TOWARDS ENGINEERED FIRE SAFETY: A GLOBAL RESEARCH STRATEGY FOR THE 21ST CENTURY

by

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Towards Engineered Fire Safety: A Global Research Strategy for the 21st Century

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Abstract

Great progress has been made in the last quarter century in fire safety engineering (FSE) and consequently further limiting the burden of uncontrolled fire. Yet, the total costs of fire continue to rise.

Rapid advances in technology offer the prospect of exciting developments in fire safe materials, innovative fire retardants and fire suppressants, and advanced, more reliable and intelligent fire sensing and control systems.

What will be required to deliver on this potential and do so economically? What are the key remaining scientific, technical, institutional challenges to be overcome in the process? How can a global fire research strategy help accelerate and assure success. What are the likely benefits for those who participate?

This paper presents a strategy and plan for addressing these issues within the next 25 years. It offers a revolutionary path to assured, affordable fire safety.

KEYWORDS: fire measurements, fire modeling, flammability, fire detection

Introduction

Fire is an ever present danger - a threat to life and a significant economic burden on each of our nations. In the last 25 years, considerable progress has been made towards the vision of engineered fire safety. This vision implies a scientific knowledge of fire sufficient to "engineer" materials, products, and buildings to be fire safe, thus "caging" the ravaging "beast" of fire. I say "beast" since society, cultures and technology are constantly changing. Consequently, the hazards and risks of fire are constantly changing as well. Thus, we need to remain ever vigilant to these changing risks.

We are faced with tight resources and budgets, and collectively we are rapidly becoming one global economy and society. That means to get the best we can from what we have we have to invest collectively in fire safety. A common, collaborative, strategic approach to fire safety is an ideal case in point.

The purpose of this paper is to outline a vision towards that end.

Overview

By way of overview, I will begin with a look at the dimensions and magnitude of the burden of fire on our global community. Next I will present a vision for what I like to call "assured fire safety" or "engineered fire safety." To motivate your support for this vision, I will then very briefly illustrate a sense of where we now are in being able to deliver against this vision using examples drawn from the fire research at the National Institute of Standards and Technology (NIST). (This is not so parochial a view, however, since similar examples of current fire research could be selected from many of the other institutes of the FORUM for International Cooperation on Fire Research.)

Next, I will comment on the issues that remain before us and offer some first thoughts on a way forward, a strategy for a global fire research agenda. The FORUM has sponsored a broader study on this topic, which will be released early next calendar year. So, some of these ideas will I hope be sharpened and improved upon. However, many of the main action steps are already clear.

I will conclude with a challenge to each of you. A challenge to think about this idea, how to participate in a global strategy to advance Fire Safety Engineering, how you can improve it, and how you can contribute to it. On behalf of the FORUM, I look forward to hearing from you.

Burden of Fire

There are many ways fire interferes with our lives or livelihoods. These are listed below:

- Loss of life and serious injury (public and fire fighters)
- Property loss
  - residential, commercial, industrial, government structures
  - agricultural, natural
- Loss of function
  - direct loss of business
  - indirect loss of business
  - threat to public
- Cost of fire protection (builders, owners, occupants, general citizenry)
  - insurance and code compliance
  - fire stations, equipment, and personnel
- Productivity limitations

    - product innovation stifled
    - international trade barriers
- Environmental limitations
    - regulations on materials
    - pollution during and following unwanted fire
    - systems testing and fire fighter training
- Security
    - arson
    - terrorism
    - degradation of military mission

Collectively, the above items comprise the total burden of fire. It begins with loss of life and injury, including the unacceptably high rate of death and injury to fire fighters. In addition to the direct loss of property to fire is the impact of such losses on the interruption of function to business or essential service. Fire protection is not cheap. Today, in most countries, it is some multiple of the direct cost of property loss due to fire. (For example, in the U.S., costs of "built-in" fire protection alone is about 5 times direct fire loss.) (Schaenman, 1991) Further, the way we implement fire safety regulation in society can have serious implications for construction delivery time, or the time required to gain approval/acceptance of innovative products or technologies. There is a significant trade-off between fire and the environment. For example, environmental issues arise in how we suppress fires and the technologies we use for flame retardancy. Similarly, fire and security interests often collide. Perhaps you can think of additional burdens of fire.

