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PROCEEDINGS OF THE 1995 WORKSHOP ON FIRE DETECTOR RESEARCH

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ABSTRACT

A workshop was convened February 6 and 7, 1995, to identify the needs of users and specifiers of fire detection systems which are not currently being met by the U.S. fire protection industry; to highlight future needs which may result from new developments in the construction, transportation, and manufacturing sectors, or from regulatory changes; to identify generic, technological barriers which may limit the U.S fire protection industry from fully meeting the users' needs; and to develop a research agenda and recommend priorities to enable U.S. industry to overcome these technological barriers. A series of experts from industry, government, certifying organizations and academia were invited to review the various applications for fire detection systems and to discuss recent developments that could impact the future of the industry. The speakers were divided into focused panels of users and specifiers, systems and components manufacturers, regulators and certifiers, and researchers. Small working groups were convened after the panel discussions to identify critical research issues, concentrating on sensors, signal processing, systems integration and regulations. The ultimate goals of a comprehensive and integrated research program were identified and include a lower ratio of false-positive-to-actual-fire indications, pre-fire warning for protection of high value operations, more fool-proof installation and maintenance methods, component compatibility for system upgrade, a wider range of fires detectable, reliable detection of noxious fire precursors, faster and more precise response of fire detection systems customized to particular processes, earlier warning in connection with halon-alternative suppression systems, situation monitoring following automatic suppression, means to evaluate system trade-offs with the advent of performance-based standards, combination gas sensors for fire/environmental monitoring, and the capability for partial integration of fire detection with other building control functions. Technological barriers which might inhibit attainment of these goals and a research plan to enable the barriers to be breached are discussed.

ACKNOWLEDGEMENTS

This workshop was a joint effort of the staff of the Building and Fire Research Laboratory and the participating panelists. The material upon which these proceedings are based is a combination of written and oral commentary provided by the following people: Lew Parks (Bellcore), Donald Bathurst (General Services Administration), Greg Grimstad (Boeing Commercial Airplane Group), Ronald Kirby (Simplex Time Recorder Co.), Ronald Mengel (System Sensor), A. Donald Goedeke (Donmar Lmtd.), John Cholin (JM Cholin Consultants Inc.), Jack Abbott (Factory Mutual Research Corp.), Isaac Papier (Underwriters Laboratory), Thor Eklund (Federal Aviation Administration Tech. Cntr.), Merton Bunker (National Fire Protection Assoc.), Richard Bukowski (BFRL/NIST), Steve Semancik (CSTL/NIST), Michael Shwe (Knowledge Industries), and James Milke (University of Maryland). The editor acknowledges their direct contributions, and thanks the organizations for which they work for allowing them to participate. The advice and assistance of Richard Gann, George Mulholland and Paula Garrett in organizing and conducting the workshop are also acknowledged. The useful comments of the many active participants in the conference were greatly appreciated. Their names are included in Appendix A.

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1995 WORKSHOP ON FIRE DETECTION RESEARCH

1. Background

Opportunities exist for new concepts in automatic fire detection that do a better job of discriminating a threatening fire from a non-threatening condition across the spectrum of applications. These opportunities arise from a number of pulls, including an increased need to protect more complex and variable structures, the need to replace an aging generation of smoke detectors, the need for detection systems to respond more quickly in tandem with less efficient halon replacement fire suppression systems, and the desire to better safeguard the public and meet evolving regulations. A technological push is being provided by new sensor technologies, by more sophisticated signal processing software, and by a greater understanding of fire physics and improved prediction capability for smoke movement. Competition from new technologies introduced into the market by European and Asian manufacturers provides additional prodding for the US industry to become fully aware of opportunities to enter new market areas and exploit advances in related technologies and scientific disciplines.

NIST has long been interested in various fire detection research issues, including smoke detector performance (e.g., Bukowski and Mulholland, 1978), detailed characterization of smoke particles (e.g., Mulholland and Ohlemiller, 1982), the impact of beamed and sloped ceilings on proper detector placement (Forney et al, 1993; Davis et al., 1995), and the impact of high bays on the activation of fire detection systems (Notarianni and Davis, 1993). Advanced fire sensing remains a priority area in the Building and Fire Research Laboratory (BFRL). The goals of this internally-funded program are to provide

- enhanced business opportunities for the U.S. fire detection industry;
- economical design alternatives for the construction, transportation, communications and manufacturing industries which have mandated fire protection requirements; and
- increased protection of the general public against unwanted fires.

BFRL is currently identifying a number of threatening fire situations and developing a data base of chemical and physical products that are emitted in each case. Working with industry and other agencies, protocols will be established to enable manufacturers to develop a new generation of detection hardware, and users and regulators to evaluate the most appropriate designs for a particular application.

There was an earlier fire detector industry workshop, held at BFRL in July, 1993. The scope and number of participants were limited, but a number of important issues were raised. The group identified the following as critical areas of research for advancing fire detection systems:

- earlier warning systems, consistent with the detected threat
- improved discrimination between unwanted fires and false signals
- estimates of most probable ignition sources as a function of occupancy
- identification of key physical characteristics, or signatures, of developing fires
- standardized methods for evaluating multi-criteria detectors
- annual meetings at NIST to transfer new and/or foreign technologies to industry

In addition, the group identified methodologies for rating detector performance in a non-fire environment as a relevant, but less critical, need. Lower priority topics for NIST to become involved which were also addressed were alternatives to radioactive ionization sources, developing detectors based upon emerging technologies, and maintenance and/or periodic testing protocols to reduce false fire alarms.

2. Organization

The 1995 workshop was designed to be inclusive of all aspects of fire detection. That is, rather than just the manufacturers and NIST personnel which made up the participants of the first workshop, the private industry and government users of fire detection systems and the agencies which regulate the equipment and installations were invited in 1995. The following objectives were set:

- to identify the needs of users and specifiers of fire detection systems which are not currently being met by the U.S. fire protection industry;
- to highlight future needs which may result from new developments in the construction, transportation, and manufacturing sectors, or from regulatory changes;
- to identify generic, technological barriers which may limit the U.S fire protection industry from fully meeting the users' needs; and
- to develop a research agenda and recommend priorities to enable U.S. industry to overcome these technological barriers.

A series of experts were invited to review the various applications for fire detection systems and to discuss recent developments that could impact the future of the industry. The speakers were divided into the following focused panels:

Panel I, Users and Specifiers
Lew Parks (chair), Bellcore, Piscataway, NJ
Donald Bathurst, General Services Administration, Washington, DC
Greg Grimstad, Boeing Commercial Airplane Grp., Seattle, WA

Panel II, Systems and Components
Ronald Kirby (chair), Simplex Time Recorder Co., Gardner, MA
Ronald Mengel, System Sensor, St. Charles, IL
A. Donald Goedeke, Donmar Lmtd., Newport Beach, CA
John Cholin, JM Cholin Consultants Inc., Oakland, NJ

Panel III, Regulators and Certifiers
Jack Abbott (chair), Factory Mutual Research, Norwood, MA
Isaac Papier, Underwriters Laboratory, Northbrook, IL
Thor Eklund, Federal Aviation Administration Tech. Cntr., Atlantic City, NJ
Merton Bunker, National Fire Protection Assoc., Quincy, MA

Panel IV, Researchers
Richard Bukowski (chair), Building and Fire Research Lab, NIST, Gaithersburg, MD
Steve Semancik, Chemical Science and Technology Lab, NIST, Gaithersburg, MD
Michael Shwe, Knowledge Industries, Palo Alto, CA
William Grosshandler, Building and Fire Research Lab, NIST, Gaithersburg, MD

Small working groups were convened after the panel discussions to identify critical research issues. The groups were organized to concentrate on sensors, signal processing, systems integration and regulations. Figure 1 was proposed as one way to consider the cross-linking of multiple topics during the ensuing group discussions. The breakout sessions continued into the second day, when presentations were made to the workshop as a whole to summarize each groups' key points.

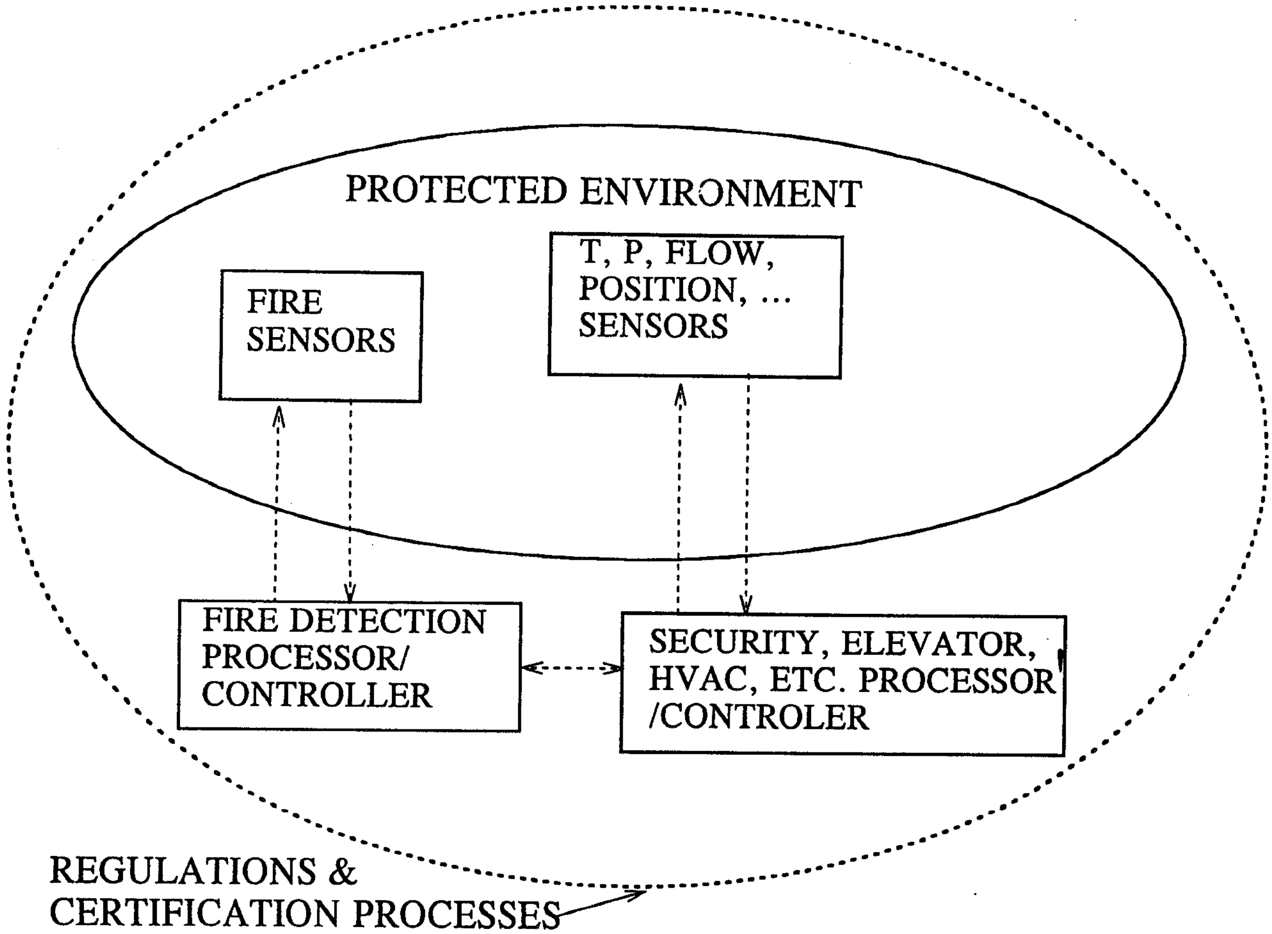


Figure 1. Cross-linking of topics for discussing fire detection research

3. Panel Summaries

a. Users and Specifiers

Telecommunications Industry: Lew Parks represented the telecommunications industry, and gave background on Bellcore to put their needs into perspective. Research issues centered around the need to maintain the integrity of the network. Reliability, survivability and risk reduction were mentioned as key topics as they apply to the network, equipment, and buildings within the regional telephone companies which they serve.

