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Real-Time Particulate Monitoring – Detecting Respiratory Threats for First Responders: Workshop Proceedings

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NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

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ABSTRACT

The overhaul of a fire scene is a stage of firefighting where respiratory protection is often disregarded due to the perception of low risk and the desire to remove the heavy and cumbersome self-contained breathing apparatus. The need for alternative options for respiratory protection that are fitted to the task and environment has been voiced by the firefighter community. Choosing the appropriate respiratory protection for individual events can only be accomplished with real-time information about the exposure hazards. Hand-held direct-reading particulate detectors have been used in other environmental monitoring applications, and it may be possible to transfer the technology to meet the needs of the firefighter.

The workshop on Real-Time Particulate Monitoring held at the National Institute of Standards and Technology (NIST) on 3-4 May 2007 brought together members of the fire service, particulate detector manufacturers, public health professionals, airborne particulate researchers, and standards organizations to discuss the need for better technology to assess the level of respiratory protection that is required for environments encountered by first responders. The program included invited speakers who presented information on characterization of respiratory threats during fire overhaul and the need for respiratory protection, performance needs and priorities for the fire service application, and state-of-the-art and recent developments in particulate detection. After the presentations, attendees divided into three breakout sessions, and each group responded to a predetermined set of questions related to the following topics: Research Needs, Performance Criteria, Standards, and Technological Advances.

The consensus of the workshop participants was that future research is needed to better understand the health effects of particulates on firefighters, to better characterize the particulates present during overhaul, and to better characterize the response of particulate detectors to the overhaul environment. Defining performance criteria to address first responder needs regarding data telemetry and logging, instrument operation and data interpretation, and the physical performance of the instrument were also areas of consensus. The group also felt that developing standards for the physical performance of the instrument was important and that data telemetry and logging would benefit from developing technology.

The consensus resulting from workshop discussions is expected to provide a strong foundation for the development of new tools to aid firefighters in selecting the appropriate respiratory protection, standard testing protocols to insure that equipment meets the needs of first responders, and performance criteria that allow industry to adapt the technology to the specific need and improve where necessary.

Keywords: particulate detector, overhaul environment, evaluation, performance metrics, fire fighting, first responder

ACKNOWLEDGMENTS

The success of any workshop is dependent on the hard work of the individual speakers, facilitators, and participants. These proceedings are an assimilation of the contributions from everyone involved in the workshop; copies of the presentations are included in Appendix 3. Thanks to all who made presentations and to those who participated in the workshop.

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INTRODUCTION

The construction and contents of both commercial and residential buildings incorporate a variety of materials with a wide range of chemical compositions. A fire within a building will result in an uncontrolled release of gaseous vapors and aerosolized matter. Many of the gases are toxic, and exposure to them by inhalation may be an immediate danger to life and health (IDLH). During fire suppression or knockdown, firefighters are required to wear a SCBA (self-contained breathing apparatus) due to the IDLH environment. The SCBA is designed to protect against gaseous toxins and respirable particulates. However, not every stage of the fire fighting event is an IDLH situation. The overhaul operation, which occurs after the knockdown of the visible fire, involves searching for and exposing hidden pockets of fire to ensure that the fire is completely extinguished. If it has been determined that toxic vapors no longer exist, firefighters are often allowed to remove their SCBA units; thereby losing their protection against any remaining respiratory threats, such as dust and particulate matter. The overhaul operation resembles a structural demolition, with the added presence of smoldering debris. Limited information exists on what respiratory threats remain during this stage of firefighting, but studies have recommended that some level of respiratory protection should be implemented. [1,2]

The need for alternative options for respiratory protection that are fitted to the task and environment has been voiced by the firefighter community. [3] Choosing the appropriate respiratory protection for individual events can only be accomplished with real-time information about the exposure hazards. The need for such real-time environmental monitoring was identified as a specific issue of the present technology gap in the Fire Service. [4] Although, hand-held gas monitors have been routinely used by some departments to aid in incident command decisions, similar devices to detect particulates are not routinely used. Hand-held direct-reading particulate detectors were first designed for use in mining environments [5], and since then have been used in many environmental monitoring applications. If the direct-reading particulate detector technology can be transferred to meet the needs of the first responder, the first responder will be aided by a new tool to increase their personal protection. However this technology transfer must proceed as a deliberate effort.

The workshop on Real-Time Particulate Monitoring held at the National Institute of Standards and Technology (NIST) on 3-4 May 2007 was convened as part of the effort to explore the use of hand-held direct-reading particulate detectors to provide real-time information to first responders and event commanders. The workshop brought together members of the fire service, particulate detector manufacturers, public health professionals, airborne particulate researchers, and standards organizations to discuss the need for better technology to assess the level of respiratory protection that is required for environments encountered by first responders. The goal of the workshop was to identify first responder needs, understand current state-of-the-art technology, appreciate where new technology may help, and prioritize research needs. The consensus resulting from workshop discussions is expected to provide a strong foundation for the development of new tools to aid firefighters in selecting the appropriate respiratory protection, standard testing protocols to insure that equipment meets the needs of first responders, and performance criteria that allow industry to adapt the technology to the specific need and improve where necessary.

This report describes the preparation, content, and outcomes of the workshop. First, a brief summary is provided on possible respiratory threats in the fire overhaul environment and on direct-reading particulate detectors. Potential technical issues that may hinder their application and the potential needs of the fire service are also outlined. This information was provided to attendees as a White Paper in advance of the workshop as a starting point for discussions. The next section describes the organization and procedures followed by the workshop, with the workshop agenda, list of attendees, speaker guidance, and workshop presentations given in Appendices 1 through 4 respectively. The results of breakout group discussions are given in the following section and are based on the discussion responses listed in Appendix 5. Final sections present the workshop conclusions and current plans for future work.

Respiratory Threats – Particulates

Particulates are tiny solid particles or liquid droplets. In the case of an aerosol, they are suspended in air. They range in size from about 0.002 μm to 100 μm and can be further classified as smoke, dust, fumes, fogs, or sprays depending upon their origin and composition. Inhalation of particulate matter may result in serious lung injury. The American Conference of Governmental Industrial Hygienists (ACGIH) "believes that even biologically inert, insoluble, or poorly soluble particles may have adverse effects and recommends that airborne concentrations should be kept below 3 mg/m^3 for respirable particles, and 10 mg/m^3, for inhalable particles…." [6] Respirable particles are defined as particulate material that is hazardous when deposited in the alveoli region of the lungs, while inhalable particles refer to particulate matter that is hazardous when deposited anywhere within the respiratory tract. [6] The U.S. Department of Labor Occupational Safety and Health Administration (OSHA) suggest that 8-hour time-weighted average (TWA) exposures be kept below 5 mg/m^3 for respirable dust and 15 mg/m^3 for total suspended (inhalable) dust.

The health effect of particulate exposure is a function of the size, shape, and chemical composition. A particle's size is often given in terms of its aerodynamic diameter, defined as the diameter of a sphere with 1 g/cm^3 density that has the same settling velocity of the particle of interest. Particles up to 100 μm can be inhaled into the respiratory system, although only particles less than 10 μm penetrate into the pulmonary region of the lung. Fine particles smaller than 4.0 μm may enter the alveoli, where only a thin layer of cells separate the respired air from blood in the circulatory system. These small particles that deposit into the alveoli may transfer out of the lungs and into the blood, where they are transported to and may affect other organs. Within the lung itself, high concentrations of deposited particles may exceed the natural ability of the lung to clear particles; when this happens, particles may become imbedded in the lung tissue itself and cause chronic pulmonary inflammation and cancer. Fibrous particles that are long and thin may also penetrate deeply into the lungs. Finally, the chemical composition of the particle and any gases that adsorb onto the particle may transport irritants or carcinogens to the lung tissue.

During overhaul of a structural fire, firefighters are exposed to products of combustion. Gases, vapors, and airborne particulates are generated by the destruction of plastics, carpeting, foams, fabrics, and wood. Fibers may be present from materials containing asbestos or fiberglass. As firefighters open walls and ceilings to search for hidden combustion sources, more gases and respirable particles are released into the environment.