A number of years ago, we commissioned a study in the USA to get a sense of the total magnitude of the economic burden of fire in the USA. The results were staggering. Whereas, the total loss of life and injury to fire have decreased somewhat over recent decades, they remain unacceptably high at about 4000 deaths, including about 100 fire fighter deaths, annually, and on the order of 20,000 debilitating fire injuries. In the US, direct fire losses to property are about $9 billion.

However, when all the foregoing aspects of fire are accounted for the total economic burden turned out to be a whopping $128 billion. (Meade, 1991) (Schaenman, 1991) This figure does not include a number of the items in the total burden of fires previously discussed. For example, it does not account for any of the productivity, environmental or security impacts listed earlier or what the U.S. Government, especially the military, spends for fire safety.

Clearly, in an increasingly competitive global economy, the burden of fire is a factor which must be taken seriously.

A hint of the relative impact of fire among different nations is provided in Figure 1, which includes data compiled by Richardson.[1] Clearly, all other factors being the same, any nation spending a disproportionate share of its resources on fire safety is at a competitive disadvantage.

Figure 1.

We are all subject to some extent to the risk of natural disasters. Figure 2 puts fire in the context of the other major natural disasters and lists a few relatively recent notable large loss fires. There are obvious interactions as well. For example, high wind and fire or fire following earthquake can turn a relatively minor event into a disaster of humongous proportions. The San Francisco (1906) and the Great Kantoh (1923) earthquakes come to

[1] J. Kenneth Richardson has been contracted by the FORUM to develop a prospectus for a Global Fire Research Study expected in January 2001.

mind as stern historical lessons to this point. The examples of large loss fires on Figure 2 make another point. Big fires do occur and when they do the devastation can be crippling. For example, the Illinois Bell central exchange fire interrupted service for hours to customers and businesses, including, for example, O'Hare International Airport, the Nation's busiest airport. The loss of the Niihama Computer Chip plant resulted roughly in doubling the cost of RAM in the USA until a new source came on line. The Urban Wildland Interface is a matter of increasing concern in the U.S. In 1991, 2449 single family dwellings and 437 apartment units were lost in the Oakland Hills fire in California. Just last summer, 240 homes were destroyed in the Los Alamos fire. Aircraft fires, especially in-flight, can be devastating as well.

Figure 2

Vision

Ideally, one would like to apply human knowledge and ingenuity to minimize the hazard and risk of fire, so that dangerous fires are no more likely than, say, being struck by lightning. History suggests two complementary and highly interrelated strategies. One is public knowledge and understanding of fire risk and what to do about it. The other, an enabler of the first, is to develop scientific knowledge and engineering disciplines of fire and fire safety. Our vision for fire safety engineering builds on this point to include also the following:

> Fire safety engineering becomes a science-based, academic discipline and engineering profession resulting in a proactive rather than reactive mindset regarding fire safety; so that cost-effective fire safety technologies become commercially available, and FSE is accepted globally as the basis for assured fire safety with the consequence that fire risk is understood and cost-effectively managed.

This is an ambitious yet achievable vision. It requires research and education to effect a proactive mindset about fire safety, practical tools and accessible databases to make fire risk information widely used, calculation effectively practiced, and, consequently, cost-effectively managed. Doing this, of course, requires cost-effective fire safe technologies. Finally, since we are now becoming one global economy, FSE must be accepted and practiced globally.

Current Status

FSE is a major priority for the members of the FORUM for International Cooperation in Fire Safety and many others. In recent decades, a great deal of progress has been made. There are now well-established academic programs at the undergraduate and graduate levels dealing with fire science and fire safety engineering. In the last two decades, authoritative textbooks and professional handbooks have appeared which collect, compile and codify this new knowledge. Fire safety engineering has emerged as a scientifically-based, respected engineering discipline and its practitioners are in great demand in many parts of the globe.

To illustrate just how far fire science and engineering have come, and where research is currently aimed, I will briefly comment on the following six areas of activity using examples from the programs at the National Institute of Standards and Technology (NIST).
Areas of fire research which are enabling the development of commercially viable technologies for:

1. Less Fire-prone Material
2. Low Nuisance-level Fire Detection
3. Integrated Building Control and Fire Safety Systems
4. Economic, environmentally Compatible, Fire Suppression Systems
5. Fire Safety Evaluation Tools and Performance-based Codes/Standards, and

6. Enhanced Fire Fighting Technologies

One could as well, compile just as impressive examples drawn from FORUM member institutes around the world.