Fire and smoke detection have long been of interest to the telecommunications industry because of the vulnerability of the switching equipment to smoke, heat and acid gases produced from even a very small fire. Fusible fire-wire coded alarms were used as far back as the 1920s for protection of cable runs. By 1970, early warning smoke detection based upon high and low voltage ionization sensors had been installed. During this century telephone equipment has evolved from electromechanical to electronic-analog to electronic-digital to fiber optic. Modern equipment is complex, compact, high heat producing and susceptible to damage from water, dirt and smoke. Many of the locations in most need of protection are unattended and/or remote. Very early warning smoke detection systems are now being installed which aspirate samples of air from multiple locations in the room. These are processor controlled, and include the capability to sense HCl. Detectors are located at intermediate levels, with return air monitors. Placement within the air ducts is under consideration.

The telecommunications industry requires the capability to detect smoke at extremely low levels, better than 1.5%/m. An environmental alert with pre-alarm and supervisory capability is needed. Other requirements include full alarm without reset and the ability to remotely monitor all features of the system. NIST could help by developing methods to prove reliability of the system, to work towards industry acceptance of two level alarms, and to continue basic research in related areas.

Large Building Owners: The building owner's perspective was represented by Donald Bathurst of GSA. The Office of Property Management at GSA is responsible for 2000 buildings owned by the US Government and 5000 leased buildings, with a total of one million occupants. GSA is more concerned about class A fires than class B fires. They require circuit returns in separate fire areas, with all conductors in conduits. The following items were listed as problem areas: the installing electrical engineers do not know fire; certain aspects of the system become obsolete before a phased project is complete; conduits are over-filled; stranded conductors are incorrectly installed; all conductors are improperly placed in a single conduit; and spare parts are difficult to obtain. What is the proper way to classify a building fire alarm, as a system or as equipment? (This issue also occurs when talking about building automation or energy management.)

What a building owner wants is reliability, maintainability, expandability and survivability. Some progress is being made in back-compatible components for fire detection and alarm systems, and discussions are beginning to expand open communications among different system controls. The following is needed to overcome current problem areas: standards for components of fire alarm systems; an open communications protocol; interchangeable components; better understanding of supervision and survivability; better trained designers and installers; and greater accountability by manufacturers.

Aircraft Industry: Greg Grimstad described the regulatory requirements, current practice and in-service experience of the aircraft industry. There are three different fire detection applications for commercial aircraft: lavatory, cargo and powerplant. Lavatory fire protection is regulated by Federal Aviation Requirement (FAR) 14CFR Part 25D (design and construction), paragraph 25.854. Airplanes with a passenger capacity exceeding 20 must provide each lavatory with a smoke detector or equivalent system that warns the crew and/or passengers. Ionization detectors are found most commonly. The experience with these systems is that they are extremely sensitive, and never has a reported fire gone undetected. Environmental pollutants sometimes cause false alarms, however.

Cargo areas may or may not require active fire detection and suppression systems, depending upon their size and accessibility during flight. Classification of cargo bays and the requirements for fire protection systems are given in paragraphs 25.857 and 25.858 of 14CFR, respectively. A typical arrangement is shown in Figure 2. The detection system, if required, must provide a visual indication to the crew within one minute after the start of a fire, and soon enough to ensure that the maximum temperature of the structure is significantly below the point where the structural integrity of the airplane may be compromised. Provisions for checking all functions of the detector in flight are necessary. Both ionization and light scattering smoke detectors are currently employed in commercial aircraft cargo areas. Some units are mounted on the ceiling, and some aspirate a sample of air from multiple sites and draw it into a remote detection cell. There have been no reported incidents of an undetected fire. However, these systems do not reliably differentiate between the presence and absence of a fire because of the multiple nuisance signals which can be generated by moisture and dust from the cargo. A regular maintenance schedule is required to reduce contamination in the system. The present designs are incapable of de-alarming following successful fire suppression.

Federal Aviation Requirement 25.1203 describes fire detector systems used to protect an aircraft powerplant. Fire or overheat detectors are installed at strategic locations around the turbine engine. The units must be able to withstand harsh environments (vibration, temperature, oil and water contamination), and there must be a means to check the status of different functions by the crew during flight. Response time is specified by the regulations depending upon the exact application and construction details of the detector. Temperature-sensitive resistance wires and pneumatic tubes which respond to temperature-generated pressure changes are installed in the nacelles surrounding the current generation of turbine engines. Figure 3a is a typical detection system circuit, and Figure 3b is a schematic of a pneumatic detector and its performance characteristics.

Both the resistive and pneumatic detectors are rugged and reliable, although contamination, loose connectors and poor support occur in service. These detectors are also used to monitor the general condition of the engine. A reduction in response time and installation space requirements, and enhanced tolerance to installation environment and contamination are desired characteristics for powerplant fire detectors.

Residential Applications: Margaret Neily of the Consumer Product Safety Commission (CPSC) spoke from the audience during the discussion period to provide background on the Commission's experience with residential smoke detectors. Two recent CPSC studies were cited (Smith, 1994; Smith, 1995) which examined the number of operable smoke detectors in the U.S. population and the performance of smoke detectors that were actually present in residential fires. The data confirmed that the major reason units in the field are inoperable or fail to alarm during a fire is a dead or disconnected battery. Nuisance alarms from cooking and sources of moisture were mentioned as being prevalent and the primary cause for the power to be intentionally disconnected by the occupant. Battery-powered ionization detectors dominate the number of installations; a disproportionate number of the nuisance alarms and inoperable units belonged to this class. The executive summaries of the CPSC reports are included in the appendix of these Proceedings. Complete copies are available as indicated therein.

b. Systems and Components

System Software Integrity: The importance of proper software management was stressed by Ronald Kirby of Simplex. Modern control panels are much more powerful and flexible than those built