Soot particles resulting from flaming combustion are agglomerates of several to millions of spherical primary particles that are each a few tens of nanometers in diameter. The inertial properties of the entire soot particle are characterized by its aerodynamic diameter. The particles given off by the fire have a log-normal size distribution, meaning that the number of smaller particles is much greater than the number of larger ones. Typically, their mass median aerodynamic diameter ranges from 0.2 μm to 2 μm. [7] Thus fires generate many fine particles that are capable of deep penetration into the lungs and that settle out of the environment very slowly.

The particles produced by smoldering combustion resemble tar, forming nearly spherical microdroplets with both solid and liquid organic components. They tend to be somewhat larger than soot particles, with a mass median aerodynamic diameter generally between 0.8 μm to 2 μm, again falling under the classification of fine particles. [8] The smoke from smoldering materials tends to be light in color, compared to the black smoke from flaming. During overhaul, this may be an active source of respirable particulates.

In addition to size, the composition of particles may affect the health outcome. Other toxic components of particulates that may be present during overhaul [2] include:

- Asbestos – Fine fibers that can cause scarring of lung tissue leading to asbestosis and lung cancer may be present in insulation and fire retardant building materials. [9]
- Lead – A neurotoxic metal that damages the central nervous system and can cause kidney and reproductive system damage is found in video and computer monitors. [9]
- Other metals – Smoke particles can incorporate metals such as chromium, cadmium, copper and mercury from electrical equipment, wiring, and other sources. Effects vary and can include cancer, damage to liver and kidneys, and nervous system damage. [9]
- PCBs – Polychlorinated biphenyls are carcinogenic. They are found in older transformers and other electrical equipment. [9]
- PAHs – Polycyclic aromatic hydrocarbons are semivolatile and nonvolatile organic compounds, many of which are carcinogenic and mutagenic. They are products of incomplete combustion of plastics, wood, and fossil fuels (e.g. diesel generators). [10,11]
- VOCs – Volatile organic compounds generated in fires include toxic gases such as acrolein, hydrogen cyanide, benzene, and toluene. They can cause irritation or asphyxia, and some are carcinogenic. They are produced from combustion of wood products and various types of plastic, and can be transported into the lungs as adsorbents on particles. [7]
- Alkalinity – In a building collapse, highly alkaline dust may result from pulverized building materials such as concrete. High alkalinity can cause persistent cough and bronchial hyperreactivity. [12]

Several studies have been conducted to characterize the respiratory exposure hazards during the stages of fire fighting: suppression [13,14,15], overhaul [1,2,13,14], and investigation of cause and origin [16]. Air monitoring was performed with area (static) sampling and some personal sampling measurements to detect toxic gases such as CO (carbon monoxide), hydrogen cyanide, benzene, total and respirable dust, and particulates such as asbestos and metals. During the fire suppression stage, concentrations such as that of CO, hydrogen chloride and acrolein often exceeded published exposure limits. Concentrations measured during overhaul and investigation of cause and origin were below published exposure limits, except for a few cases. However, the studies warn that adverse health effects may still result from multiple low-level exposures and therefore respiratory protection should be worn during the latter stages of fire fighting. Even in the absence of visible smoke or alarming concentrations of toxic gases, particulates are still present. One study suggests that these particulates may absorb harmful chemical reactive species and serve as an entry mechanism to the lungs. [14]

An extreme case of exposure to dust and smoke was encountered after the collapse of the World Trade Center. While overhaul of a standard house fire takes on the order of 30 minutes, the rescue and cleanup operations after the World Trade Center collapse lasted for several months. Respiratory protection equipment was not widely available at first, and proper use was never enforced. Many rescue and cleanup workers spent days at the site with infrequent or no respiratory protection. Chronic respiratory symptoms including persistent cough, shortness of breath, and chest tightness are common among this group, and some have suffered permanent lung scarring leading to disability and, for a few, death. A relationship between exposure and reduced pulmonary function has been established. [17,18] Some particulate-related respiratory hazards measured during fire overhaul and at the World Trade Center site are listed in Table 1.

Table 1. Particulate Sampling Results from Some Fire Overhaul and WTC Studies

Event	Description	Particulates	Concentration*	Collection/Analysis Method
Overhaul[1]	Air sample	Respirable dust (personal sample)	6.18 mg/m^3	Filter/Gravimetric
Overhaul[2]	Air sample	Total dust (area sample)	1.82 mg/m^3	Filter/Gravimetric
		Respirable dust (personal sample)	8.01 mg/m^3	Filter/Gravimetric
		Asbestos	0.073 fibers/cc	
		Lead	0.03 mg/m^3	
Fire/ Overhaul[14]	Air sample	Smoke	-	Impinger/ Chemiluminescence Filter/Electron Spin Resonance
		Aerosol	-	Impinger/ Chemiluminescence Filter/Electron Spin Resonance
World Trade Center[19]	Air sample, middle of pile, Oct 2001	Total dust (area sample)	1.401mg/m^3	Filter/Gravimetric
World Trade Center[20]	Air samples, WTC 5 + three perimeter sites, Sept - Nov 2001	Fine particles (10/4/01)	0.4 mg/m^3 (max.)	Saturation samplers
		Lead (9/22/01)	0.0055 mg/m^3 (max.)	X-ray Fluorescent Analysis
		PCBs (10/2/01)	153 ng/m^3 (max.)	High-Volume PU Foam and Glass Fiber Filter Sampler
		Asbestos (Sept-Oct 2001)	(0.04 to 0.08) fibers/cm^3	Phase Contrast Light Microscopy/ Transmission Electronic Microscopy
World Trade Center[21]	Dust samples collected east of WTC, 16-17 Sept 2001	Fine particles	(0.88 to 1.98) % of total mass	Gravimetric Sieving/ Aerodynamic Sizing
		Respirable dust	(1.2 to 2.4) % of total mass	Gravimetric Sieving/ Aerodynamic Sizing
		Lead	(101 to 625) µg/g	X-ray Fluorescent Analysis
		PCBs	(0.59 to 0.75) µg/g	Gas Chromatography/ Mass Spectrometry
		PAHs	> 0.1 % of total mass	Gas Chromatography/ Mass Spectrometry
		Asbestos	(0.8 to 3.0) % of total mass	Microscopic Analysis
		Glass and other fibers	40 % of total mass	Morphologic Analysis/ Gravimetric Sieving
		pH	(9.2 to 11.5)	Ion Chromatography
World Trade Center[10]	Prediction of PAH levels in air after 9/11/01	PAHs (9/14/01)	(1.3 to 15) ng/m^3 est.	Sample Assays/ Trend Analysis

*Mean values and ranges unless otherwise stated.

Real-Time Detectors – Particulate/Dust

Traditionally, particulate exposure limits have been quoted as mass concentration (mg/m^3). The mass concentration of aerosolized matter is most reliably determined by passing a known volume of gas through a filter and determining the increase in mass of the filter due to the amount of particulates deposited on the filter. Determining particulate mass concentration by accurately weighing the filter before and after sampling is simple, accurate and widely used. However, analysis requires a substantial amount of time since it requires the use of a sensitive microbalance, typically at a location different from the sample location. Direct-reading instruments can provide almost real-time results, within seconds to minutes depending on the sampling time and the nature of the instrument. The class of direct-reading instruments that will be considered here are optical instruments that measure particle mass, size, or occurrence indirectly from light scattering. In terms of mass response, these instruments tend to be less accurate than gravimetric filter measurements, but their rapid delivery of results allows one to measure environments that are changing, and to correlate the change with the measurements.

The detection and characterization of aerosol particles can be accomplished by exploiting their optical properties. Because the particles' optical properties differ from that of the surrounding air, incident light is both scattered and absorbed by the particles. In principle, both the scattering and absorption effects can be utilized for particle measurements. However, because many particles of interest absorb very weakly, optical scattering provides a more practical basis for measurement instruments. Two properties of the light scattered by particles are generally used to measure their size and concentration: i) the total amount of light that is scattered, and ii) the geometry, or pattern exhibited by the scattered light. Both properties carry information regarding the size and the concentration of the aerosol. The recent advent of extremely compact, low cost, and reliable solid-state laser sources (laser diodes) and optical detectors (PIN diodes) similar to those used in Compact Disc (CD) and Digital Video Disc (DVD) players has led to the availability of a wide array of portable field devices to measure the size and concentration of aerosol particles.