1. Less Fire-prone Material

NIST scientists are partnering with scientists from industry to understand the basic mechanisms of polymer decomposition in fire and the mechanisms which may be brought in to play to retard fire growth. Figure 3 illustrates, for example, the impact of a small quantity of nano-sized clay particles in a polymer on rate of heat release. Other similarly promising strategies are emerging from studies modeling the relationships between molecular structure and flammability.

Figure 3

Figure 4 illustrates three such models. On the left is a single frame from a molecular dynamics model, which illustrates how fragments split off as it is heated. In the middle is a model of the formation of bubbles in a heated thermoplastic material and the consequences to its flammability. As these bubbles, which contain flammable pyrolysis gases, burst they feed the flames directly and also in the process of bursting through the material surface eject additional quantities of liquid polymer into the flame. The chart on the right side of the figure shows a prediction of mass loss rate profiles resulting from a cone heater pyrolysing a polymer in inert atmospheric (lower curve) and the same heater with flaming combustion (upper curve).

Figure 4

2. Low Nuisance-Level Fire Detection

Until very recently, reliable fire detection has been an elusive goal. Figure 5 depicts our strategy for addressing this goal. We have developed an apparatus, the fire emulator/detector evaluator that is being used both to better characterize various potential fire and non-fire sources, and to guide development with industry of more reliable technology. For example, we are using this apparatus to explore the potential virtues of combining multi-element and multi-function sensors with intelligent systems to achieve very significant improvements in reliability performance.

Figure 5

3. Integrated Building Control and Fire Safety Systems

Another promising area of research builds on recent advances in smart building control systems, and the acceptance of international standards for interoperability of components in such systems. We are expanding these concepts to integrate signals from sensors related to all building functions. This will result in more effective communications about what is happening under "normal" as well as emergency conditions, and enables more efficient management of them.

A specific application of this thinking is to combine state-of-the-art fire models and real-time sensor data in a building to create an inverse fire model. The inverse, sensor driven, fire model would (a) use information from sensors throughout building (fire alarm system, HVAC controls, security, indoor air quality), (b) update and predict fire growth and spread based upon changes in sensor output, (c) increase veracity of fire alarm and knowledge of the extent of hazardous conditions, and (d) provide fire fighter with an overview of changing conditions.

4. Environmentally Compatible Fire Suppression Systems

The issue of global warming and its implications for halogenated fire suppressants has spurred a search for alternative suppressants, and a sharper understanding of the fundamentals of flame suppression. Consequently, a number of promising new technologies are beginning to emerge. Currently, we are looking at military and civilian aircraft system applications. Ultimately, we hope these technologies will migrate to a much broader range of application.

What is desired are suppressants with Low Oxygen Depletion Potential (ODP) and Global Warming Potential (GWP). Candidates include gases (e.g., C_3HF_7), liquids (water mist), powders, and solid propellant gas generators (SPGG). The latter, SPGG, have already been deployed for fire protection in dry bays of some military aircraft. (This is the same technology used to inflate automobile air bags.)

We are doing experimental and analytical/simulation work on these gas generator systems. Figure 6 depicts three successive intervals of time in a simulation of flame extinction behind a baffle following a 100 ms pulse of nitrogen.

Figure 6.

5. Fire Safety Evaluation Tools: Fire Dynamics Simulator

Computer based fire models have evolved significantly over the last decade. Twenty years ago, many of our own fire researchers were skeptical of the potential practicability of such models. Now, a wide variety of types of computer-based models are used routinely in fire re-creations, and design and product approvals. At the research and application frontier are models such as the NIST Fire Dynamics Simulator (FDS), which generates a "large eddy" solution to the Navier Stokes equations. This preserves the large-scale structure of the fire driven flows..

We are using this powerful tool in scientific and practical applications. For example, the FDS is being used to model flame radiation to a nearby surface. It has also been used to simulate the performance of sprinkler systems with and without the presence of draft curtains; resulting in changes in industrial insurance requirements and significant cost savings to the automobile industry.