Industry Practice Cargo Compartment Fire Detection System

(a) Boeing

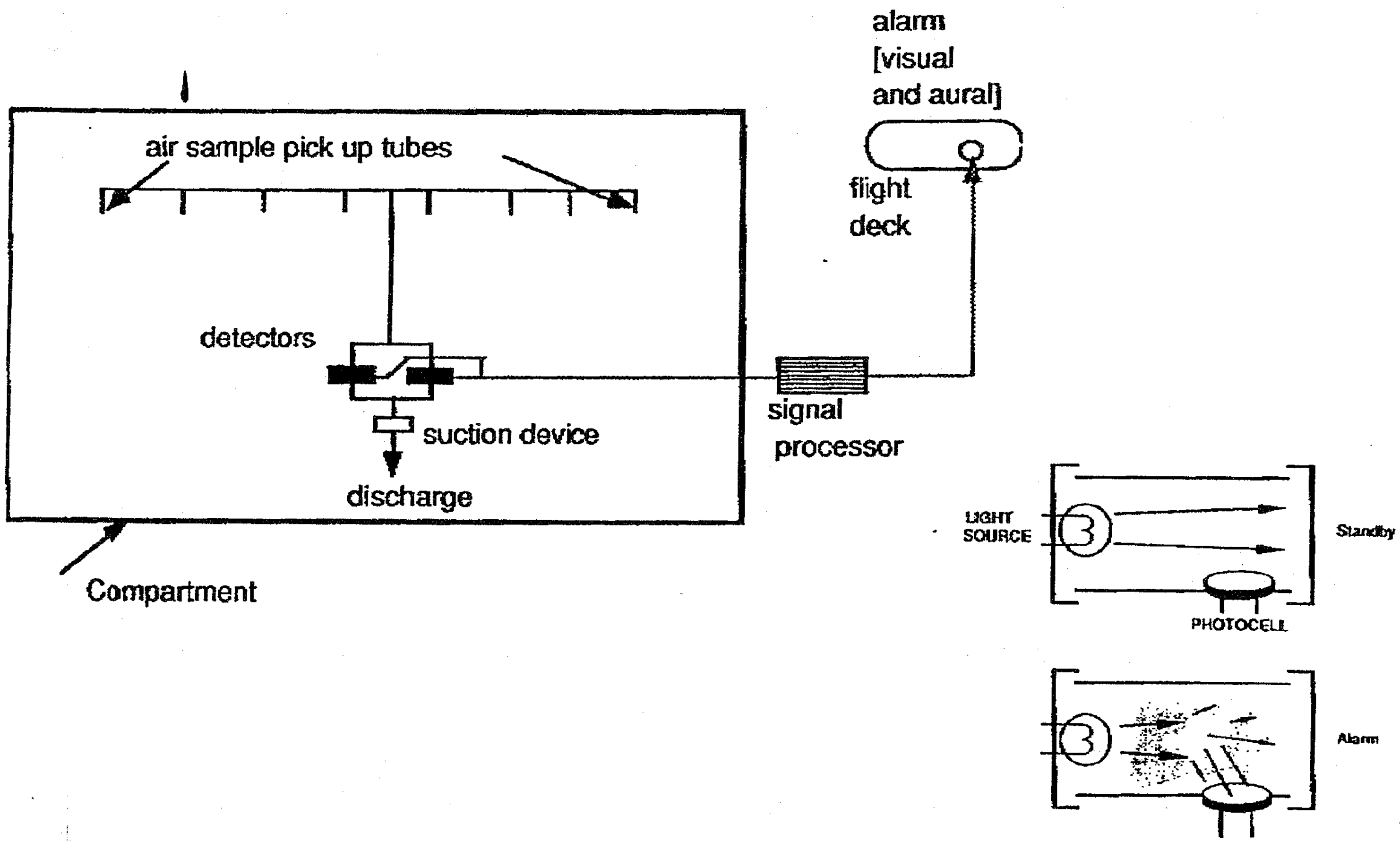


Figure 2. Industry practice cargo compartment fire detection system

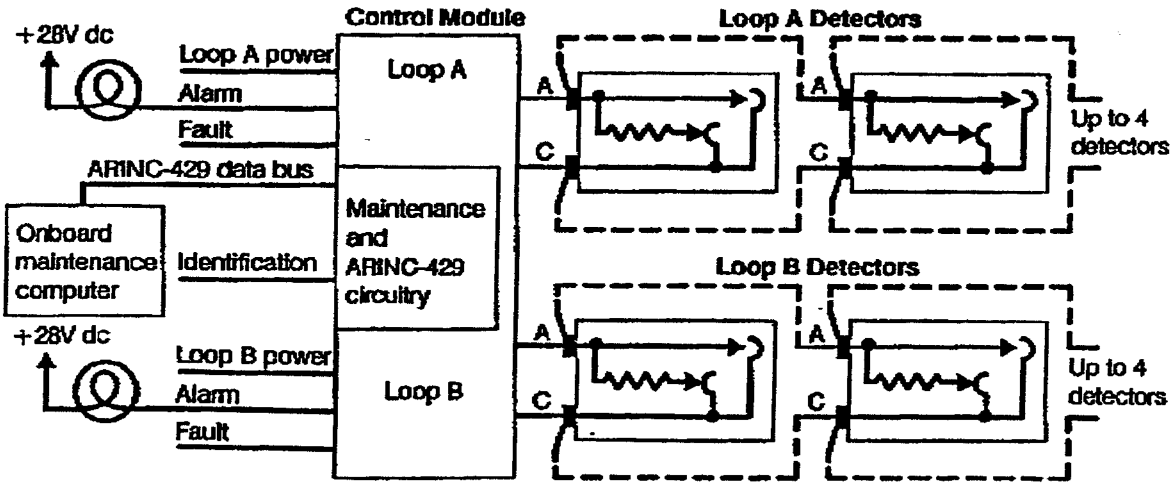
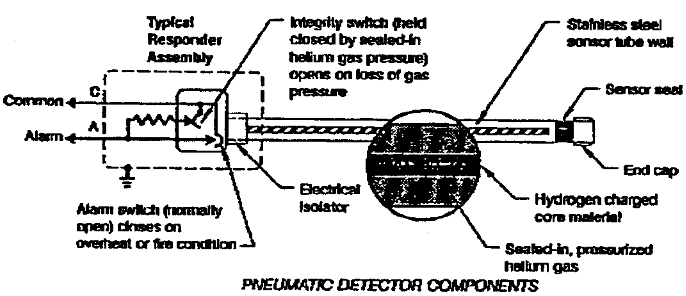


Figure 3a. Powerplant typical detection system circuits

2. Pneumatic (Pressurized) elements whose internal pressure changes with temperature.

Detector components



Typical Performance Characteristic

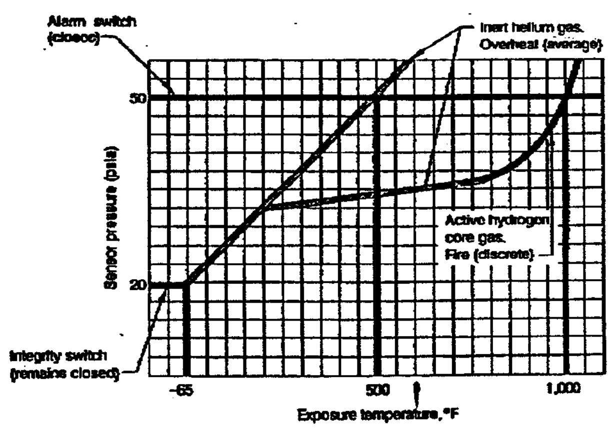


Figure 3b. Powerplant fire detectors

twenty years ago because of the widespread use of integrated circuits and digital components which allow functions to be fully computer controlled. The executive software that is originally designed to run the system is approved along with the hardware before listing and installation. Software changes made in the field can lead to serious problems if not done by trained personnel and properly documented. Improper changes can result in errors, bugs, or outright failure of the system. For fire alarm control panels that are integrated with security and HVAC systems, it is critical to maintain mutual inaccessibility to software to protect the integrity of each. Various segments of the industry are called upon to develop quality control procedures. A complete text of the presentation can be found in the paper by Kirby (1995).

Signal Processing and System Controls: Ronald Mengel of System Sensor presented his view of the direction fire sensing is heading. It is clear that performance-based standards will greatly impact the way the industry does things in the future. Direct integration with suppression systems and additional safety functions are likely to be incorporated. Protocols will have to be developed to allow the integrated systems to communicate with each other. Detectors with multiple sensing elements are already being introduced, in spite of the lack of acceptance standards tailored to this type of product.

Discrimination between a real and a nuisance alarm, and identification of the seriousness of the threat from an actual fire are desirable, but as yet unattained, attributes of a fire alarm system. Improved signal processing using analytical tools such as neural networks and fuzzy logic could be used if one knew the signals characteristic of an unwanted fire. Additional research in processing signals from fires is needed to close the gap that has widened between the domestic and foreign industries. As well, there is a need for new fire detector system and component test methods that encompass situations that are representative of real world fires, but these methods must be repeatable.

Machine Vision Fire Detection Systems: For aerospace and defense applications in which the presence of an unwanted fire must be identified in a very short period of time with no tolerance for a false indication, a machine vision fire detection system (MVFDS) may be appropriate. Donald Goedeke of Donmar Ltd explained how such a system operates and its potential in different applications. Several thousand false detections and hundreds of suppression system false activations were reported during 1990 in Air Force facilities equipped with flame (ultraviolet and/or infrared), temperature and temperature rate-of-rise detectors. An MVFDS is much more selective than these conventional detection systems. Machine vision relies on a video charged-couple device (CCD) camera to monitor the environment. Multiple fiber optic cables allow one CCD to view simultaneously multiple directions. The spectral output of the camera is stored in computer memory as a function of time and space. Pattern recognition and image processing logic are used to analyze the images on the fly. The major components are shown schematically in Figure 4 and include a camera (color, monochrome or ir video CCD, or focal plane 2-D array), a fast frame grabber, a microprocessor with unique algorithms and system software, input and output devices, and a remote CRT display. An advanced system, shown in Figure 5, is being developed to control a fire suppressor turret on an airplane crash fire fighting vehicle.

The advantages of the MVFDS are the following: it cannot be fooled by uv, visible, or ir emissions from common background sources; it processes multiple spectral images in real time to reliably detect an actual fire; it can be trained for very rapid response, making it suitable for explosion suppression systems; person-in-the-loop provides real time verification and manual override capability; it can identify the location, track the growth and monitor suppression; and it can be tailored to many different specialized applications. The capabilities of image processing technologies are increasing as the cost per unit is decreasing, making MVFDS more attractive as a possible alternative for protecting high cost facilities in which suppression decisions must be made quickly.

