can be several times greater than death rates, with approximately five times more injuries than deaths annually in the U.S.[1]

- **Reduction of fire related costs.** The cost of fire and fire protection – combining spending to prevent or mitigate losses with human and property losses – within developed (G7) countries, constitutes a large percentage of gross domestic product.’ For example, despite dramatic loss rate declines over the past century, the total cost of fire in the **USA** is particularly high, estimated at $100 to $200 billion a year,[3] or over 2% of the gross domestic product.

- **International Competitiveness.** In Europe and the Pacific Rim, fire protection is typically 2-3% of construction cost.[4] In the U.S., this cost is higher, as approximately 5% of every U.S. construction dollar is spent on built-in fire protection.[3] This high cost of fire protection in buildings is passed on to product costs, which can have a negative effect on competitiveness with countries where the cost of fire protection in buildings is lower.

- **International trade.** The cost in the U.S. of meeting fire safety product standards, including testing to demonstrate compliance, is estimated at more than $25 billion per year.[3] Multi-national firms face this cost repeatedly in global markets with varying standards. Less reliance on prescriptive, pass-fail standards will allow producers to test once and sell anywhere. However, development of harmonized, performance-based testing standards requires research, data, and tools to demonstrate equivalence of tests and to convert test results between systems,

- **Regulatory reform.** The industrialized world is adopting performance-based codes for fire safety design. Performance-based design requires engineers to seek out and appropriately apply engineering tools not contained within the codes. Uncertainties in predictions from these tools are often undocumented, and appropriate safety factors often have not been identified or substantiated.

- **Protection of the Environment.** Fire can have a detrimental impact on the environment by introducing toxic or hazardous materials. Products used for fire protection, such as fire suppression agents, must continue to meet changing environmental requirements. Research can be used to identify fire protection measures and products that are environmentally benign,

These benefits would affect all segments of society. However, there is limited funding available for fire research, which requires that expenditures on fire research are in areas which hold the best potential for benefit. This paper identifies the research that is most needed by the fire protection engineering community to make meaningful gains in the areas identified above.

RESEARCH NEEDS

Participants in the workshop identified four primary areas where research is most urgently needed:

- Application of risk concepts
- Fire phenomena
- Human behavior
- Data

Application of Risk Concepts

Workshop participants noted that fire protection engineering has typically focused only on the consequence (or hazard) part of risk. To bring about significant cost-benefit improvements in fire protection engineering design, and to better focus fire protection resources where they are needed most, it is necessary to apply risk management. Using risk management in fire protection engineering practice requires definition of the level of risk that society is willing to accept and a risk management framework.

Society is willing to accept a certain degree of risk. However, exactly how much risk society finds acceptable is unknown. Compliance with prescriptive codes and standards is intended to provide an "acceptable" level of safety. However, as more detail and new requirements are added to prescriptive codes, it becomes more difficult to explicitly define what is considered an acceptable risk.

One workshop participant concluded that "it is not possible to incorporate society's perception of acceptable risk into design, particularly as perception of 'acceptable risk' varies." Determining what constitutes an acceptable risk will require the input and concurrence of public policy makers. Since definition of risk involves deciding how much loss is acceptable, this can be a politically challenging task. However, lessons can be learned from other industries, such as the automobile and aircraft industries.

Once an acceptable level of risk is known, it will become necessary to design to meet this level of risk, This will require the development of a risk analysis framework that considers the risk exposure and the costs, both initial and lifecycle, of any protection methods used.

The development of a risk analysis framework for fire protection would bring many benefits. In addition to maximizing cost effectiveness of fire protection designs by designing to meet the risk that is acceptable to society, a risk analysis framework would allow consideration of the effectiveness of fire protection designs as a complete system. The contribution of individual components (such as active and passive systems, the fire service, fire prevention, and fire safety education) could be considered collectively.

As risk analysis has been applied in other engineering disciplines, one can look to these disciplines as a starting point. The risk analysis tools used in other engineering disciplines can be evaluated for their applicability to fire protection engineering, and possibly modified accordingly.

Fire Phenomena

A common concern expressed at the workshop was that "gaps in current design methods result in excessive conservatism."