The forensic value of such simulations is terrific. For example, the FDS was used to understand the outcome of a real fire, which claimed the lives of three fire fighters in New York City. The simulation showed the fatal influence of prevailing wind on the outcome of the fire and specifically how it resulted in the fire fighters being overcome. Such re-creations are helping fire fighters develop safer and more effective strategies for dealing with real fires. Also, we are developing an adaptation of the FDS to simulate wind blown fire in the urban wildland interface to provide a tactical tool for fire fighters.

6. Enhanced Technologies for Fire Fighting

For years, we have lamented the fact that fire fighters work with such crude, unsophisticated tools compared, for example, with a modern soldier in combat. Thus, we are trying to harvest and adapt much of what has been so highly effective in the one domain for application in fire fighting. There are many possibilities. For example, we envision and are working with the U.S. fire services applying available sensing, computing, materials and information technology for:

- Tracking of fire fighter inside of structures
- Sensing for warning about limits of protective clothing
- Non-intrusive physiological measurements of fire fighter condition
- Wireless transmission of information from building systems
- Reliable sensing to warn in advance of structure failure.

What Remains to be Done?

This glimpse of current fire research makes clear that engineered fire safety is no longer simply a dream, but rather an emerging reality. What, then, will it take to achieve our vision for engineered fire safety?

A number of difficult issues remain before us. First, fire science is far from fully developed. For example, many important aspects of polymer decomposition, burning, and flame spread need to be understood. Key issues remain in providing adequate scientific measurements of real fires. Similarly, despite the existence of computer-based fire incident-reporting systems in a number of countries, the knowledge and data needed to reliably predict fire risk simply do not exist. Fire research efforts around the world are meager relative to the challenge, and sadly many of these are duplicative, not well coordinated or collaboratively focussed on mutually agreed needs and priorities. Internationally, fire test methods vary considerably. Industry is troubled by costly, duplicative systems for product acceptance. As noted earlier, the fire services are poorly equipped. Finally, there are many typically national, independent, often duplicative research and testing efforts. Each of these issues has important research components. We lack a common framework and agenda for pursuing research in fire safety.

Suggested Approach

Those of us involved in fire research, fire safety testing, in fire safety regulation and practice need to get our collective act together and begin working as a team. Towards this end, I suggest a simple approach:

- We form a global network. Research and testing labs form a Global network to develop a research agenda and work collaboratively to address priority needs. This network could include research laboratories and centers, academic centers, product and fire testing laboratories, corporate research and development centers, fire service organizations, standards developing organizations, insurance industry, and representatives of "at risk" populations.

- We collaboratively work a common agenda to develop science-based test and approval methods, and harmonize global standards, enabling "once tested accepted everywhere." This is a mighty big step requiring very substantial industry and governmental participation and support.

- We collectively pose the business case for it. The business case and value proposition for a global fire research strategy are developed to gain support from multinationals and national governments for the activities outlined above. The FORUM-sponsored study to develop a Prospectus for a Global Fire Research Strategy is a first step here. It will be released early next year.

What will it take for this strategy to work? It begins with our resolve. If I may assume collective support for such a notion, that network is in our best interests, then the principal needs we face include:

- Advocacy – multinationals and national governments and organizations
- Resources – collaborations, funding
- Leadership
- Participation and commitment.

The central question for all of us is simply, are we willing to work together to do these things?

Conclusion

In conclusion, we have offered a case for a global fire research strategy and agenda. There is no question of the need, or of the practical benefits. The current state of fire research combined with advances in technology generally offer the promise of very significant improvements in fire safety cost-effectiveness over the next decade if we get our act together. I have outlined some first thoughts on an approach and invite your comments and suggestions. Most importantly, I seek your participation in developing the network and agenda. Together we can do it. The FORUM is seeking like-minded partners to join in this challenging effort.

Acknowledgment

I gratefully acknowledge the thoughtful comments and suggestions of David D. Evans, Chief, Fire Safety Engineering Division, and William G. Grosshandler, Chief, Fire Science Division, Building and Fire Research Laboratory, National Institute of Standards and Technology.