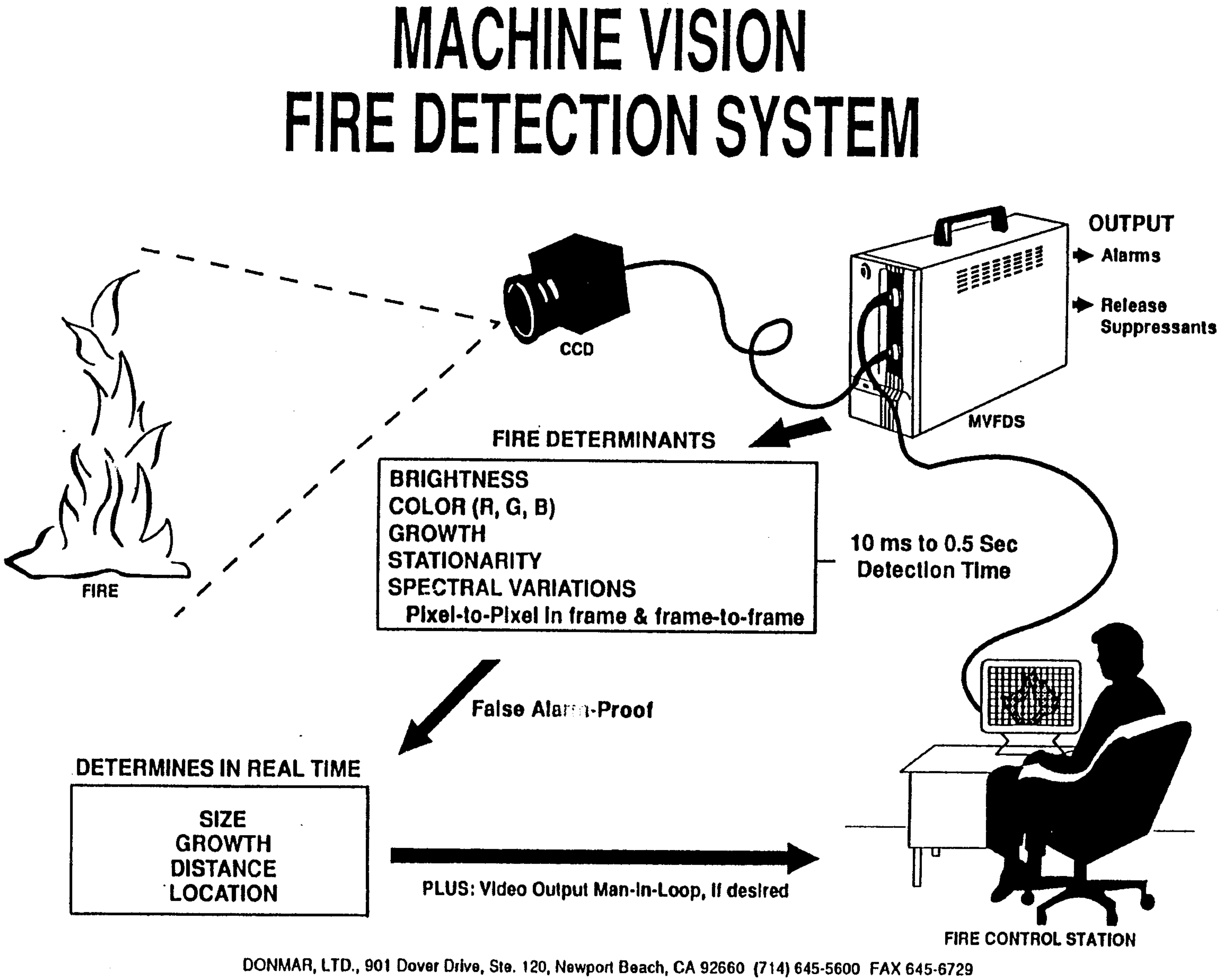


Figure 4. Machine vision fire detection system

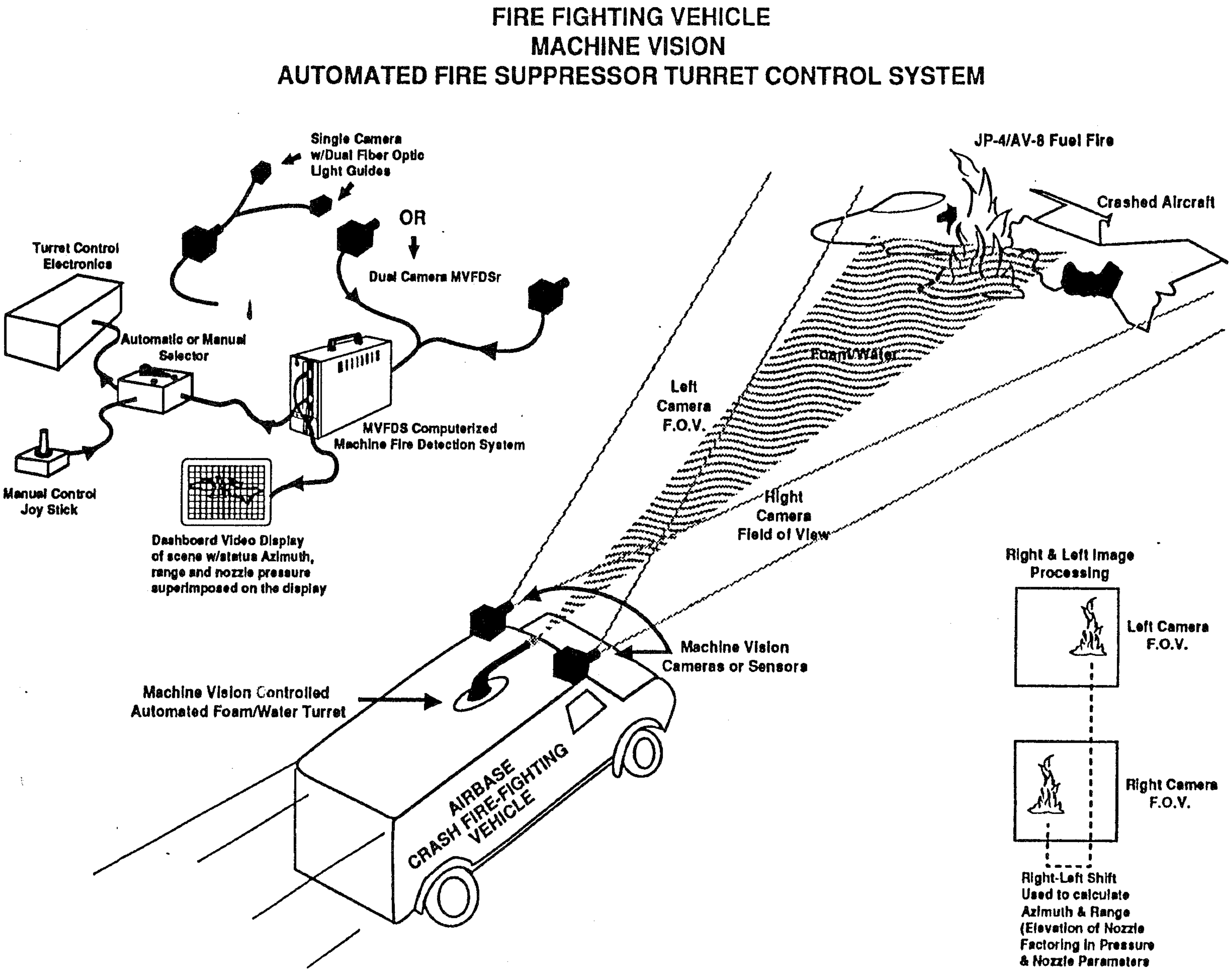


Figure 5. Automated fire suppressor turret control system

Product Liability: John Cholin, a fire protection engineering consultant, discussed how the manufacturers of fire protection systems and components increasingly are being held liable for losses due to fire or equipment failures. This is occurring even if the failure can be traced to improper maintenance or modifications to the system by the owner of the building or business. Workman's compensation laws are slanted in a way that encourages this behavior. The main point of his presentation was that in bringing new products to market, the manufacturers need to consider the consequences of product liability, and that the threat of possible legal action is a real deterrent to new technology development and encourages the status quo.

c. Regulators and Certifiers

Factory Mutual: Jack Abbott of Factory Mutual distinguished between his company's role as a testing laboratory (FMRC Approvals) and as an authority having jurisdiction (FM Engineering's support of the Factory Mutual insurance companies). The approvals process for fire detection equipment makes use of field application feedback so as to minimize misapplication of FM-approved equipment. Approvals are generally system-oriented for the same reason. Standards on fire detection systems which have been developed by Factory Mutual include FM 3210, FM 3230-3250 and FM 3260. To meet the needs of the customers, where established consensus standards do not yet exist, FM often tries to base new approvals on verification of application-specific performance claims. Examples of this have been high sensitivity smoke detection systems, spark detection and flame detectors. It is more difficult to be as flexible in approval work now because of industry's more recent desire to have all testing laboratories use harmonized standards. Accordingly, the approvals process is slow when it must wait for the development of a new consensus standard.

From an insurance company's perspective, a proven detection system is much preferred to being a partner in beta testing of a new detector or a so-called enhancement. More reliability (and faster response, if false alarms are not the trade-off) in fire detection is needed. Thus, some form of intelligent multi-sensor looks promising. Another need, with somewhat limited application, is a fast fire detector capable of tolerating multiple fire exposures without loss of calibration for use in multi-cycle, clean agent extinguishment system actuation. For reliability reasons, it is usually necessary for critical fire detection functions in large building management systems to be capable of stand-alone operation.

Underwriters Laboratory: The UL perspective was presented by Isaac Papier, from Standards and Product Testing. The current generation of detectors are limited to measuring a single attribute of a growing fire. This limited amount of information leads to a tradeoff between detector sensitivity and increased frequency of false alarms. Increasing numbers of false alarms are putting a large burden on fire departments, with the result that some municipalities are considering fines for false alarms.

A lot of work is being done overseas to develop multi-sensor detection systems. UL, under sponsorship of NEMA, is investigating different fire types (e.g., smoldering mattress, burning toast) to identify unique signatures that will permit better discrimination between an unwanted fire and an environmental nuisance signal.

Papier pointed out that the US fire protection industry was falling behind their foreign competition. He suggested that if they were unwilling to invest in new technologies, they would run the risk of being shut-out in future markets. (Richard Roby of Hughes Associates commented that current UL fire detector testing methods needed to be upgraded to accommodate multi-sensor detectors.) Papier felt that NIST should perform research to help US industry remain competitive. From the audience, Richard Gann of NIST mentioned that the Advanced Technology Program is designed to do just that, and invited the industry representatives in attendance to submit research proposals in this area.

Examples of UL standards related to fire detection devices include UL 217, UL 268, UL 268A, UL 521, UL 539 and UL 2034.

National Fire Protection Association: The NFPA's mission, as described by Merton Bunker, is to reduce the burden of fire on the quality of life through scientifically-based codes and standards, through research, and through fire safety education. It is an international organization, with voluntary membership. The staff of NFPA does not write standards, but they support the Standards Committee and the numerous volunteer Technical Committees that do. Codes, standards, recommended practices, and guides are all generated through NFPA. Codes describe mandatory procedures and are written in a form suitable for adoption directly into law. Standards include mandatory, advisory and nonmandatory provisions. Recommended practices and guides are less stringent and more informative than codes and standards.

Standards are developed using the consensus process. Quoting from the presentation, "consensus requires that all views and objections be considered and that a concerted effort be made toward their resolution." The Standards Council is responsible for judging when consensus has been achieved. Membership on NFPA committees offers the greatest opportunity to participate in the standards making process. The Standards Council ensures that a wide cross-section of interests is solicited and that the committees are balanced. Members are classified as users, manufacturers, enforcers, testers/researchers, special experts, insurance representatives, installers/maintainers, consumers, or representatives of labor. No more than 1/3 of a committee can be made up of any single classification.

The standards development cycle is about a two year process. There is a ten week public comment period about midway through the cycle to allow those affected by the proposed standard (or changes to an existing standard) to provide feedback to the Technical Committee. A 2/3 affirmative vote from the Committee brings the revised proposal to the membership as a whole at the next national NFPA meeting. The membership vote is advisory to the Standards Council, which then rejects or accepts the proposal from the Technical Committee.

The current NFPA standards for detection devices can be found in the National Fire Code, volume 4, section 72, chapter 5.

Federal Aviation Administration: Thor Eklund described the role played by the FAA in certifying fire detection systems for commercial aircraft and the Technical Center's perspective on research needs. Detectors are located in the following spaces: engine nacelles, class C cargo compartments, electronics bays, lavatories, auxiliary power units, hot bleed air ducts, and the wheel wells. Statistics gathered between 1974 and 1989 reveal that well over half of all in-flight fires occur in the galley or lavatory. In this time period, there were a total of nine accidents resulting from fires beginning in the following locations: lavatory (2), passenger cabin (2), and cargo bay (5). All of the fatalities resulting from fires located in the cargo bays were initiated within the contents of the cargo. The heater, insulation, pneumatic duct, and battery were listed as sources of the seven remaining fire incidents. Overall, accidents which were fire initiated and resulted in the loss of the aircraft numbered 0.1 per million departures.

The problem of false alarming in class C cargo areas was discussed. These are cargo bays that are inaccessible in flight and have a volume greater than 28 m^3. Because every alarm results in a halon release into the cargo area, the false alarms can be determined from the number of bottles that were discharged during flight. Based upon recent statistics, there are about 48 class C cargo area false alarms per year in the U.S. fleet. From the previously cited statistics, one would expect, on average, a single fire per year in the cargo area. The result is a 48:1 ratio of nuisance to actual alarms.

The cargo compartment detection requirements and guidance are covered in the following documents:

Federal Aviation Regulations - FAR 25.855, 25.857 and 25.858
FAA Technical Standard Order - TSO C1c (7/10/87)

SAE Aerospace Standard - AS8036 (4/1/85)
Radio Technical Commission for Aeronautics - RTCA DO 160B (1/25/80)
FAA Advisory Circulars - AC 25-7, AC 25-9A

The most relevant regulation is FAR part 25.858. This specifies that the detection system must give flight deck visual indication within one minute, that the fire detection must occur at temperatures below those which decrease aircraft structural integrity, that systems must have means for the flight crew to check circuit functionality during flight, and that the detection system must be demonstrated to be effective for all approved operating conditions.

The most common cargo compartment smoke detectors are either *in situ* ionization, *in situ* light scattering or aspirating light scattering configurations. The acceptance process for detector systems requires the applicant to submit designs, specifications, and data showing compliance with the Technical Standing Order (TSO) via previously cited standards and guidelines. For new installations, the applicant submits a flight test plan for demonstration of compliance with the one-minute rule for detection of smoke.

There is a need for research that will improve the speed of response to a fire which has been detected by the crew, and to enhance the crew's effectiveness. Diagnostics to assess the remote fire scene following a suppression action are also needed. Proper characterization of smoke and its transport, and standardized smoke sources would greatly assist the certification process. The FAA has been experimenting with a helium smoke simulator as an alternative to using particulates.

d. Researchers

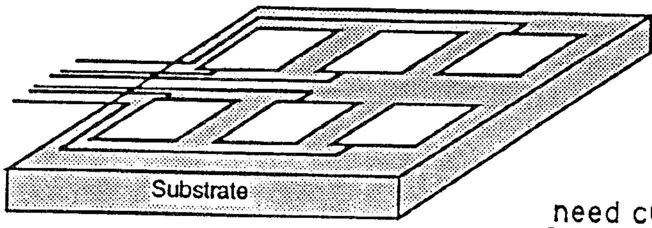
Conductometric Microsensor Arrays: Steve Semancik of the NIST Chemical Science and Technology Laboratory reviewed some new sensing concepts, described work underway within his group on complementary metal oxide semiconductor (CMOS) sensor array structures, and presented response data from recently completed experiments (Semancik and Whetstone, 1994). The motivation for this work has been the desire to develop an "electronic nose," capable of discriminating odors in a mixture of gases in a reliable, low cost manner. Possible applications include process control, environmental monitoring and safety systems.