An understanding of fire phenomena forms the foundation upon which engineered fire protection is based. Consideration of the effects of fire on people, buildings, property or the environment first begins with consideration of the types of fires that might be expected and how those fires would behave (fire growth, heat release rate, smoke production, etc.). While there are significant opportunities for improvement in design that would result from research in other areas, strengthening the knowledge base in fire phenomena would lead to improvements in all designs.

Current predictions of fire phenomena are too often based on rules of thumb, extrapolation from small scale testing or expensive large scale testing. While these methods are based on a significant body of experience, the margin between predictions and actual behavior is often unknown, and the applicability of these methods to new fire hazards, new technologies, and any changes in the future, cannot be assumed.

Fire development is typically categorized into three regimes: growth, full development and decay. Typically, fire growth is assumed to be proportional to time squared. While this method has been used successfully for quite some time, it is based on limited testing and may not apply to all configurations. In some cases, more scientifically grounded predictions are possible where test results can be balanced against the available ventilation.

Methods of predicting heat release rates from fully developed fires are relatively well established where the enclosures are approximately the size of a common office. However, these methods do not hold well for larger or elongated enclosures. The ability to predict heat release during the decay period is very limited, but the decay period is typically of little consequence for fire protection design.

Methods currently exist for predicting the response of detectors, but these methods are limited to thermal detectors that are installed under horizontal, unobstructed ceilings. Prediction methods are needed for detectors that are installed in other geometries. Also, smoke detector response is typically predicted assuming a temperature rise necessary for operation, a method that does not have a strong scientific basis. While these methods have worked reasonably well, a more detailed understanding would be beneficial such that detection system design and performance could be better matched with design objectives.

In the area of fire suppression, there has been a fair amount of research into halon alternatives and water mist; however, a quantitative understanding of fire suppression is still lacking in most areas. The minimum water application rates from sprinkler systems, which are the most widely used suppression systems, to achieve fire suppression or control are unknown in all but a limited number of cases. Research is needed to better predict suppression system efficacy.

However, a greater understanding of fire phenomena in itself is not sufficient. It is necessary to transfer knowledge gained through research into fire protection engineering practice through the development of models and other tools. A greater understanding of fire phenomena which is readily applicable through models will lead to better and more cost effective fire protection.

Human Behavior

A participant noted that "fire protection system designs assume that people will leave buildings in the event of fires. However, this often does not happen; ... we need to design for these actions." Designs that are based solely on fire behavior, equipment performance, and materials response overlook a significant factor that can often by the key to the outcome of a fire: human behavior, human performance, and human response. To provide better life safety, it is necessary to better understand the actions that people will take in response to a fire.

While there is a significant body of research on movement speed during evacuation, there is little understanding of how to predict pre-movement times. These pre-movement times include the time necessary to correctly interpret fire cues, to decide what actions to take, to complete any pre-movement activities, and to begin to move to a safe place. These pre-movement delays have been significant in many cases. Increased understanding of human behavior and psychology is needed to better predict how and when building occupants react to fire cues, such as smoke and alarms, and what actions they take upon recognizing a cue.

The fire environment can also impact human behavior. People may become impaired or incapacitated from exposure to toxic fire products. Decreased visibility thorough smoke can affect decision making. While there is knowledge concerning the impact of combustion products on human capability, survivability, and behavior, most of it is based on animal testing for lethal effects. Sub-lethal health effects, effects on behavior, and animal-to-human conversions are among the points not now well understood.

Considering human behavior in design is complicated by variations in the behaviors of different people. People in family settings may put the safety of other family members above their own. People with mobility or sensory limitations might react differently than people without impairments. People might have varying degrees of consciousness, particularly where they could be expected to sleep. These occupant factors, and their implications on design, need to be better understood.

As with fire phenomena, increased understanding of human behavior in fire must be quantitative and predictive. Readily available models will be needed to facilitate the consideration of human behavior in engineered fire protection system design. An increased understanding of human behavior in fire will lead to more efficient life safety systems, thus providing necessary protection at acceptable cost.

Data

A common concerti expressed at the workshop was that there is a paucity of data available to fire protection engineers. Statements made included: "A significant amount of fire testing is conducted; however, the results from these tests arc not readily available," and "forensic research is needed to capture performance data of real fires."