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Schaenman, Phililp (1991), Estimated Impact of the Center for Fire Research Program on the Costs of Fire. TriData, Arlington, VA, USA

Figure Captions

Figure 1: Impact of Global Fire Problem

Figure 2: Fire Losses Relative to Other Disasters

Figure 3: Less Fire-prone Material – Experiments

Figure 4: Less Fire-prone Material – Models

Figure 5: Low Nuisance-Level Fire Detection

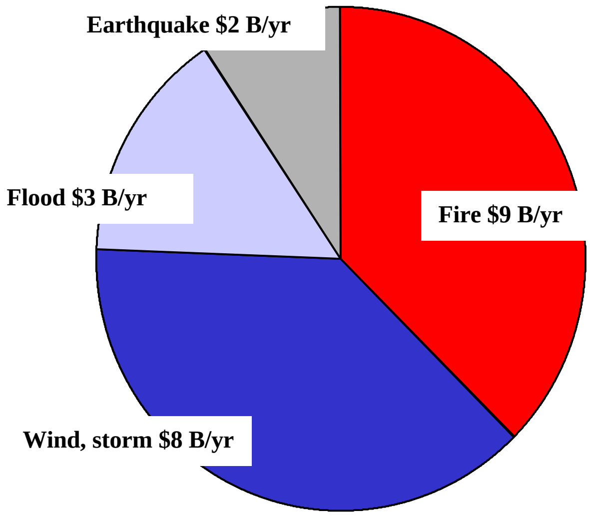
Figure 6: Numerical Simulation of Fire Suppression

Impact of Global Fire Problem

Country…	Fire Costs as % of GDP*
United States	.80
Canada	.91
Japan	.78
Sweden	.63
United Kingdom	.66
European Union	1.00

* Wilmot 1999, ENBRI 1999

Fire Losses* Relative to Other Disasters



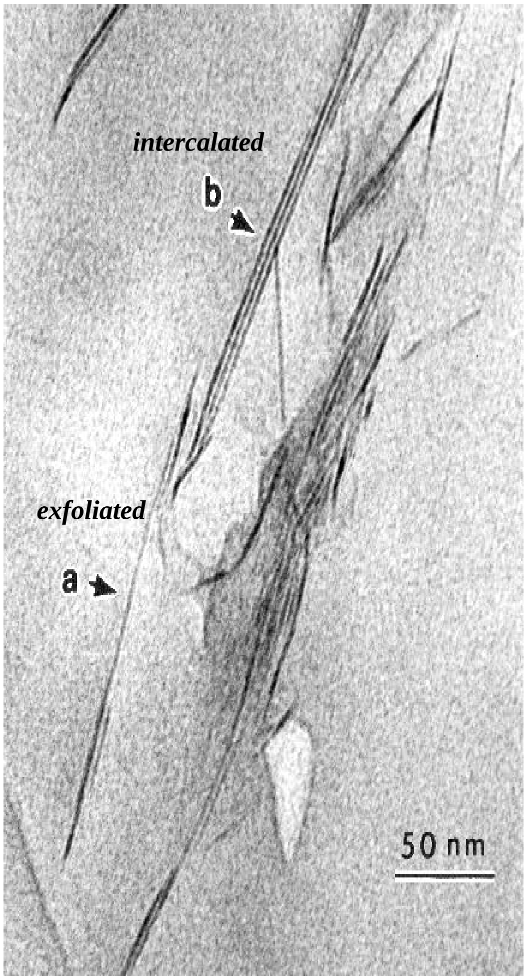
High loss single events:

- **MGM Grand, 1980 - 85 deaths, 650 injured**
- **Illinois Bell, 1988 - $50 M + loss of service**
- **Silicon chip plant, Niihama, Japan - $/RAM doubled**
- **Los Alamos, 2000 - 240 homes**
- **TWA 800, Swiss Air- 100s of lives lost**