Conventional tin oxide (Taguchi-type) sensors change their conductance in the presence of a reducing gas such as CO or CH_4. The Taguchi-type sensor is formed from sintered powder, rendering the individual elements bulky. This leads to slow response times and relatively large electrical power requirements since the sensor must be maintained at an elevated temperature. By doping multiple tin oxide sensors with differing amounts of catalytic metals such as platinum or palladium, the selectivity of each sensor can be varied. By coupling together the electrical response of each detector, an expert system can be developed to recognize mixtures of different reducing gases.

A planar array of thin film microsensors has been fabricated directly onto a silicon substrate. This type of design overcomes three of the major shortcomings of Taguchi-type sensors: slow response time, limited selectivity, and high power consumption. The oxide base and overlayer additive can be customized to tailor the response of each element in the array (See Figure 6). The temperature of each element can also be individually controlled by depositing the sensing film onto a micromachined hotplate structure such as that illustrated in Figure 7.

Figure 8 is the response of a palladium-doped tin oxide thin film deposited on a temperature-controlled micro-hotplate. The conductance changes in a repeatable manner when the sensor is exposed to small and varied concentrations of CO. Pulsed temperature program cycles can also be applied to the micro-hotplates to develop unique response signatures. The benefits of individual, fast temperature control with these small, ultra-low mass devices include the following: the capability for doing localized deposition for fabricating active films, kinetic selectivity using multi-valued static matrix and pulsed

PLANAR ELEMENTS NEED (SOME) SELECTIVITY



need custom elements

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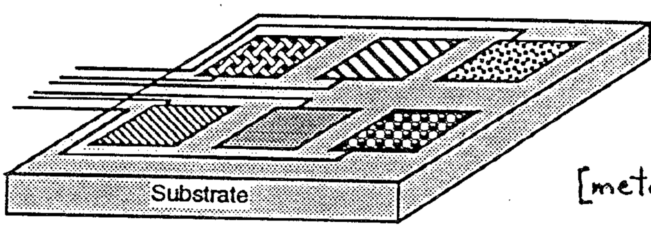


[metal/oxide combinations]

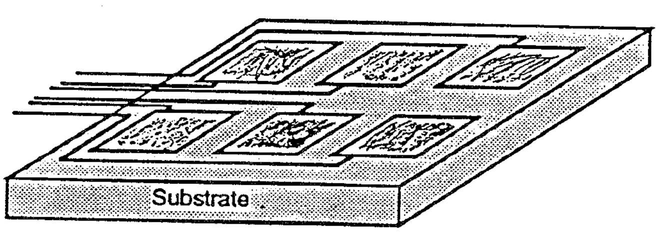
by MATERIALS (gas-solid chemistry)

- oxide base:
  - film type
  - orientation
  - stoichiometry
  - thickness

MODEL STUDIES

- overlayer additive:
  - metal type
  - coverage
  - structure

OR



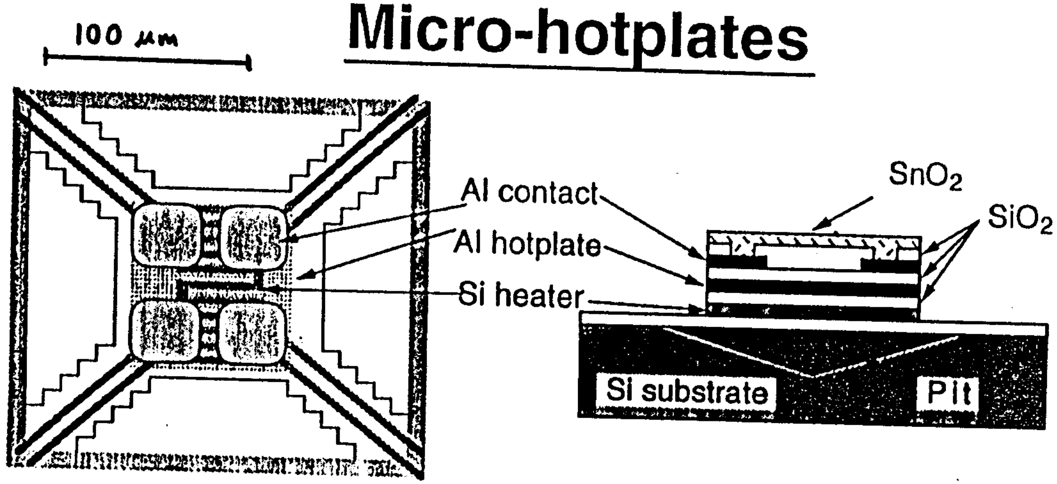
by TEMPERATURE (interaction kinetics)

[micromachining]

Figure 6. Selectivity-enhancing concepts for micro-machined planar sensing arrays.

Micro-hotplates

single element of sensor array



mass 0.2 µg

array ⇒ T matrix

Specifications:

Temp Range: 0-600°C with Al hotplate
>1000°C without Al

Time Constant: 1mS

Power: 10's mW

Current: 4mA at 4V, typical

Size: 50-200 microns

Fabrication Method:

CMOS Foundry using MOSIS system (on-chip electronics-compatible)

Post-CMOS etch to realize microbridges

Bond and Package

Figure 7. Schematic representation of a single micro-hotplate structure.

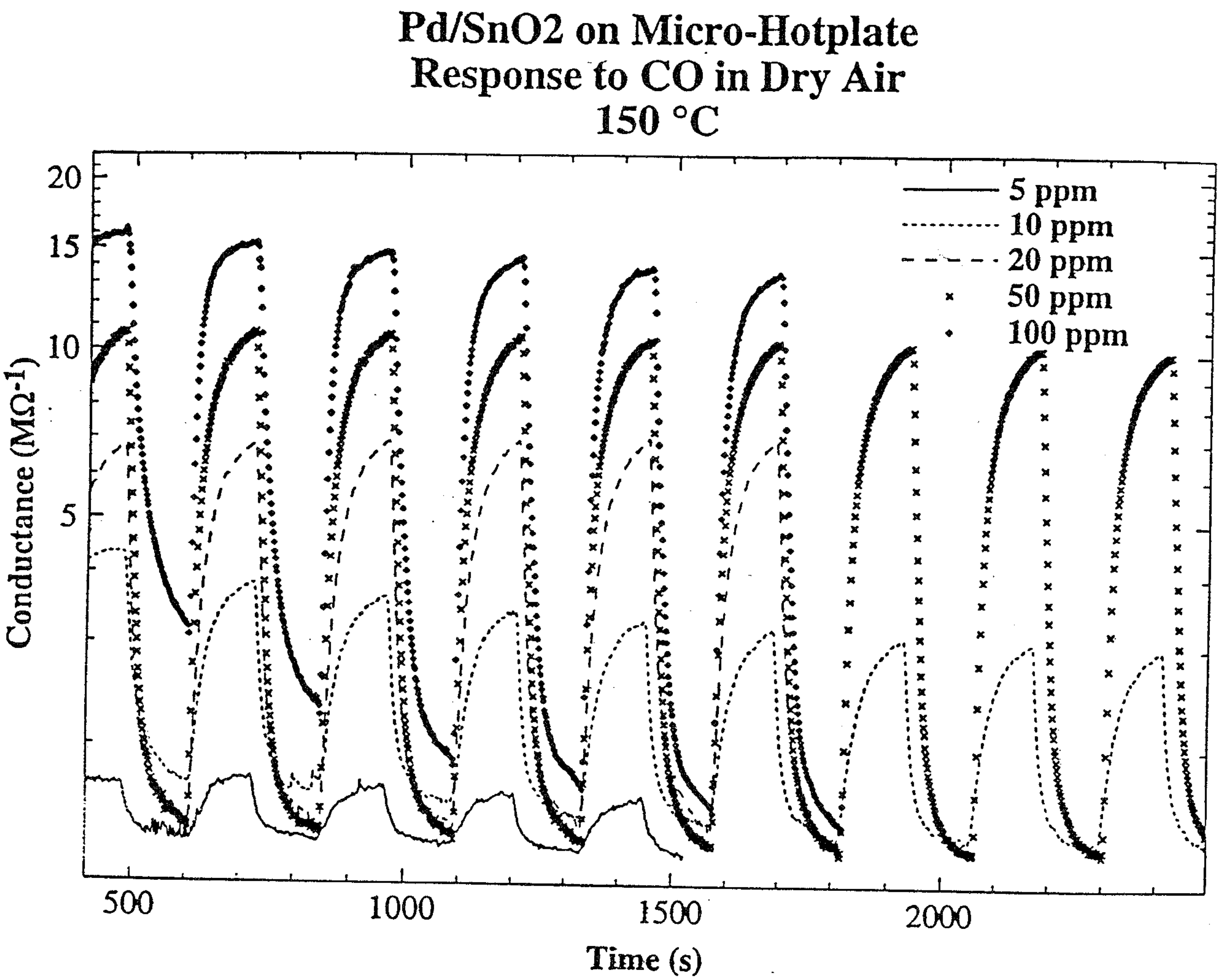


Figure 8. Conductance response of a micro-machined, Pd-dosed, tin oxide sensor to periodic exposure of CO/air mixtures at the varying CO concentrations indicated.

modes, selective operating range (pressure, concentration), about 0.1 to 1.0 % of the power requirements of a Taguchi-type sensor, and the capability to burn off contaminants and use reset calibration pulses.

Advanced Detection and Fire Signatures: William Grosshandler discussed research developments in fire detection in the Building and Fire Research Laboratory at NIST. He presented the lab's perspective, summarized past activities, discussed fire signatures, and proposed the idea of a fire-emulator/detector-evaluator (FE/DE).

It was stated that detailed descriptions of early fire development have not been established because ignition is a highly non-linear phenomena and because fire events are stochastic rather than deterministic. It is appropriate to divide ignition according to the class of fire (i.e., class A, or solids; class B, or liquids; and class C, or electrical) and the dominant mechanism (i.e., pyrolysis, smoldering, deflagration, or detonation). Significant advances in fire detection are tied to more knowledge of the environment (in time, space and composition) and the ability to adapt to environmental changes. It is equally important to recognize the signatures of common non-fire events.

Effectiveness and flexibility may be gained by coordinating building controls with fire protection strategies. A number of new concepts for fire detection systems have been demonstrated. The question is, where should NIST go with them beyond demonstration? Other questions were raised: Is the concept of a "designer fire" meaningful? Can we develop appropriate laboratory-scale detection evaluation systems that are scientifically sound and of use to industry? What guidance can NIST provide the industry to minimize the size and number of full-scale tests required for new technology development and certification?