Data forms the input to engineering tools and calculations. Data is needed to assess how products and materials would behave in fires. Reliability data is needed for fire protection systems. Forensic data is needed to learn more about how fires arc started and for feedback regarding failures and successes. Human behavior data is needed to learn more about what types of people can be expected in different occupancies, and what types of actions they might take that could lead to fires or alter the course of fires.

There is currently a significant amount of testing conducted to evaluate products. However, the data resulting from these tests are often unavailable or proprietary. In the absence of readily available product data, engineers are faced with applying engineering judgment or making assumptions regarding how products might behave. Mechanisms must be sought to remove proprietary concerns, or incentives must be created to promote the sharing of product data.

Fire protection systems are not always operational. A fire protection system may be unavailable due to accidental shutdown or maintenance. A fire protection system may be available, but might still not perform as intended. Data is needed regarding availability and reliability of fire protection systems so engineers can better predict their dependability. Additionally, data is needed to learn how the performance of systems change with time and to gain a quantitative understanding of the effects of inspection and maintenance at different intervals and depths. With improved knowledge of reliability and availability, redundancy could be provided where it is needed, and not provided where a component is sufficiently dependable.

Forensic data is needed to provide feedback from fires. An increased availability of forensic data would give additional opportunities to learn which strategies work well and which strategies don't work well. Forensic analysis could also be used to gain additional insights into frequencies of fire ignitions in different occupancies. While there is considerable useful fire incident data available, the level of detail on all but the largest fires typically falls well short of engineering needs. The full range of scientific investigative techniques are applied to only a few major fires each year, leaving unanswered questions about the details that are provided on many fires. More detail is needed on smaller fires and investigation that is more thorough would be valuable for most fires. Particularly of interest are small fires that would have become large but for mitigating factors.

While many forms of data are needed, all data must be readily available and have known limitations. Workshop attendees suggested establishing a central contact for fire data. This central contact point would not need to physically house data, but could index data that is contained in other locations. Workshop attendees also identified a need to maintain data in such a manner that it can be used with confidence, the responsibility for which would fall to all who collect or store data.

Prioritization

At the conclusion of the workshop, participants were given forms to evaluate the impact, cost, feasibility and timeframe for the research needs identified at the workshop. These forms were completed after the workshop and used to rate the potential, impact, cost, timeframe and feasibility of each of the research needs identified.

A summary of the research needs identified, their benefits, and the ranking of their impact, cost, timeframe and feasibility can be found at the end of this paper.

Implementation

Workshop attendees were also asked to give their thoughts on how best to accomplish the research that was identified. It was noted that implementing the research agenda will not be easy, and will require a significant financial investment over several years. Since there are a number of organizations involved in research, including both private companies and governmental agencies around the world, each of these organizations will have a role to play in implementing the research agenda.

As many stand to benefit from the results of the research agenda, it is not reasonable to depend only on the organizations now involved in fire research to conduct the necessary research with the resources they currently have available. Collaboration and partnerships, including international partnerships, will be crucial to the success of implementing the research agenda.

Additionally, a champion will be needed to coalesce the diverse interests that will need to come together to ensure successful implementation of the agenda. This champion will need to advocate the agenda, break down inter-organizational barriers, and oversee and monitor completion of agenda topics.

FOLLOW-ON ACTIVITIES

In 2001, the Society of Fire Protection Engineers and the United Engineering Foundation jointly sponsored a conference to better define the research agenda. The results of this conference were better definition of the research needs within each of the areas identified at the 1999 workshop.

Additionally, following development of the research agenda, the Society of Fire Protection Engineers began to focus some resources towards implementation of the research agenda. To date, these efforts have taken the form of advocating the increase in the U.S. federal government expenditures on fire research.

We have prepared a short “white paper” that identifies the societal benefits of increasing the knowledge base of fire research. This white paper was distributed to all members of the U.S. House of Representatives Subcommittee on Technology and the Senate Subcommittee on Science, Technology, and Space. We have also met with the (then) chair of the House Subcommittee on Technology, who indicated that while immediate funding was not available, there was a possibility of holding Congressional hearings for later funding.