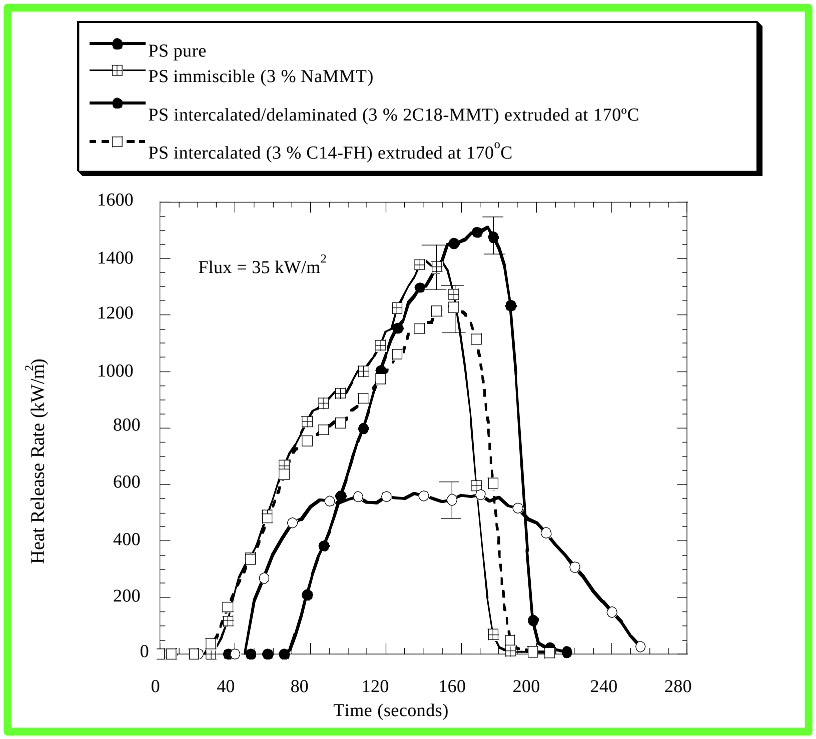
(*data from various sources)

1. Less Fire-prone Material - <u>Experiments</u>

Polymer filled with layered-silicate clay, where nanometer sized clay layers/plates have polymer between each.

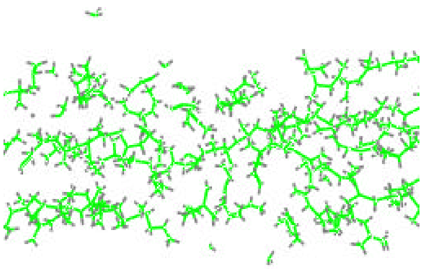


- Improved mechanical properties
- Improved thermal properties
- Improved flame resistance