Over the past few years BFRL has been involved with a number of activities, including technology reviews (Bukowski and Jason, 1991; Grosshandler, 1992), development of alternative sensing techniques (Grosshandler and Jackson, 1994; Bakkom et al., 1994; Lattimer et al., 1993; Serio et al., 1994), knowledged-based multi-sensor expert systems (Gottuk et al., 1994; Milke, 1995; Shwe et al., 1995),

Table 1. Approximate fuel loss and heat release rates of standard fire tests.

Test Fire	Fuel (density, kg/m^3)	Enthalpy of Combustion	Initial Mass	Consumption Rate	Average Heat Release Rate	Max. Heat Release Rate
TF 1	beechwood (80)	20.7 MJ/kg	2.8 kg	2.7 g/s	56 kW	145 kW
TF 2	beechwood (80)	20.7 MJ/kg	0.13 kg	0.11 g/s	2.3 kW	3.8 kW
TF 3	cotton	16.7 MJ/kg	0.27 kg	0.19 g/s	3.2 kW	3.6 kW
TF 4	polyurethane (20)	25.6 MJ/kg	0.30 kg	1.2 g/s	30 kW	84 kW
TF 5	heptane	48.5 MJ/kg	0.65 kg	3.1 g/s	150 kW	214 kW
TF 6	ethanol	29.7 MJ/kg	2.0 kg	4.0 g/s	120 kW	125 kW
UL A	newsprint	17.5 MJ/kg	0.043 kg	0.18 g/s	3.2 kW	--
UL B	dry firwood	21 MJ/kg	0.593 kg	2.5 g/s	52 kW	--
UL C	gasoline	47.7 MJ/kg	0.025 kg	0.13 g/s	6.2 kW	--
UL D	polystyrene (30)	25.5 MJ/kg	0.025 kg	0.20 g.s	5.1 kW	--

detector placement criteria (Forney and Bukowski, 1993; Notarianni and Davis, 1993), and examination of fire signatures (Grosshandler, 1995a).

In the ongoing fire signatures study, the physical and chemical transformations associated with a burgeoning fire are being reexamined. The UL, FM and European standard test methods have been reviewed and relevant experimental measurements summarized. Additional measurements are being conducted to fill in the many gaps in data documenting the early stages of a fire. The six test fires prescribed in EN 54 (1982) are listed in Table 1. They are being run to establish repeatability based upon the time-varying weight loss, concentrations of CO, CO_2, and O_2, and temperatures measured above the primary reaction zone. There are plans to characterize the smoke, velocity, radiation field, and trace species such as HCl, SO_2, NO, H_2 and hydrocarbons formed in the six standard fires and from other representative fuels.

Once the products of the standard fires have been thoroughly documented, along with uncertainty levels, numerical modeling can be brought into play. The most appropriate standard fire can be "placed" within a numerical model of the geometric space of interest. Then, the fire can be treated as a point source of mass, momentum and energy if it is assumed that the chemical reactions have ceased. A detector can be located within the modeled space, and its response to the standard fire estimated.

If the basic measurements and numerical models are available, it would be possible to certify a new detection system for a particular application by providing a physical environment that emulates the key elements of the actual fire. A universal fire-emulator/detector-evaluator (FE/DE) is envisioned which would do just that (Grosshandler, 1995b). Conceptually, it would produce the chemical soup prescribed as a function of time within a controlled chamber. The temperature, velocity and smoke levels would also be controlled. It would be possible to duplicate nuisance signals as well (i.e., dust, cooking aerosols, fireplaces, heaters, automobile exhaust, and environmental changes). Such a system would permit the evaluation of the response of fire detectors to realistic, yet totally controlled, environments. It is likely that more than a single fixture would be required to accommodate both point and volume detectors.

Decision-theoretic Controls: Michael Shwe of Knowledge Industries summarized the results of a Phase I SBIR project funded by NIST on decision-theoretic control of fire alarm systems. The desired qualities of such a system include the ability to integrate and interpret (in real time) information from multiple on-line sensors based upon previously studied burn tests, simulations, and experiential evidence; to model sensor error; and to consider alarm consequences. Decision theory is based upon probability theory which makes use of subjective information and Bayes' rule. It involves utility theory, Bayesian belief networks, and influence diagrams, and provides an alternative (and superior) approach to rule-based neural net systems for this type of application.

Smoke spread models are being incorporated to assist in the decision making process. Signal processing to reduce noise, sensor error models including multiple faults, and an assessment of the different stages of the fire are being added in continuing work. A sensitivity analysis to sensor response, and to raw data versus summary statistics will be performed, and the extended prototype software will be tested.

4. Summaries of Breakout Sessions

The participants were broken into four smaller groups to discuss in some detail specific research issues associated with sensors, signal processing, systems integration and regulations. The group leaders were provided with the list of questions shown in Table 2 to help focus but not limit the discussion.

a. Sensors

The sensors breakout group, consisting of 13 industry, five government and two academic

Table 2. Questions posed to breakout session leaders.

HOW SHOULD OUR ATTENTION BE DIVIDED AMONG THE MANY POSSIBLE END-USES OF FIRE DETECTION SYSTEMS?

ARE THERE CRITICAL RESEARCH ISSUES THAT CUT ACROSS RESIDENTIAL, COMMERCIAL AND INDUSTRIAL APPLICATIONS?

IS THE CONCEPT OF "TECHNOLOGY TRICKLE-DOWN" FROM SPECIALIZED, HIGH-COST APPLICATIONS TO UNIVERSAL, RESIDENTIAL APPLICATIONS A VIABLE ONE?

ARE CURRENT FIRE DETECTOR COMPONENTS AND SYSTEM DESIGNS "GOOD ENOUGH"?

WHAT WOULD CONSTITUTE THE PERFECT SENSOR? THE PERFECT SIGNAL PROCESSING SYSTEM?

WHAT ARE REASONABLE GOALS FOR FIRE ALARM SYSTEMS AND COMPONENT HARDWARE REGARDING INITIAL COST, POWER REQUIREMENTS, FLEXIBILITY/BREADTH OF APPLICATION, MAINTENANCE, AND RELIABILITY?

DO EXISTING CERTIFICATION PROCEDURES AND REGULATIONS NEGATIVELY IMPACT THE INTRODUCTION OF NEW SENSORS, SIGNAL PROCESSING METHODS, OR SYSTEMS INTEGRATION?

ARE THERE SITUATIONS IN WHICH PRESCRIPTIVE STANDARDS WOULD BE PREFERABLE TO PERFORMANCE STANDARDS FOR FIRE DETECTION SYSTEMS?

WHAT IS THE POTENTIAL FOR INTEGRATING FIRE DETECTION SYSTEMS WITH OTHER STRUCTURAL SYSTEMS INCLUDING SECURITY, HVAC, ELEVATOR, EQUIPMENT PERFORMANCE, AND PRODUCT QUALITY CONTROL?

HOW SHOULD ONE COMMUNICATE ACROSS SYSTEM BOUNDARIES?

WHAT PITFALLS NEED TO BE AVOIDED IN INTEGRATING SYSTEMS?

WHAT ARE THE PROS AND CONS OF CERTIFYING COMPONENTS SUCH AS SENSORS SEPARATELY FROM THE SYSTEMS IN WHICH THEY ARE USED?

HOW DOES ONE CERTIFY THE PERFORMANCE OF NEW SIGNAL PROCESSING HARDWARE AND SOFTWARE?

IS THERE A RATIONAL WAY TO CERTIFY THE CLAIM THAT A NEW FIRE DETECTION SYSTEM CAN REDUCE FALSE-POSITIVE RESPONSES BY X%?

IS THE CONCEPT OF A FIRE-EMULATOR/DETECTOR-EVALUATOR (FE/DE) USEFUL TO THE DEVELOPMENT OF IMPROVED COMPONENT HARDWARE OR SYSTEM SOFTWARE?

WOULD THE AVAILABILITY OF A RELIABLE FE/DE BE USEFUL TO CODES AND STANDARDS SETTING ORGANIZATIONS?

WHAT SHOULD BE NIST'S ROLE IN DEVELOPING NEW SENSORS, SIGNAL PROCESSING SOFTWARE, SYSTEMS INTEGRATION PROTOCOLS AND STANDARDS FOR FIRE DETECTION SYSTEMS?

IF THERE IS A SIGNIFICANT ROLE, HOW MIGHT NIST INTERACT WITH INDUSTRY, REGULATORS AND OTHER GOVERNMENT AGENCIES TO MAXIMIZE THE BENEFIT TO PUBLIC SAFETY AND TO THE U.S. ECONOMY?

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representatives, was co-chaired by Steve Semancik and Jim Milke. The discussion was broken into the following primary topics: defining the perfect sensor, fire signatures, new technologies, barriers to development, testing and certification, and the NIST role.

The Perfect Sensor: The "sensor" is defined to be the active interface between the instrument and the environment, and excludes the associated signal processing system. In a perfect sensor, the target sensitivity is high and the interferant sensitivity is low (i.e., high S/N). Other attributes of a perfect sensor include high reliability and low maintenance requirements, with a useful lifetime greater than ten years, low power consumption requirements, a wide dynamic range, and a response time and stability consistent with the application (e.g., spark detection needs a response time of 200 μs, safe egress from a residential application is possible with response times up to minutes). The capability for multi-parameter detection (e.g., multiple gas species and temperature, or detailed spectral information) is also a desirable attribute.

Sensors can respond to different kinds of physical stimulation: molecular gases, condensed phase aerosols, heat conduction, thermal radiation, and acoustic waves. A lot of work has gone into identifying the signatures of the first three produced in fires, with lesser activity focused on the latter two. With the exception of heat conduction (i.e., heat flux or temperature), the group was unable to identify much which has been done to characterize the signatures of pre-fire and non-fire events. In particular, is it possible to develop a sensor that can detect unique, partially oxidized material quickly enough to ascertain a threatening pre-fire condition?

New Technologies: A number of new technologies with the potential for sensing the gaseous products from a fire were discussed. (The paper by Grosshandler (1992) expands on some of the items mentioned here.) Active films for specific molecular recognition used in conjunction with surface acoustic wave (SAW) devices are extremely selective, but are not robust. Micromachined devices with temperature programmable, conductometric active elements are flexible and can operate in multiple modes, they have low power requirements, and they can be made in a cost-effective bulk manner. They are often not nearly as selective as SAW devices, but can be generated in large arrays which are amenable to complex signal processing techniques. Open-path FTIR instruments can measure the emission from and transmission through a large volume over the spectral range of 2.5 to 25 μm. The method is relatively fast, has a sufficient sensitivity, can detect particulates, and can discriminate among a large number of infra-red active gases. It suffers from high initial costs and maintenance requirements. Perforated hollow waveguides, thermoelectrically-cooled, and room temperature detectors may overcome some of these drawbacks.