The basic construction of an optical particle detector is shown in Figure 1. An aerosol sample is first drawn into the instrument, at a specific volume flow rate, by way of an internal pump. The flow is continuous and typically set at several liters per minute. The sampled aerosol stream is then illuminated by an optical source located within the instrument. Suitable optics are used to focus the light from the source onto the sample. One or more detectors are then used to collect the light scattered by the particles. The scattered light provides information about both the size and number of particles. Depending on the sophistication of the instrument, a number of detectors may be employed, to increase its accuracy or range. The output of the detector(s) is then processed by an internal computer, which computes the concentration of the sample, and in some cases, by particle size. This information is then logged into the instrument's memory. In many devices, the logged information includes the volume of the sample that is collected and the time of collection.

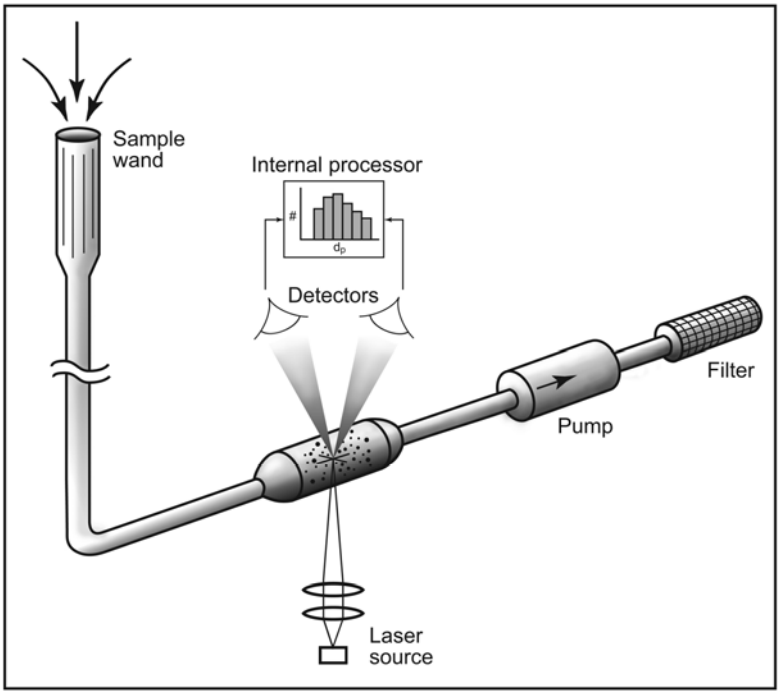

Figure 1. Schematic of the basic construction of a hand-held particle detector.

One class of instrument is the aerosol or dust monitor, typically reporting concentration as mass/volume. It is designed to measure the total mass of the aerosol particles, since mass is often used as a measure for exposure. In a dust monitor, the light scattered from a sample of particles is collected. The total mass of the sample is proportional to how many particles the sample contains, so a dust monitor measures mass by adding up the scattered light contributed by all of the particles together. Thinking more about how the mass of a group of spheres is determined, it is possible to understand that the total mass in the sample not only depends on how many spheres (particles) there are, but it depends on how big they are as well (the mass of each sphere being proportional to the cube of its diameter). In reality, the amount of light scattered by a particle is *not* exactly proportional to the cube of its diameter, so this aspect affects the ability of a dust monitor to measure mass accurately. Commercially available instruments are capable of measuring mass concentration over the range of (0.001 to 400) mg/m^3 over a particle size range of (0.1 to 10) µm. Most instruments are calibrated by comparing the instrument response to a standard dust, such as the ISO Test Dust, with standard gravimetric measurements. Because the light scatter depends on the physical and optical properties of the aerosol, the calibration does not guarantee that the instrument will respond accurately to other aerosols. Therefore, when the properties of the aerosol are unknown, which is likely the case for field measurements, filter sample gravimetric measurements are recommended for direct comparison to calibrate the instrument to the specific aerosols in the environment.

A separate class of instrument is the Laser Particle Counter (LPC) or Optical Particle Counter (OPC), typically reporting concentration as number of particles/volume. As the names imply, this device is configured to literally count or detect the occurrence of single particles. This differs from the dust monitor which measures a group of particles. In the case of the LPC, the incoming aerosol sample must be diluted with particle-free air to ensure that particles are counted one at a time. Some LPCs simply display the total number of particles counted in a certain amount of time. However, most LPCs also display the size of the counted particles. This is possible because the light scattered by a particle carries information related to its size. The output of a LPC is generally broken down and displayed in ranges or bins, i.e. the number of measured particles occurring from (0.1 to 0.5) µm, (0.5 to 1.0) µm, (1.0 to 5.0) µm, etc. Generally, LPCs have an upper size limit for detection on the order of (20 to 35) µm. Upper limits of particle concentration usually occur in the range of (18 to 71) particles/cm^3. Because exposure limit guidelines are not expressed as number of particles/volume, interpreting the output of LPCs with regard to exposure limits poses difficulties.

The instruments described above are portable hand-held instruments. They are designed for the purpose of collecting information in the field and workplace environments. Most instruments are capable of logging data to memory for one to two hours or more, and many are capable of transferring data to a portable computer so that near-real-time analysis of the data can occur. The applications of these instruments range from indoor air quality, HVAC (Heating Ventilation and Air Conditioning) inspections and filter efficiency testing, clean room contamination and monitoring, and workplace exposure monitoring such as construction, demolition, manufacturing, industrial processing, and mining. A few instruments such as the dust monitors have been adapted for use as personal exposure monitors.

Technical Issues

For a direct-reading particulate detector to be useful to the firefighter, it must provide information that accurately describes the environment of the firefighter. This list of potential technical issues and related questions is intended to serve as a starting point for discussions aimed toward providing sound technical guidance on using these instruments for the specific applications of the fire service.

<u>Tools at Hand</u>
Direct-reading instruments to monitor harmful gases, such as CO, are routinely used by some fire departments to aid in incident command decisions. Many of the direct-reading particulate counters and dust monitors are designed for field applications where conditions are less controlled. In principle, these instruments could be used immediately by firefighters to provide some information about the respiratory threats present during overhaul. Ultimately the firefighter needs the instrument to provide a “Go” or “No Go” output. Lessons learned from the immediate use of off-the-shelf instruments can provide guidance on future device development.

Issue: What guidance should be applied to interpreting the measurements of the direct-reading particulate counters or aerosol monitors?

Issue: Are there simple modifications to the current off-the-shelf devices that can improve the usefulness to the firefighter?

Issue: Should the current off-the-shelf devices incorporate size-selective features (and which are most important) to mimic particle deposition? (Examples are the personal samplers that make us of aerodynamic diameter size cuts.)

Measurement Fouling

Fire suppression will introduce large amounts of water to the structure. Combined with the high heat from the fire, a high humidity environment can exist during overhaul.

Issue: Will high humidity foul the measurement?

Issue: Should water droplets be removed from the measurement or included? Are there harmful gases produced by the fire that can be absorbed by water droplets?

In some jurisdictions it is standard procedure to actively ventilate enclosed spaces that are being overhauled. Large fans are typically used which can produce significant wind speeds.

Issue: What are the effects of wind speed on the measurements?

Issue: Will temperature extremes foul the measurement?

Issue: What are other sources of measurement fouling?

Monitoring the Unknown

Direct-reading particle counters and dust monitors produce the best results when they can be applied to detect particulates that are spherical, have a known refractive index, and a known size distribution. This set of conditions is not likely to occur during field measurements, and it is only achieved in a controlled laboratory setting with a great degree of difficulty. The present applications of these instruments are largely to monitor respiratory threats in environments where engineered controls are the first level of protection. Generally in these cases, the optical properties of the particulates are known or at least enough information is known to estimate the properties from similar particulates. The fire overhaul environment exists only after an uncontrolled release of respiratory threats from an array of burning sources and activities associated with the firefighting response. It is safe to classify it as an uncontrolled environment and one for which the particulate respiratory hazards are not well characterized.

Issue: Because no two fires or their fire responses are exactly alike, how is the overhaul environment best characterized to promote increased respiratory protection through improved monitoring equipment and operating procedures?

The measurement from the direct-reading devices should correlate well with some adverse health effect or preliminary markers. Current exposure limits for nuisance dust or particulates not otherwise characterized (PNOC) are expressed as mass concentration, respirable and inhalable. Since the total mass of any distribution of particles is dominated by the larger particles, size selective measurements are most appropriate. Very little information exists on the particle size distribution during overhaul. Since the fine particulate matter produced by the fire has longer settling times compared to the large particles, assumptions about how much of the particulate matter is respirable need to be considered. Therefore, more data is required to develop a better understanding of the actual respiratory hazards that are encountered.