We continue to explore ways that we can contribute to implementation of the research agenda. We are also encouraged to see that the International Forum on Fire Research is exploring the creating of a “center” that would coordinate fire research worldwide.

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Research Needs: Application of Risk Concepts

Research Need	Benefits	Impact on Need (1 = no impact; 5 = high impact)	Cost (1 = high; 5 = negligible)	Feasibility (1 = very difficult; 5 = simple)	Time (1 = 5 or more years; 5 = 1 or fewer years)
Determine what level of risk is acceptable to society, and how acceptable risk varies from community to community.	• Understand the level of safety society desires, and the costs of providing this level of safety. • Understand how much society's risk acceptance varies in different communities.	4	2	3	2
Develop a risk management framework to describe the fire/building/people interaction and impact of system operation success or failure.	• The ability to provide the level of safety that society requires at the most reasonable cost. • The ability to balance the strengths and weaknesses of individual components of a fire protection strategy.	4	3	3	2

Research Needs: Human Behavior

Research Need	Benefits	Impact on Need (1 = no impact; 5 = high impact)	Cost (1 = high; 5 = negligible)	Feasibility (1 = very difficult; 5 = simple)	Time (1 = 5 or more years; 5 = 1 or fewer years)
Human behavior in fire, including responses to cues, pre-movement decision making and the impact of fire products (heat, gasses, etc.) on behavior.	• Better understanding of how people will react to fire and the actions that they will take • Better understanding of how people are affected by exposure to fire and fire effects	5	3	3	2
Develop design methods based on human behavior in fire situations.	• Egress system design could be matched to the expected actions that people might take • Improved life safety designs	5	3	3	2

Research Needs: Fire Phenomena

Research Need	Benefits	Impact on Need (1 = no impact; 5 = high impact)	Cost (1 = high; 5 = negligible)	Feasibility (1 = very difficult; 5 = simple)	Time (1 = 5 or more years; 5 = 1 or fewer years)
Heat release rates (fire growth & fully developed fires)	• Better prediction of fire protection performance • Stronger underpinning of fire protection designs • Better predictions of the effects of fire • Improved protection of people and property	4	1	2	2
Suppression system effectiveness	• Better prediction of suppression performance • Suppression system designs could be more closely matched with expected fire characteristics • Improved protection of people and property	4	2ω	2	2
Response of fire detectors (smoke, heat, flame, etc.) to different fire signatures	• Better prediction of detector response • Detection system designs could be more closely matched with expected fire characteristics • Improved protection of people and property	2	3	3	3
Smoke movement from low energy (smoldering) fires	• A better understanding of a type of fire that can be difficult to protect against	2	3	3	3
Investigate the impact of fire and fire protection on the environment	• Reduced environmental damage from fire and fire protection	2	3	3	3

Research Needs: Data

Research Need	Benefits	Impact on Need (1 = no impact; 5 = high impact)	Cost (1 = high; 5 = negligible)	Feasibility (1 = very difficult; 5 = simple)	Time (1 = 5 or more years; 5 = 1 or fewer years)
Develop a data reporting/collection method such that reliability, failure, near miss, product, and occupant data, with known confidence and limitations, is available to the design community.	• Allow engineers greater access to data • Better prediction of the performance of individual components • Improved protection of people and property	4	4	3	2
Investigate how installations vary from design.	▪ Better prediction of as-built performance ▪ Improved protection of people and property	3	2-3	2	2
Data collection from post fire analysis.	▪ Increased feedback from failures and successes • Help overcome gaps in data stemming from proprietary concerns	4	4	4	4
Improve collection of system reliability data from maintenance and inspection	▪ Better prediction of how components could fail and how frequently failures occur ▪ Improved protection of people and property	5	3	4	3
Determine the effects of aging on equipment performance.	▪ Better predict how fire protection performance changes over time • Improved protection of people and property	5	2	1	1
Better monitor and manage systems and components that affect building performance.	• Changes that would adversely impact fire protection performance could be avoided (changes in occupancy, changes to fire protection system components, etc.) • Improved protection of people and property	4-5	2-3	3-4	2

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