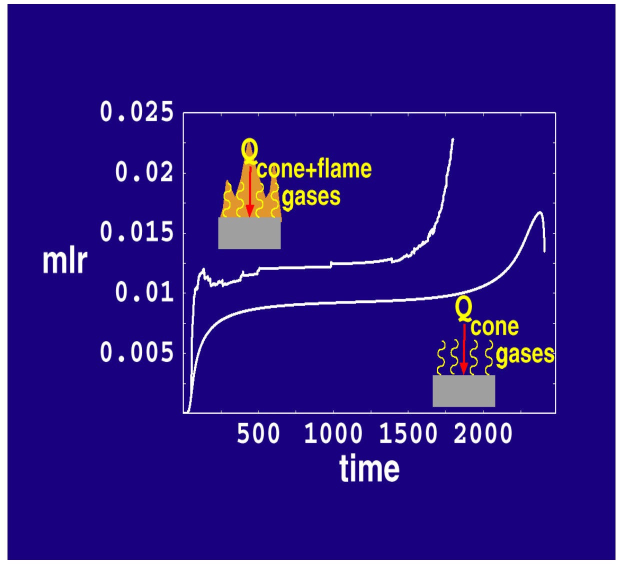


Less Fire-prone Material - <u>Models</u>

Molecular Dynamics Model

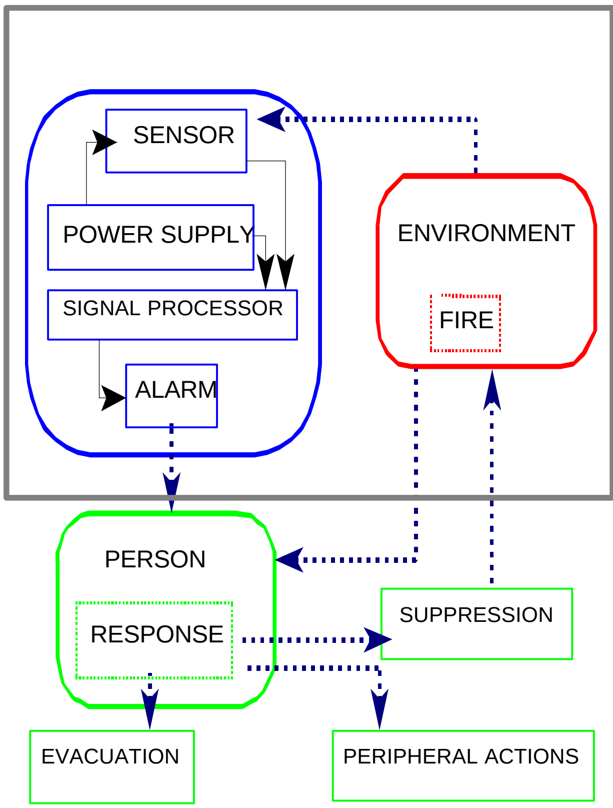


Continuum Transport Model

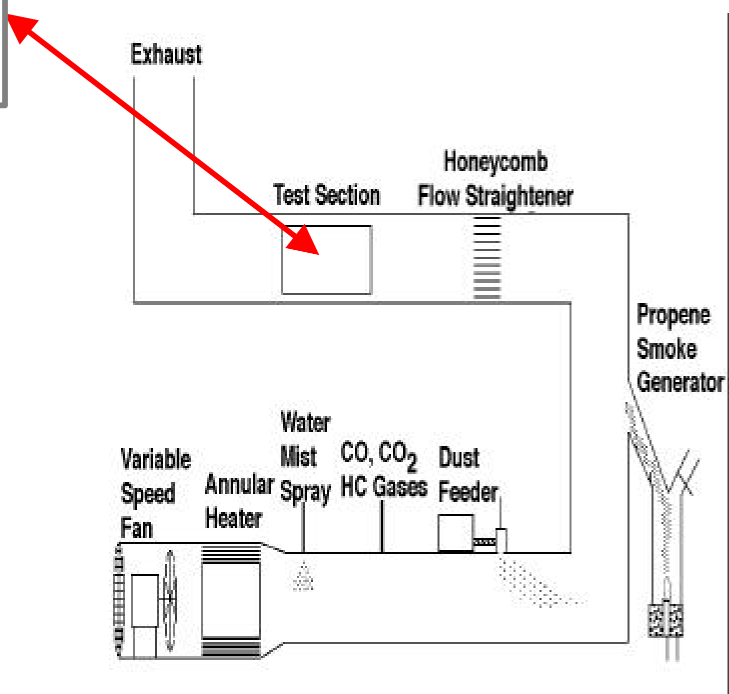


Gas Phase Combustion Model

2. Low Nuisance-Level Fire Detection

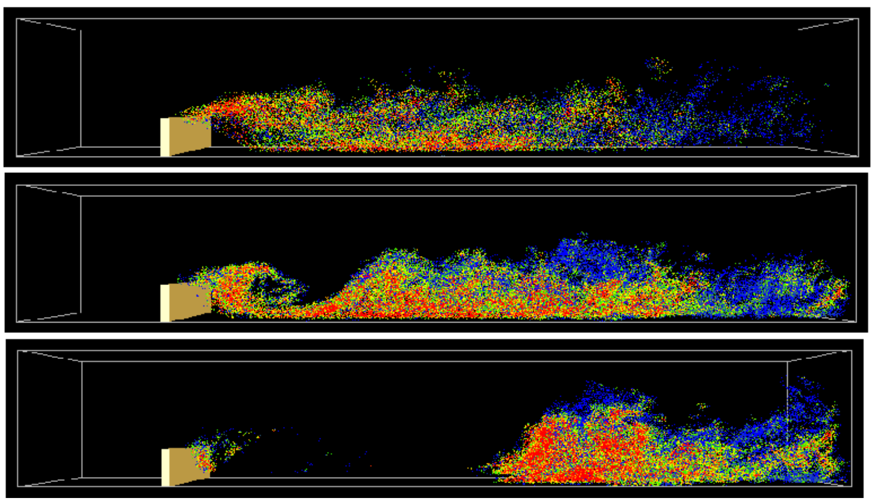


Multi-element, multi-function sensing



Fire-emulator/detector-evaluator

Numerical Simulation of Fire Suppression


t = 0

t = 10 ms

t = 20 ms

Propane flame extinction behind 25 mm baffle with 100 ms N_2 pulse.