Issue: Are particulates serving as vehicles for exposure to other more toxic substances?

Issue: If so, can adverse health effects be correlated with particulate concentrations?

Issue: Which measurement, particulate mass concentration, particulate number concentration, or particulate surface area, most reflects the hazard caused by the unique conditions of particulate exposure during fire overhaul?

Optical Properties of Particulates

A number of considerations must be factored into the design of a LPC. In virtually all commercial devices, the particles are treated as equivalent spheres, i.e., the calculated particle size is that of an ideal sphere that most closely matches the observed signal. Particles that radically deviate from this assumption can provide misleading results. In addition, a value for the particle refractive index must be assumed. For cases when this value is not accurately known, or when the sample consists of a combination of materials with differing refractive indices, the resulting measurement accuracy is also affected.

Issue: Can the particulates found during fire overhaul be accurately measured using a generic set of optical properties?

Issue: How appropriate is ISO dust as a standard particulate set for the fire overhaul measurements?

Issue: Will it be necessary to develop a standard particulate set for the fire overhaul measurements?

How Small is Small Enough?

A shortcoming of LPCs is their inability to detect nanometer sized particles. This is because light scattered from particles of this size is extremely weak. One class of instruments capable of extending this lower size limit down to (10 to 20) nm are called Condensation Particle Counters (CPC), also referred to as Condensation Nucleus Counters (CNC). These devices amplify the light scatter from the particle by condensing a solvent around it and growing the particle to a micrometer sized droplet, similar to the process that forms clouds in the atmosphere. The micrometer sized droplets are easily detected but the measurement is independent of the particle size. Therefore size information is lost.

Issue: For the fire overhaul scenario, what is the lower limit of particle size that should be considered?

User Needs

For a firefighter to find particle monitoring equipment useful in their work, many needs must be met. This list of potential requirements and issues is intended as a starting point for discussions.

1. Ruggedness in overhaul environment

   a. Lightweight
   b. Impact from dropping
   c. Impact from falling debris
   d. Direct water spray
   e. Heavy soot conditions

2. Ruggedness in fire environment (if permanently attached to firefighter's turnout gear)
   a. Lightweight
   b. High temperatures
   c. Heavy soot conditions from fire
   d. High humidity of firefighting operation

3. Simple operation
   a. Turn the instrument on and it begins to take readings
   b. No navigation through multiple levels of menu displays
   c. Any buttons, dials, or switches must be capable of manipulation by the gloved hand of a firefighter
   d. Large display with its own backlight
   e. Sufficient display lighting for viewing under all lighting conditions

4. Firefighter training
   a. Instrument operation
   b. Instrument output: "Go" or "No Go" (no time to interpret the output)

5. Sufficient warning for a variety of particulates
   a. Accurate output
   b. Standard criteria for what constitutes a hazard
   c. Audible / discernable alarm
   d. Distinguishable from other alarms in the environment (e.g. PASS (Personal Alert Safety System) device, low pressure air alert on SCBA)

6. Monitoring and Recording
   a. Remote transmission to external command post, using a variety of electronic incident command board systems
   b. Type of information – received and sent
   c. Method of transmission

WORKSHOP OBJECTIVES AND ORGANIZATION

The workshop provided a forum to discuss the strategies, technologies, research needs, performance criteria, and potential standards for particulate monitoring, in order to inform the provision of respiratory protection in environments encountered by first responders. The participants included members of the fire service, particulate detector manufacturers, public health professionals, airborne particulate researchers, and members of standards organizations. Several participants represented more than one type of organization, enabling them to discuss respiratory protection issues from multiple perspectives. The workshop agenda and list of attendees are provided in Appendices 1 and 2 respectively. The slides and summaries for each presentation are provided in Appendix 3. Appendix 4 presents the results from the discussions of three breakout groups.

Presentations

The objectives of the workshop were explained in the first presentation, provided in Appendix 3A. The most important of these objectives were to draft performance criteria for direct-reading particulate detectors that address the needs of the firefighting community. This presentation also demonstrated the analogous use of these devices in industrial work environments while recognizing the challenges of transferring the application to the work environment of the firefighter. To prepare the participants for discussions on the priorities for research and performance criteria, the remaining presentations explored:

- Fire Overhaul Characterization
- Particulate Detection Equipment
- Firefighter Needs
- Federal Agency Activity

The first three presentations (Appendices 3B, 3C, 3D) were given by public health professionals who have studied firefighter exposure to respiratory hazards. They were asked to address some specific issues such as the following in their presentations:

- Important sources and/or activities that generate respiratory hazards in the fire overhaul environment
- The effectiveness of standard methods of environmental monitoring and personal sampling for respiratory threats in the fire overhaul environment
- Correlating the long term health of firefighters to multiple low level exposures to hazardous substances
- Firefighter training regarding respiratory protection and the actual use of protective equipment
- Procedural changes that can reduce exposure during fire overhaul and the factors that impede the change

The presentations point out the challenges of characterizing the respiratory hazards during fire overhaul and of establishing a link to the long term health of firefighters, as well as the challenge to convince firefighters to follow recommended safety procedures regarding respiratory protection even when the perceived risks are low.

The next two presentations (Appendices 3E and 3F) were given by researchers in the field of airborne particle detection. They were asked to address some specific topics such as the following:

- The physical characteristics of particulates generated by a fire
- The physical properties of the particulates that may be measured by direct-reading particulate detectors
- The basic theory of operation of the detectors
- The advantages and general limitations of direct-reading particulate detectors

These presentations describe the nature of the particulates to be found in the environment encountered by the firefighter, particularly during overhaul, and methods by which particulate properties, such as mass, size, and concentration, may be measured.

The presentation in Appendix 3G was given by a Hazardous Materials Team Leader for the fire service. The speaker was asked to address topics regarding the needs of the fire service such as the following:

- Instrument operation, output, accuracy, power requirements and durability
- Cost of instrumentation – initial and lifetime
- Training, instrument maintenance, and service

The presentation describes the characteristics of an ideal particulate detector for the firefighter community, as seen by a member of the fire service. In addition to expectations of accuracy and sensitivity that would be required from any measuring device, the design of this detector should consider ease of use, minimal weight, and durability under conditions of extremes in temperature, high humidity (including steam), and physical abuse.

The final two presentations (Appendices 3H and 3I) describe the research and standards development activities related to firefighter technology at two U.S. government agencies: NIST and the Department of Homeland Security (DHS). The Advanced Fire Service Technologies Program at NIST provides the science and performance metrics for development and implementation of new technology. DHS identifies and adopts standards and creates mechanisms to accelerate standards development.

During the workshop, participants were given tours of some NIST Fire Research testing facilities in order to provide further stimulation for the breakout group discussions. Tours of the Fire Emulator/Detector Evaluator (FE/DE), Firefighter Equipment Evaluator, and the Large Fire Research Facility (LFRF) were given. The FE/DE tests fire detector response to various gas and particulate mixtures, and the Firefighter Equipment Evaluator tests the performance of firefighter equipment such as PASS devices under a variety of conditions, including high temperatures. The LFRF provides NIST with the capability to construct and measure fires in configurations from stovetops and chairs to full rooms and small buildings.

Breakout group procedures

To determine priorities for actions after the workshop, the workshop participants were split into three breakout groups. The members of each group were determined before the workshop so that the composition of each group would represent a mix of fire service members, detector manufacturers, regulators, and researchers. Facilitators assigned to the three breakout groups were Robert Vettori and Kathryn Butler from NIST and Paul Greenberg from NASA (National Aeronautics and Space Administration), all of whom had been involved in the organization of this workshop. Rodney Bryant, the fourth workshop organizer, visited each group to monitor progress and document results. The facilitators directed the brainstorming and ranking processes for the groups but did not take part in the voting to determine the final set of priorities.

The groups were asked to respond to the following list of questions:

- What are the prioritized research needs for direct-reading particulate detectors for first responders?
  - What are the prioritized research needs for assessing firefighter exposures during overhaul?
- What are the prioritized performance criteria that are suitable for the first responder application?
  - How do they differ from current performance criteria?
- What standards will be necessary?
- What technological advances are necessary?