Three new temperature sensing technologies were identified. Piezoelectric transducers for the measurement of the emission of ultrasonic waves resulting from the expansion of an overheated materials was one, which has the advantage that it can detect a fire threat hidden within a wall cavity (Grosshandler and Braun, 1994). Thermal chromic liquid crystals, placed at strategic locations in a room, could be used to indicate that a temperature threshold has been breached at a particular position (Bakkom et al., 1994). Raman scattering within an optical fiber has matured to a point where it can be used to measure a temperature increase at various locations along the fiber (Ishii et al., 1995).

Barriers: Products based upon new technologies often require new test methods and procedures to be developed. The cost of having this done by testing agencies such as UL or FM must be borne by the submitting company. The cost of the development, itself, is difficult to justify by a profit-driven manager who is currently making money with a less-than-perfect sensor.

Institutional inertia acts as a major barrier to new product development. There is an understandable reluctance to switch to something new even if potential benefits are clearly identified. The company does not want to become the test bed for a new technology because of liability exposure.

Marketing the new technologies can also be a barrier because it becomes necessary to communicate the advantages of the new product to existing customers or to an uncertain expanded marketplace.

Testing and Certification: A number of items were discussed related to testing and certification. There is a need to develop standard methods for multi-criteria detector evaluation. The fires chosen for testing sensors in various applications need to be selected to more closely duplicate real world applications. A test protocol for sensors exposed to nuisance sources also needs to be developed. The current certification process forces manufacturers to produce to the testing criteria. There is no incentive to develop a product that has capabilities beyond the minimum. In fact, there is a significant economic dis-incentive to test outside of established guidelines. A number of agencies are involved with fire detector certification: Cenelect, Factory Mutual, ULI and ULC, CSA, BASEEFA, NEMKO, Vds, Calif. State Fire Marshal (CSFM), and NYCEMA. It is common for each agency to have its own certification standard. There is a need to harmonize testing requirements internationally and regulations locally.

The Role for NIST: The group felt that NIST could best serve the development of sensor technologies by taking the lead in the following activities: develop and maintain a data base of signatures and sensor responses; develop test protocols for sensor evaluation; investigate new sensor materials and fabrication methods; form government-industry consortia; and coordinate various research activities. The consortia could involve partnerships (or CRADAs) with US manufacturers, expanded use of the Advanced Technology Program (ATP), and strategic selection of internally-funded research projects.

The push for NIST involvement comes from the desire to more quickly develop technologies that will provide low cost, effective fire/smoke detection (without unwanted false alarms) as a means to further reduce property damage and fire deaths and injuries. NIST also has a role in increasing the competitiveness of US manufacturers in domestic and global markets; however, they should spearhead research while leaving industry to worry about manufacturing and production.

b. Signal Processing

About eight people representing industry and government organizations participated in the signal processing group, which was co-chaired by Donald Goedeke and Mike Shwe. The discussions were broken into the type of end-user, pre-alarm opportunities, implications for testing and certification, communications protocols, and the NIST role. Residential applications were not felt to be hampered by lack of fundamental understanding. However, NIST could examine studies performed by CPSC, HHS and USFA to summarize the state of signal processing in residential applications, and point out where further study might be fruitful for others to pursue.

The opportunity to incorporate a pre-alarm condition exists in commercial and industrial applications. These would be aimed at slow growing fires, or to situations in which the environment has a high sensitivity to fire products including acid gases. A pre-alarm option would lower the cost associated with false alarms while maintaining sufficient protection. NIST has a role in reviewing NFPA 72 pre-alarm procedures, and in performing case studies to identify appropriate uses for this approach.

End-users who deal with munitions or pyrotechnics require special signal processing approaches to permit millisecond response to a threat. Commercial air transport cargo and engine fires do not need the fast response time, but cannot tolerate missing a fire. At the same time, there is a high penalty associated with a false alarm. Post-fire suppression status monitoring capability is also desirable.

On-site testing that permits self-diagnosis, drift compensation, and sensor integrity status (i.e., dynamic supervision) can be approached through modern signal processing techniques. The open communication among different components of the fire alarm system was not thought to be needed nor desirable (from a manufacturer's point of view) since current sensor-to-panel protocols are proprietary.

This implies no plug-and-play sensors are likely to be developed. There is a need to develop open protocols between the output of the fire alarm panel and other building control functions (e.g., HVAC or security).

It was recognized that testing and certification become more complex when processing multiple sensor signals. NIST could recommend test scenarios, including possible false alarm sources, which are application specific. Such a test would be welcomed by the user but is open to criticism from manufacturers of new signal processing hardware and software. It might be better for NIST to concentrate on developing a data base of generic fire signatures and smoke spread models.

c. Systems Integration

Richard Bukowski and Ronald Kirby led a group of about ten government and industry representatives in a discussion of the pros and cons of integrating fire alarm systems with other building control functions. Two big questions would arise if such integration were to occur: Who is in charge of the overall functions? and, Who assumes the liability should a failure occur? The group felt that integration makes sense when there is overlap in function. For example, close coordination and communications among the environmental monitoring, smoke control, and elevator systems would provide additional egress options and strategies for attacking a fire. An overriding concern was that whatever one does to reduce the isolation of a system, do no harm. The increased complexity may not be warranted in many situations, where the disadvantages would outweigh the advantages.

Exchange of information among systems is distinct from overlapping control functions. NIST should work with NEMA to ensure that this is done safely and accurately. The software reliability issue was raised, and it was suggested that NIST formulate a certification procedure based upon the ISO 9000 model. The Institute could also assist in demonstrating new systems integration technologies in full-scale facilities.

d. Regulations

The regulations subgroup consisted of about 14 individuals, half representing user and supplier industries, and the other half government organizations and certification laboratories. Jack Abbott and Merton Bunker served as co-chairs. False alarms were the prominent topic of debate, which is where it was felt that new standards should be focused. There is a need to know the causes for false alarms before the problem can be fixed. These were categorized as resulting from improper installation, poor maintenance, or detection of non-fire sources such as cooking fumes or dust.

False alarms resulting from improper installation could be tackled by requiring that installers be certified. NICET represents the best qualifications program in place today. A level II certification would be required for the workers who actually make the physical installation, and level III or IV for installation designers or supervisors. More guidance is required for the installers to ensure that the detectors are not inappropriately placed. NIST should conduct the necessary research to validate detector placement criteria.

Poor maintenance seems to be a leading cause of false alarms, but is beyond the control of standards. Instead, it is a problem of enforcement. Manufacturers should develop a detector that is more immune to poor maintenance practices. A multi-sensor detector could be useful in this regard.

NIST should identify differences between friendly, threatening and hostile fires, and non-fire nuisance sources, and should share this information with industry. Is it possible to delineate these different sources? At what point does the fire become hostile? Cooking caused false alarms are best to focus on for residential and commercial applications. Industry may then develop different sensors that will be less sensitive to cooking vapors. Inputs and outputs could be mapped for each room, and detector settings changed to account for different occupancies. Possible liabilities associated with decreasing sensitivities need to be kept in mind.

Multi-sensor detectors require new standards for certification. Raw data is required on the causes of alarms (NFPA 904), to determine the signatures of fires, and to develop requirements for testing alarm/false alarm discrimination. There is a need to have a number of laboratory tests that permit identification of different attributes. This could be in the form of a relatively sophisticated test chamber for laboratory evaluation, and a portable version for field use that mimics different fire signatures. The regulations and standards for multi-sensor technology will follow as products are prepared for market.

The advantages of certifying components of a fire detector as well as the installed alarm system were debated. On the positive side, component certification would promote competition among component manufacturers, it would lower costs, and it would ease verification. On the down side, using a competitor's component in your system muddles the liability issue. How would compatibility be assured? Possible restraint of trade concerns were also raised.

The group addressed the following question posed in the table above: Is there a rational way to certify the claim that a new fire detection system can reduce false-positive responses by X%? Their answer was no. This would be only a prediction without a credible baseline. Another issue that was raised was whether or not a product that meets an earlier standard would continue to be listed after the standard had been altered. It was felt that assuming the change is non-safety related, legal exposure after the effective date of change could be a problem.

5. Conclusions and Recommendations

a. Have Workshop Objectives Been Met?

The number of participants, the range of their interests and applications, and the spirit of the debate were evidence that the workshop was appropriate and timely. One can conclude that there are a number of generic issues that need to be worked from different angles. The four workshop objectives (repeated in bold below) were met with varying degrees of success.

The following items have been identified as **needs of the users and specifiers of fire detection systems which are not currently being met by the U.S. fire protection industry**:

- lower ratio of false-positive-to-actual-fire indications
- pre-fire warning for protection of high value operations
- more fool-proof installation and maintenance methods
- component (software and hardware) compatibility for system upgrade
- wider range of fires detected (e.g., smoldering and flaming)
- reliable detection of noxious fire precursors (e.g., HCl and CO)
- faster and more precise response of fire detection systems customized to particular processes, such as in the microchip and optical components manufacturing industries
- capability for partial integration of fire detection with other building control functions

Future needs which may result from new developments in construction, transportation, and manufacturing sectors, or from regulatory changes include the following:

- earlier warning in connection with halon-alternative suppression systems
- situation monitoring following automatic suppression (e.g., on-off water sprays and aircraft cargo areas)
- means to evaluate system trade-offs with the advent of performance-based standards
- combination gas sensors for fire/environmental monitoring

It goes without saying that research and developmental costs can restrict any one company from seriously exploring new technologies. The increase in liability associated with new, unproven products is probably an even bigger hinderance to corporate investment. But beyond cost and legal barriers, the list below includes **generic, technological barriers which also may limit the U.S. fire protection industry from fully meeting users' needs**:

- unawareness of new technological opportunities
- difficulty in assessing benefits of emerging technologies
- lack of performance-based testing and certification methods for double-sensor detectors currently ready for market
- certification procedures for multiple combinations of traditional sensors, or for radically different detection technologies, do not exist
- evaluation criteria for susceptibility of new hardware and/or software designs to false alarms need to be established
- a strategy for communicating among different building control systems while maintaining each system's integrity needs to be coordinated

The final objective was to **develop a research agenda and recommend priorities to enable U.S. industry to overcome these technological barriers**. The following list contains a number of tasks which need to be undertaken, some of which are less research oriented and more aimed at changing established practices. Those marked by a double asterisk are deemed appropriate for NIST to take the lead, while those with a single * indicate NIST involvement with leadership (monetary and/or technical) coming from industry or other government agencies and regulators.

- quantify common non-fire sources which confound fire sensors**
- quantify common ignition events**
- develop and maintain data base of signatures and sensor responses**
- experimentally verify numerical models of the transport of products from young fires to likely detector sites**
- develop open protocols for communicating among different building control functions*
- increase predictive capability for ignition and fire spread over realistic fuels**
- establish unbiased test methods for detector performance evaluation**
- establish fundamental operating principles for new sensing devices**
- develop scientifically sound, performance-based standards*
- harmonize requirements nationally and internationally*
- establish system software certification procedures*
- develop guidance to increase effectiveness of installation and maintenance*
- establish government/industry research consortium*

b. The NIST Research Plan

Based upon past NIST activities, current capabilities, and the discussions held at the workshop, a long range (five years and up, depending on funding levels and the extent of industry/other agency involvement) research program in advanced fire control technologies is proposed. The overall goals are to enable economical design alternatives for controlling unwanted fires that will provide industry and government agencies with effective protection of lives and assets against excessive losses, and to identify new sensing principles, signal processing techniques, and suppression mechanisms as a way to enhance business opportunities for the fire protection industry.