These questions were categorized as Research Needs, Performance Criteria, Standards, and Technological Advances. The tables in Appendix 4 present the results from the brainstorming sessions of each breakout group.

The next task after brainstorming was for each group to determine and rank their top five priorities in each category. In two of the groups (2-Blue and 3-Green), each participant was asked to vote on their top five choices. From these votes, further discussion identified and ranked the top five priorities for the group. In one group (1-Red), consensus to identify the top five priorities was achieved through open discussion but rankings were not assigned. During the discussion of the top five priorities, each group discovered commonalities among the responses that allowed multiple responses to be combined.

After the breakout group sessions on the first day, all three groups had determined a set of five priorities from each of the four categories. Rankings had also been determined by two of the three groups. The four workshop organizers met to identify commonalities among the three groups, which were assembled and labeled. These common responses became the tentative priorities from the workshop as a whole. The responses in each group that did not overlap other responses were identified as outliers.

A difficulty in this analysis resulted from differences in the definition of Technological Advances. Two groups set a short time horizon for their discussion and one group (2-Blue) set a long time horizon. Group 1 (Red) discussed longer term development but did not rank these responses. As a result, there was less overlap among ranked responses in this category.

On the morning of the second day of the workshop, the breakout groups were assigned the task of clarification for the responses identified as outliers. Each group was allowed to bring two outliers back to the full body of workshop participants along with arguments for retaining them as workshop priorities. During this process, some outliers were found to belong to the common responses forming the tentative set of workshop priorities. This final set of sessions allowed each group to complete the task of setting group rankings of their top five responses in each category, along with descriptions of why each priority was important. The top five responses in each breakout group are presented first in each list in Appendix 4.

In a final meeting of the organizers, the breakout group conclusions were assimilated into the tentative list of workshop priorities. This list was presented to the full body of workshop attendees, and a final discussion determined the conclusions of the workshop.

The results of this final discussion are presented in the following section.

BREAKOUT GROUP RESULTS

The concluding list of priorities from the workshop on Real-Time Particulate Monitoring was determined in a final discussion by the entire workshop. Tables 2 through 5 present those priorities in each of the four categories of Research Needs, Performance Requirements, Standards, and Technological Advances. Each priority is classified under the heading of Priority, with the specific issues needing to be addressed assembled under the heading of Scope. The number of breakout groups that initially raised each priority as a group response is also listed in the final column. No attempt was made to further rank the priorities identified under each category.

Under Research Needs, the priorities identified by this workshop are:

- Health Effects for Firefighters from Overhaul
- Particulate Characterization in Overhaul
- Detector Response in Overhaul
- Demonstration of Benefits
- Hazard of Overhaul
- New Filter Cartridge

This workshop strongly supports the need for a better understanding of the health effects of particulates on firefighters, more comprehensive data on what the firefighter actually encounters during overhaul, and better understanding of the response of the detector to the overhaul environment. If air-purifying respirators are acceptable for firefighter use during overhaul, a new filter cartridge specifically designed for that environment is needed. In addition, this workshop recognizes the need to convince members of the fire service of the necessity of proper protection, based on good science.

The priorities for Performance Criteria resulting from this workshop are:

- Data Telemetry and Data Logging
- Interpretation of Output and Instrument Operation
- Physical Performance in the Environment
- Types of Particulates
- Cost of Ownership
- Form and Function

For good decision-making, a particle detector for the fire service needs to collect accurate data and transmit it to both the command post and the firefighter. It needs to indicate Hazard or No Hazard clearly and be easy to use, calibrate, and maintain. It must operate under the physically challenging conditions inherent to the firefighting environment (extremes of temperature, steam, shock, etc.). The types of particulates and procedures for use need to be well specified and will ultimately dictate the form of the device.

The workshop priorities for developing Standards are:

- Physical Performance in the Environment
- Calibration and Maintenance
- Standard Material and Testing Methods
- Exposure Limits

Some of the priorities for Performance Criteria are also reflected in this category. In order to give good measurements in the overhaul environment, standards that reflect the physical challenges must be established. Maintenance and calibration standards must be set. A standard material that reflects the composition (smoke/dust/droplets) of the aerosol in the overhaul environment is needed. Detectors should be tested against this standard material. Exposure limits need to be established for the workplace conditions inherent to firefighting.

For Technological Advances, the workshop priorities are:
- Real-Time Analysis
- Data Telemetry and Data Logging
- Device Packaging
- Multi-Hazard Detection
- Miniaturization

Decision-making on proper respiratory protection requires real-time measurement analysis, display, and transmission to the firefighter and the command post. Exceptional events such as low battery signals and ceiling value alarms should be logged along with the measurements. Current technology particulate detectors need to be repackaged for use in the firefighter environment. And, over the long term, a small, lightweight, integrated all-in-one device containing detectors for both particulates and gases and other instruments such as a GPS (Global Positioning System) would be easier to carry and capture a richer set of information to guide decisions regarding firefighter safety.

Further ranking of the priority issues was not a task of the workshop. However the issues that were agreed upon by all three groups or that occur in multiple categories deserve to be recognized as important among this group of participants. Those issues of priority were the following:

- Health Effects for Firefighters from Overhaul (Research Needs)
- Particulate Characterization in Overhaul (Research Needs)
- Detector Response in Overhaul (Research Needs)
- Data Telemetry and Data Logging (Performance Criteria and Technological Advances)
- Interpretation of Output and Instrument Operation (Performance Criteria)
- Physical Performance in the Environment (Performance Criteria and Standards)

In addition, common themes occur in the context of the scope of the priority issues. Two of these occur in at least three categories and they are the need to characterize the particulates generated during a fire and firefighting activities (Research Needs: *Particulate Characterization in Overhaul*, *Hazard of Overhaul*, Performance Criteria: *Types of Particulates*, Standards: *Standard Material and Testing Methods*) and the need to develop an instrument that can stand up to the physical insults of firefighting while delivering credible results (Performance Criteria: *Physical Performance in the Environment*, Standards: *Physical Performance in the Environment*, Technological Advances: *Device Packaging*).

Table 2. Responses to: "What are the prioritized research needs for direct-reading particulate detectors for first responders?" and "What are the prioritized research needs for assessing firefighter exposures during overhaul?"

Priority	Scope	# Groups
Health Effects for Firefighters from Overhaul	The exposure risks of firefighters need to be better understood. This includes an enhanced understanding of dosimetry metrics, including ways to distinguish between chronic and acute exposure, correlations with firefighter activities or procedures and other environmental factors, and dependence on particulate size and composition. Specific questions include: What is the toxicological response to different sizes and compositions of particulates? Considering that particulates may also carry adsorbed gases, how should the hazard be defined with respect to particulates and gases? Do water particles play a role in health effects? What about confounders such as contaminated turnout gear and exposure to truck exhaust that may also affect firefighter health? What are the procedures for overhaul, and how do they affect the timeline for safe operation?	3
Particulate Characterization in Overhaul	More comprehensive data are needed on the particle environment associated with real overhaul environments, such as particle size distribution (PSD), number density, and particle composition. A database of what fires actually generate should be developed. The data should address issues of statistical sufficiency and local vs. global measurements.	3
Detector Response in Overhaul	Improved characterization of the instrument response function is needed to address complications inherent in mixtures, such as variations and combinations of composition and interference with other gas-phase constituents or nuisance backgrounds. For example, how does water affect the measurement and should water droplets be included in the measurement? Instrument sampling efficiency and biases as functions of environmental conditions need to be understood. Multi-metric methods of evaluating performance should be developed to account for the range of particle sources and particle sizes (ultrafines to 10 µm particles). The procedures of overhaul (including timelines) should be defined to guide the development of sampling/measurement strategies that are representative of the activity of the firefighters.	3
Demonstration of Benefits	Firefighters need to be convinced that it is beneficial to wear a respirator mask or SCBA during overhaul. Demonstration of the benefits that will result from the use of particle detector technology is necessary. Is it worthwhile to do the research? Consider the evidence of adverse health effects from scenarios that are analogous to overhaul, such as events of repeated low-level exposures, below published threshold exposure limits, to hazardous airborne matter.	2
Hazard of Overhaul	Quantify the respiratory hazard from particulates (and gases) found in the overhaul environment: mass, number concentration, size. This information is necessary to predict the exposures and toxicological response.	1
New Filter Cartridge	Due to a range of multiple respiratory hazards found in overhaul, a new filter cartridge should be designed for optional respiratory protection for firefighters during overhaul. Features such as an end-of-service indicator should be included.	1

Table 3. Responses to: "What are the prioritized performance criteria that are suitable for the first responder application?" and "How do they differ from current performance criteria?"

Priority	Scope	# Groups
Data Telemetry and Data Logging	A particulate detector should collect measurements through data logging. In addition to the firefighter or safety officer taking the measurements, the information should also be transmitted to the incident commander / command post. This provides a redundant system for safety.	3
Interpretation of Output and Instrument Operation	The instrument should provide a simple indication of Hazard or No Hazard ("Go" or "No Go"). It should be simple to use, easy to calibrate, and have a simple display.	3
Physical Performance in the Environment	The instrument should take credible measurements throughout the range of environmental exposures. It should handle extremes of temperature and be waterproof, vibration-proof, and shock-proof. It should not create a new hazard. Other physical considerations include size, power, weight, and display visibility. Criteria need to be set for performance under a range of environmental conditions.	3
Types of Particulates	The hazards to be measured, including size range, concentration range, and accuracy, need to be determined in order to build the device.	2
Cost of Ownership	The burdens placed on the user (first responder) of particulate detectors, such as maintenance and calibration, should be low.	1
Form and Function	A sampling/measurement strategy that is representative of the activity will dictate the form of the device. Therefore the procedures of overhaul need to be defined. Specific questions include: Where should the particulate measurement be taken? Should a safety officer perform an area sample of the overhaul site or should a personal device be assigned to each firefighter?	1

Table 4. Responses to: “What standards will be necessary?”

Priority	Scope	# Groups
Physical Performance in the Environment	The instrument needs to maintain its performance over the full range of environmental insults, including humidity, temperature, and shock. Standard methods of evaluating the performance will be necessary.	3
Calibration and Maintenance	Maintenance and calibration standards must ensure that the unit performs to the manufacturer’s specifications. There should be a calibration artifact (available to the user) that is used to perform field calibrations.	2
Standard Material and Testing Methods	A standard material that can be aerosolized needs to be defined that is reflective of overhaul-specific particulates. Testing protocols and performance criteria need to be defined with regard to the standard material.	2
Exposure Limits	Firefighter exposures need to be quantified against the accepted workplace exposure standards. Exposure limits need to be defined for the overhaul-specific standard material. Guidelines that establish the action to take when limits are reached need to be specified.	2

Table 5. Responses to: “What technological advances are necessary?

Priority	Scope	# Groups
Real-Time Analysis	Decisions on alternative respiratory protection must be made in the field, therefore real-time analysis (1 sec to 5 sec) is necessary. Quick turn-around on the analysis of particulate composition should be a targeted goal.	2
Data Telemetry and Data Logging	In addition to measurements, exceptional events such as low battery and ceiling value alarms should be logged. Correlating measurements with specific firefighting activities during overhaul (localized demolition, forced ventilation, accelerometer, etc.) should be attempted.	2
Device Packaging	The equipment needs to be repackaged for firefighter use. This will involve ruggedization, environmental tolerance, and improvements to expand device lifetime.	2
Multi-Hazard Detection	Develop a device with integrated functionality, such that it can measure particulates and gaseous species, physical location using GPS, sampling volumetric flow rate, humidity, etc. (long term goal)	2
Miniaturization	Shrink equipment (including battery and pump) to make a smaller and lighter device that would be better accepted by users (long term goal)	2

SUMMARY

Fire overhaul is a stage of firefighting where respiratory protection is often disregarded. However it is an occupational environment and appropriate respiratory protection should be worn when warranted. The combination of a vast amount of research and development in the fields of aerosol science, optical technology, environmental monitoring, and industrial hygiene, to name a few, has led to the existence of hand-held direct-reading particle counters and dust monitors. Making use of these devices to provide information to aid firefighters in selecting the appropriate respiratory protection should be explored. Exploring this potential application requires a better understanding of the respiratory hazards of overhaul, the needs of the firefighter, the current state-of-the-art technology, and the benefits of recent developments in particulate detection.

The effort to explore this potential use of hand-held direct-reading particulate detectors began as a workshop. The workshop brought together members of the fire service, particulate detector manufacturers, public health professionals, airborne particulate researchers, and standards organizations to discuss the need for better technology to assess the level of respiratory protection that is required for environments encountered by first responders. The goal of the workshop was to identify instrument performance criteria based on first responder needs, prioritize issues in need of more research, identify necessary standards, and appreciate where new technology may help.

The consensus of the workshop participants was that the following issues were important.

- Conducting future research in the areas of
    - Health effects for firefighters from overhaul
    - Particulate characterization in overhaul
    - Detector response in the overhaul environment

- Defining performance criteria for
    - Data telemetry and data logging
    - Instrument operation and interpretation of instrument output
    - Physical performance of the instrument in the overhaul environment

- Defining standards with respect to the
    - Physical performance of the instrument in the overhaul environment

- Developing new technology to benefit
    - Data telemetry and data logging

This list of priorities provides guidance toward selecting the next steps forward. It also provides a foundation of research needs to further refine and to build upon.

This workshop was a first attempt to define the needs of the firefighter community for monitoring particulates in overhaul environments and to prioritize areas of research and development to meet those needs. The consensus resulting from workshop discussions is expected to provide a strong foundation for the development of new tools to aid firefighters in selecting the appropriate respiratory protection, standard testing protocols to insure that equipment meets the needs of first responders, and performance criteria that allow industry to adapt the technology to the specific need and improve where necessary.

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APPENDIX 1 - WORKSHOP AGENDA

Thursday, May 3, 2007

7:40 am	**NIST Shuttle Pick-up From Holiday Inn**	
8:00 am	**Registration - Coffee and Refreshments**	
8:30 am	Welcome	**William Grosshandler** NIST Fire Research Division Chief
8:45 am	Workshop Objectives	**R. Bryant** NIST
9:00 am	Firefighter Health Effects: Overhaul and Beyond	**J. Burgess** University of Arizona
9:20 am	Fire Overhaul Characterization and Exposure Assessment	**R. Anthony** University of Arizona
9:40 am	No Smoke, No Fire, No Hazard: A Firefighter's Perspective on the Hazards of Fire Overhaul and How to Protect Against Them	**D. Bolstad-Johnson** City of Phoenix Fire Department
10:00 am	Detecting Particulates in Real-Time: Optical Techniques	**D. Chen** Washington University in St. Louis
10:20 am	**Break/Coffee and Refreshments**	
10:30 am	What We Know About Particulates Resulting From Fires	**G. Mulholland** NIST
10:50 am	The Ideal Detector for the Fire Service	**R. Stephan** Montgomery County Maryland HazMat
11:10 am	NIST Fire Fighter Technology Program Overview	**N. Bryner** NIST Program Manager
11:30 am	DHS Standards Development Program Overview	**P. Mattson** NIST Program Manager
12:00 pm	**Lunch/NIST Cafeteria**	
1:00 pm	**Tours: Fire Emulator/Detector Evaluator, Firefighter Equipment Evaluator**	
1:30 pm	Guidelines for Breakout Sessions	**R. Bryant**
1:50 pm	Breakout Sessions Begin	
3:30 pm	**Break/Coffee and Refreshments**	
3:40 pm	Breakout Sessions Resume	
4:30 pm	**Each Group Wraps Up Session with Summary**	
5:00 pm	**Adjourn for the Day/NIST Shuttle to Holiday Inn**	

Friday, May 4, 2007

7:40 am	**NIST Shuttle Pick-up From Holiday Inn**
8:00 am	**Coffee and Refreshments**
8:30 am	Reconvene Working Groups
9:30 am	**Tour: Large Fire Research Facility**
10:00 am	**Break/Coffee and Refreshments**
10:20 am	Reconvene Workshop (All Participants)
10:30 am	Deliberation on Results from Breakout Sessions
11:40 am	**Summarize the Results**
12:00 pm	**Lunch/NIST Cafeteria: Discuss Collaboration Opportunities**
1:00 pm	**Tours: SCBA Leak Experiments**
1:30 pm	**Adjourn the Workshop**