The fire sensing and signal processing project contains three elements: identification of signatures for discriminating fire sensors; development of a fire-emulator/detector-evaluator (FE/DE); and real-time risk analysis and on-line training of sensing systems. The proposed research products include a physical and statistical description of most common ignition sequences and confounding detector stimuli, industry-accepted test fire and non-fire protocols for next generation detection systems, and enhanced understanding of ignition and early fire spread mechanisms. Using the accepted test fires, the following parameters (time-varying mean values and standard deviations) need to be measured as a way to fully characterize the fires: plume temperature and velocity; concentrations of CO, CO_2, H_2O, CH_4, total hydrocarbons, HCl, HF, SO_2 and NO; particulate volume fraction, size distribution, scattering coefficient and plume transmittance; UV, visible and IR spectra; and acoustic emission.

The fire emulator would generate the key aspects of the thermal, velocity, radiation, and concentration fields as measured in the accepted test fires and non-fires. The detector evaluator would have a capability for multi-sensor and line detectors. Opportunities provided by computational fluid dynamic models for optimizing detector design and the certification process would be demonstrated. The capability to integrate fire recognition into building intelligence would be explored, along with protocols for assessing the adequacy of knowledge-based fire discrimination algorithms.

Other related projects will be aimed towards increasing our understanding of the chemistry of flame inhibition and extinction, physical mechanisms of fire suppression, the performance of materials when exposed to fires, the modeling of fire spread in structures, and the fundamental principles underlying new sensing techniques (micro-chip gas and heat sensors, and FTIR line-of-sight instruments, in particular). State-of-technology assessments will be performed and industry-wide conferences will be sponsored by NIST to enhance the transfer of research results to those who can best use them. Finally, BFRL will help develop certification protocols and participate in the standards making process to the extent appropriate to streamline acceptance of new and improved fire detection system technologies. All of these activities taken together would establish BFRL as a world leader in new fire sensing research.

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Appendix B.

Smoke Detector Operability Survey Report on Findings

(revised)

October 1994

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I. Executive Summary

The Smoke Detector Operability Survey was done to fill a need for new field data on the numbers and types of smoke detectors installed in households, the proportion of installed smoke detectors that are working, the ways in which smoke detectors are failing, factors leading to non-working detectors, and types of households or housing that are more likely to have non-working smoke detectors. A total of 1,012 in-person interviews were conducted from October 1 through December 23, 1992: 811 from the main sample and an additional 201 field interviews of lower socioeconomic status (lower SES) households. All aspects of the full survey were conducted by Market Facts, Inc., under contract to the CPSC.

The results of the survey will provide support for the major elements of the National Smoke Detector Project, which are intended to increase the presence of working smoke detectors in U.S. households. The National Smoke Detector Project is a joint project among the Consumer Product Safety Commission (CPSC), the Congressional Fire Services Institute, the U.S. Fire Administration (USFA), and the National Fire Protection Association (NFPA). The Department of Housing and Urban Development and many other organizations are also project participants and have a strong interest in the results of the survey.

The survey found that an estimated 88 percent of households (84.5 million) have at least one installed smoke detector. Of these, about 5 million had detectors connected to a central alarm system. The remaining 79.5 million households (or about 83 percent of all households) had non-central system detectors, and were the subject of the Smoke Detector Operability Survey. Some major findings of the survey are:

★ About 71 percent of the smoke detectors tested in the study operated by battery power only, and about 26 percent operated by AC power; most of these (91 percent) were hard-wired, rather than plug-in. About 2 percent of detectors were operated by a combination of AC power with backup battery power. The power source of 1 percent of the detectors could not be determined.

★ 76 percent of detectors contained radioactive material labels, signifying that they were ionization detectors; 11 percent did not, signifying that they probably were photoelectric. Interviewers were unable to determine whether radioactive materials were present in another 13 percent of detectors.

★ Field operability testing found that 73 percent of detectors worked when subjected to the first series of smoke and button tests administered by the field interviewers. An additional 15 percent alarmed at the second series of tests (after the battery was replaced or power was restored). Two percent of detectors could not be tested by field interviewers.

★ An estimated 63.5 million households had at least one working non-central system detector in 1992 (based on the results of the first series of smoke and button tests); this was 66 percent of all households and 80 percent of all households with smoke detectors. An estimated 16.0 million households with installed smoke detectors had no working detectors (20 percent of households with smoke detectors). Adding these households to the estimated 11.1 million households without a smoke detector, the survey found that an estimated 28 percent of households were without a working smoke detector.

★ At least 26 percent of households with smoke detectors did not have enough detectors to meet the requirement of every-level-protection endorsed by fire services.

★ The field interviewers found that, for all households surveyed, nearly 20 percent of detectors did not have functioning power sources. This was by far the most common cause of smoke detector inoperability. About 5 percent of detectors had dead batteries, and the other 15 percent had missing or disconnected batteries or were disconnected from AC power. Almost 93 percent of detectors observed to have problems with power sources were powered by batteries only.

★ More than one-third of respondents providing reasons why power sources were missing or disconnected said that the battery or AC power supply was intentionally disconnected because of nuisance alarms. Cooking was most frequently cited as a source of nuisance alarms.

★ CPSC Engineering Laboratory evaluation of smoke detectors collected from the survey because of problems with nuisance alarms found three factors associated with nuisance alarms: 1) detector type -- 32 of 33 detectors collected for nuisance alarms were ionization detectors; 2) location -- 34 percent of the detectors collected for nuisance alarms were placed within 5 feet of the source of smoke, steam, or moisture; and 3) maintenance -- unless detectors are cleaned by vacuuming (recommended by many manufacturers), contaminants such as dirt, insects and spiders can increase their sensitivity, leading to an increase in nuisance alarms.

★ It appears that the significance of the low-battery warning "chirp" is widely misinterpreted as a nuisance alarm.

★ Households with incomes of less than $15,000 comprised an estimated 23 percent of all households with detectors; however, they accounted for 33 percent of those without at least one working detector ("inoperative households").

Appendix C.

FIRE INCIDENT STUDY

NATIONAL SMOKE DETECTOR

PROJECT

JANUARY 1995

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EXECUTIVE SUMMARY

The Fire Incident Study was conducted, as part of the National Smoke Detector Project, to identify the reasons why smoke detectors failed to alarm in residential fires. It was based on data collected from fire departments in 15 U.S. cities. Follow-up investigations on detectors that failed to alarm in fires were conducted by fire service personnel in accordance with a protocol and questionnaire developed by the Field Investigations Committee of the National Smoke Detector Project. Data collection occurred between April 1992 and February 1993. Investigations of detector operability were completed for 263 fires in which it was believed that the detector did not alarm when it should have. (It is noted that a companion study of detector operability in non-fire households was conducted in October - November 1992.)[1]

Major findings:

Smoke detectors are very effective in saving lives. The death rate in fires where they were present and operated was nearly half the rate in fires where they were present but did not operate.

For households where at least one detector in the household failed to alarm:

- About 81 percent of these fire households had only one detector, while 16 percent had two detectors.
- Among the detectors in these households, 81 percent were powered by batteries alone, 18 percent were alternating current (AC) powered alone.
- About 89 percent were ionization type alone.
- About 70 percent of the study households were in rental rather than owner-occupied dwellings. Of these, 43 percent were one- or two-family dwellings; 56 percent were apartments.

For detectors that should have alarmed in the fire but did not:

- Investigators found that 59 percent of the detectors that failed to alarm were found disconnected from their power sources. Batteries were missing or disconnected, or the AC power source was disconnected.

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[1] *Smoke Detector Operability Survey: Report on Findings*, Charles L. Smith, U.S. Consumer Product Safety Commission, as Revised, October 1994.

- Among those that were disconnected and the occupant was available, 35 percent of the detectors (21 percent of the total) were said by the occupant to have a problem. These problems may have resulted in their disconnected status.

- For the remainder of those disconnected where the occupant was available, 65 percent (38 percent of the total), the occupant denied that the detector had a problem.

- Investigators found that 41 percent of the detectors were found connected to the power source.

- Among the 189 detectors that were tested with aerosol smoke, 136 (72 percent) alarmed to the smoke test. Most did so only after a new battery was installed or AC power reconnected. The remaining 53 (28 percent) detectors that were tested did not alarm to the aerosol smoke test.

- Detectors that were found disconnected were more likely to respond to the aerosol smoke test, after reconnection, than were detectors found connected.

- The percentage of hard-wired detectors was significantly greater among connected detectors than among those disconnected.

- Although detectors are designed to emit a low-battery power warning signal, 8 percent of the detectors were found with a dead battery.

Following completion of the on-site testing procedure, 114 of the detectors were sent to the CPSC Engineering Laboratory for analysis. Since these detectors were in fires and may have been damaged or contaminated, interpretation of their pre-fire condition was difficult. However, it was found that detectors collected for nuisance alarms were more sensitive on average than detectors collected for non-nuisance reasons in the Smoke Detector Operability Survey. In addition, a variety of problems such as deteriorated battery clips, defective or corroded components, excessive debris inside the detectors, and visibly corroded horn terminals were found.

It is further noted that the results of this study for the most part are consistent with the results regarding inoperable detectors identified in the Smoke Detector Operability Study of the non-fire population. Together, they indicate that **component failures were involved in many detectors failing to alarm.** They also document the finding that **many detectors were disconnected by occupants to address unwanted alarms.** Also, **large numbers of detectors were found disconnected for reasons apparently unrelated to** what might be termed **malfunctions.** To make significant reductions in the proportions of detectors that fail to operate in fires, these issues will need to be addressed.

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A workshop was held to identify the needs of users and specifiers of fire detection systems which are not currently being met by the U.S. fire protection industry; to highlight future needs which may result from new developments in the construction, transportation, and manufacturing sectors, or from regulatory changes; to identify generic, technological barriers which may limit the U.S fire protection industry from fully meeting the users' needs; and to develop a research agenda and recommend priorities to enable U.S. industry to overcome these technological barriers. Various experts were invited to review the applications for fire detection systems and to discuss recent developments. The speakers were divided into focused panels of users and specifiers, systems and components manufacturers, regulators and certifiers, and researchers. Critical research issues were identified regarding sensors, signal processing, systems integration and regulations. The ultimate goals of a comprehensive and integrated research program were identified and include a lower ratio of false-positive-to-actual-fire indications, pre-fire warning for protection of high value operations, more fool-proof installation and maintenance methods, component compatibility for system upgrade, a wider range of fires detectable, reliable detection of noxious fire precursors, faster and more precise response of fire detection systems customized to particular processes, earlier warning in connection with halon-alternative suppression systems, situation monitoring following automatic suppression, means to evaluate system trade-offs with the advent of performance-based standards, combination gas sensors for fire/environmental monitoring, and the capability for partial integration of fire detection with other building control functions.

KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)

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