APPENDIX 2 - WORKSHOP ATTENDEES

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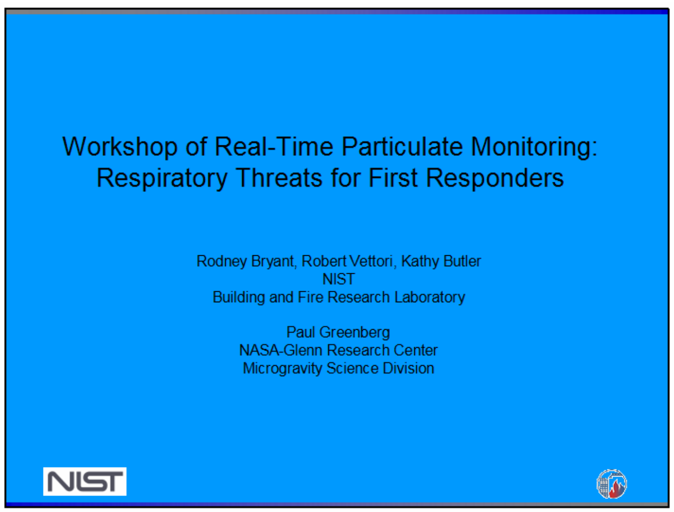
APPENDIX 3 - WORKSHOP PRESENTATIONS

APPENDIX 3.A – Workshop Objectives

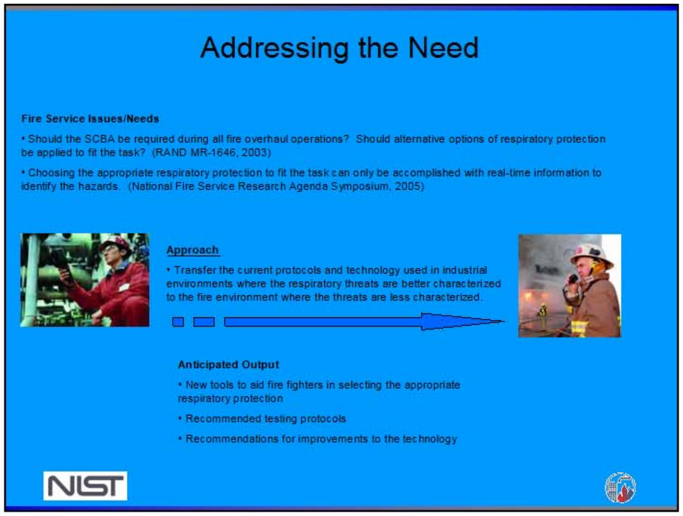
Rodney Bryant, Building and Fire Research Laboratory, NIST

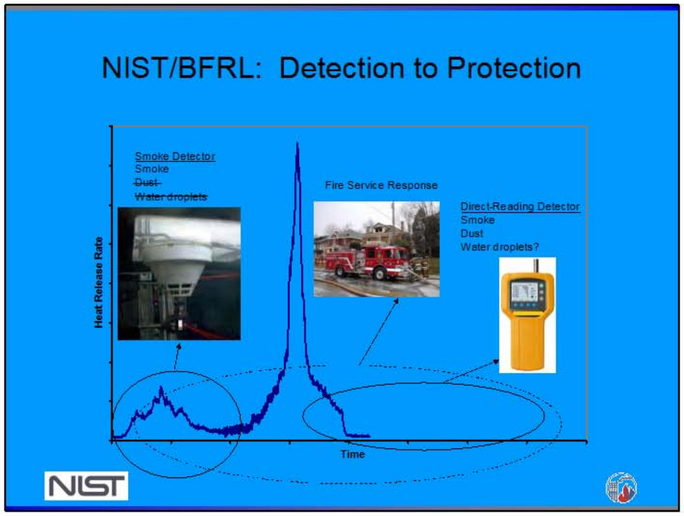
There is a need for real-time identification of hazards to enable selection of appropriate respiratory protection for firefighters. The challenge is to transfer the protocols and technology used in industrial environments where the respiratory threats are better characterized to the fire environment where the threats are less characterized. This can be accomplished by first identifying existing devices that can be applied for read-time particulate detection during fire overhaul, then determining performance criteria and standards that modify these devices to better suit the application. The workshop is intended to bring members of key organizations together to begin this process. In addition to the production of a report that lays out priorities for research and detector performance, the workshop is anticipated to expose attendees to new tools and methods to improve safety, provide opportunities to expand the applications of available technology, and present opportunities for new research, new focus, and future collaborations.




Fire Overhaul: Occupational Environment
overhaul
salvage
rekindle
overhaul
overhaul
Unknown respiratory threats
Limited active monitoring of threats
SCBA first option of defense
Low compliance


Manufacturing: Occupational Environment
Known respiratory threats
Frequent monitoring of threats
Engineered control of threats is first option of protection
Applications
Personal monitoring for compliance
Walk-through surveys
Site dust levels
Filtration systems
Indoor air quality (IAQ)
Clean room contamination
NIST


Addressing the Need
Fire Service Issues/Needs
• Should the SCBA be required during all fire overhaul operations? Should alternative options of respiratory protection be applied to fit the task? (RAND MR-1646, 2003)
• Choosing the appropriate respiratory protection to fit the task can only be accomplished with real-time information to identify the hazards. (National Fire Service Research Agenda Symposium, 2005)
Approach
• Transfer the current protocols and technology used in industrial environments where the respiratory threats are better characterized to the fire environment where the threats are less characterized.
Anticipated Output
• New tools to aid fire fighters in selecting the appropriate respiratory protection
• Recommended testing protocols
• Recommendations for improvements to the technology
NIST

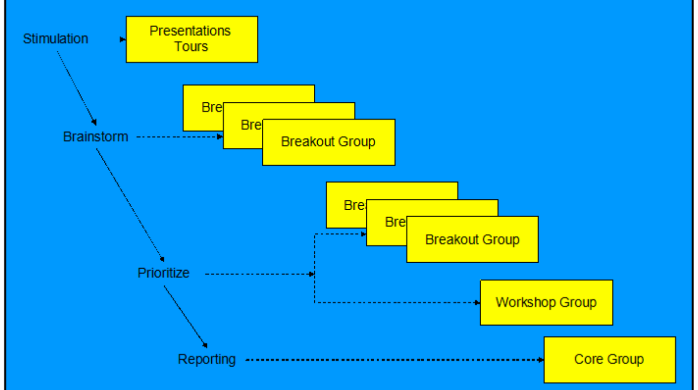

NIST/BFRL: Detection to Protection
Smoke Detector
Smoke
~~Dust~~
~~Water droplets~~
Fire Service Response
Direct-Reading Detector
Smoke
Dust
Water droplets?
Heat Release Rate
Time
NIST

Key Steps

- Identify existing devices and technology that can be applied for real-time particulate detection during fire overhaul
- Define performance criteria for these devices that considers the needs of the first responder community and their applications
- Design and conduct experiments to evaluate the devices according to the performance criteria

Particulate Challenge	Single source: smoke, dust	Mixtures: smoke, humidity, dust
Measured Response	Mass, Other	Number concentration (size distribution)

Workshop Overview



Anticipated Results of the Workshop

- NIST Report
  - Priorities for performance
  - Priorities for research
- Exposure to new tools and methods to improve safety
- Opportunities to expand the applications of available technology
- Opportunities for new research, new focus, and future collaborations
- Additional energy and momentum

APPENDIX 3.B – Firefighter Health Effects: Overhaul and Beyond
Jeffrey Burgess, University of Arizona

This presentation addresses the question of whether it is possible to establish a link between long-term health effects in firefighters and low-level exposure to multiple hazardous substances, and if so, what further research is needed. Annual pulmonary function tests performed on firefighters indicate accelerated rates of decline in pulmonary function. Although SCBAs provide the best respiratory protection in hazardous environments, they are heavy and impede communication, so there is resistance to using them during overhaul. Air purifying respirators (APRs) are lighter and more comfortable, but there is evidence of breakthrough of hazardous materials. A comparison of biomarkers for Phoenix firefighters wearing APRs during overhaul operations that take place immediately after fire extinguishment and Tucson firefighters with no protection during slower overhaul operations shows the difficulty of making meaningful conclusions from data in the absence of good controls. The respiratory function of Phoenix firefighters is worse despite the use of protective gear, raising the issue of whether the difference is due to possible breakthrough and poor fit, or to differences in overhaul procedures. Exposure studies need to consider different types of fires, such as dumpster fires and automobile fires that occur outdoors, where firefighters may not use respiratory protection.

Firefighter Health Effects: Overhaul and Beyond

Jefferey L. Burgess, MD, MPH
Associate Professor, Environmental and Occupational Health
The University of Arizona
Mel and Enid Zuckerman College of Public Health

NIST Questions

- Is it possible to establish a link between long-term health effects in firefighters and low-level exposure to multiple hazardous substances?
- If it is possible to establish a link, what are some recommended research focus areas?

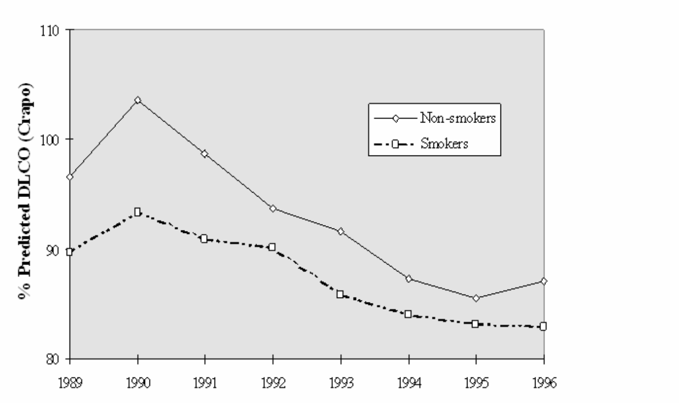
Firefighter Health

- Historically, accelerated rates of decline in pulmonary function
- With improved use of SCBA, less rapid decline in pulmonary function
- Continuing low-level exposure to products of combustion with unknown consequence
- Elevated cancer rates (brain, leukemia, NHL, bladder, kidney, prostate, colon)
- Cardiovascular line of duty deaths

Firefighter Medical Surveillance

- Seattle Fire Department since 1988
- Voluntary for 1,108 uniformed firefighters
- Annual pulmonary function tests including forced vital capacity (FVC), forced expiratory volume- 1 second (FEV_1) and diffusing capacity of the lung to carbon monoxide (DL_{CO})

DL_{CO} by Exam Year



DL_{CO} regression model (n = 812)

Parameter	Estimate	Std Error	p
Intercept	-6.448	4.168	0.1223
Age (years)	-0.124	0.023	0.0001
Height (m)	19.956	2.362	0.0001
Female	-4.966	0.694	0.0001
Minority	-2.184	0.432	0.0001
FVC	2.400	0.200	0.0001
Pack-years	-0.060	0.017	0.0005
Smoking	-2.065	0.483	0.0001
AVEFIRE	0.050	0.015	0.0013

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DL_{CO} regression model (cont.)

Parameter	Estimate	Std Error	p
Time	-0.913	0.291	0.0017
Age*time	0.017	0.004	0.0001
Female*time	0.230	0.115	0.0467
FVC*time	-0.111	0.035	0.0006
Smoking*time	0.241	0.075	0.0014
AVEFIRE*time	-0.006	0.003	0.0333

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Phases of Firefighting

- Extinguishment (knockdown)
- Entry/ventilation
- Rescue
- Support/standby
- Overhaul

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SCBA Performance

- The NIOSH recommended PF is 10,000
- We have shown that firefighters can over-breath their SCBA
- The degree of potential exposure depends on facepiece fit and extent of negative pressure excursions
- Some firefighters report black phlegm after using SCBA

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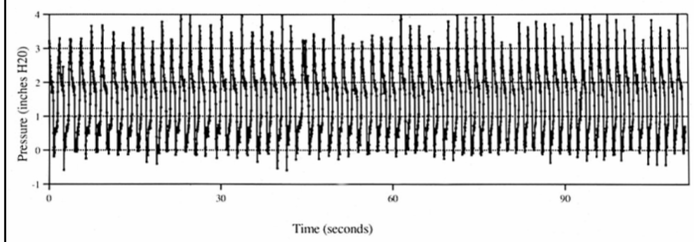

Firefighter #3 facepiece pressure during exertion.

Overhaul Study

- Baseline and 1 hour post-overhaul FEV_1, FVC, serum Clara cell protein (CC16), and surfactant associated protein A (SP-A)
- Phoenix firefighters wore full face negative pressure air purifying respirators equipped with combo HEPA/Smart cartridges
- Tucson firefighters wore no respiratory protection
- All firefighters were monitored for exposure

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Overhaul Monitoring

- Aldehyde screen
- Benzene
- Carbon Monoxide
- Carboxyhemoglobin
- Hydrochloric acid
- Hydrogen cyanide
- Nitrogen dioxide
- Respirable dust
- Sulfur dioxide
- Sulfuric acid

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Overhaul biomarkers

Group	n	CC16*	SP-A*	n	FVC (L)	FEV_1 (L)
TFD	25	8.9±3.5	287±144	19	5.42±0.72	4.10±0.62
TFD-OH	25	**12.3±3.6†**	306±157	19	5.36±0.73	3.94±0.65
PFD	26	9.6±3.5	250±117	26	5.44±0.68	4.22±0.51
PFD-OH	26	**14.6±5.2†**	**334±141†**	26	**5.29±0.74†**	**4.09±0.56†**

* units µg/L

† p <0.01

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Overhaul correlations

Biomarker	Tucson	Phoenix
FEV_1	Carboxyhemoglobin	Sulfur dioxide
CC16		Acetaldehyde
		Carboxyhemoglobin
		Respirable dust
SP-A	Acetaldehyde	
	Formaldehyde	
	Carboxyhemoglobin	

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Genetic Susceptibility and ΔFEV_1

SNP	genotype	N*	Adjusted mean† ± s.e.
IL-10 3699	AA	216	-0.037 ± 0.005‡
	AT	132	-0.031 ± 0.006
	TT	18	-0.012 ± 0.011

† Adjusted for age, gender, smoking and baseline FEV_1.

‡ $p < 0.05$

Other significant SNPs include TGFβ-1 -509, TNFα -238 and -308, AATZM and A1AT3

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Lung Inflammation and Δ FEV_1

- Retrospective study of 67 current nonsmoking Phoenix firefighters
- At least 5 years of spirometry tests
- Sputum induction, evaluation of IL-1β, IL-1RA, IL-8, IL-10 and TNF-α
- Medical and diet history

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Regression model of ΔFEV_1

Variable	Coefficient	p-value
constant	0.180	0.004
baseline age (yrs)	-0.002	0.047
baseline FEV_1 (L)	-0.057	<0.001
ln(IL-1RA/protein)	0.019	0.025
weight change (lbs)	-0.001	0.014

*Adjusted for race, gender, smoking and asthma

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Discussion/Recommendations

- Long-term firefighter exposure is associated with altered lung diffusion (measured through DL_{CO})
- Low-level exposure to multiple contaminants results in acute respiratory changes
- Genetic susceptibility is important
- At least one marker of sputum inflammation (IL-1RA) is associated with ΔFEV_1
- Prospective studies of exposure (including different types of fires), intermediate biomarkers and health effects (respiratory, cardiovascular and cancer) are needed

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APPENDIX 3.C – Fire Overhaul Characterization and Exposure Assessment

T. Renee Anthony, University of Arizona

Effects of various contaminants found in overhaul environments are presented along with a comparison of reported overhaul exposures with short term exposure limits. Particulates may be classified as PAH (polycyclic aromatic hydrocarbons), some of which are carcinogenic, and PNOR (particulates not otherwise regulated), for which size is an important factor. Monitoring methods for particulates include pump-filter and direct-reading monitors. Environmental studies correlate cardiovascular disease and fine particulates. Monitoring free radicals is a new effort to find a measurement that indicates levels of many contaminants, since CO is not a good predictor. PAHs are expensive to analyze and difficult to analyze when sampling from fires. The irritant index, which includes the respirable mass of particulates along with gas concentrations of HCHO (formaldehyde) and acrolein, is a possible way to quantify multiple exposures. Measurements indicate that the irritant index is much greater than unity during fire overhaul. In a respirator cartridge breakthrough test, other materials such as metals were found riding on the particulates.

Fire Overhaul Characterization and Exposure Assessment
for
NIST Workshop
May 2007

T. Renée Anthony, PhD, CIH, CSP
Assistant Professor, UA - MEZCOPH

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Overview - TRA

- Exposure Assessments
  - Single Compounds
  - Methods Available
- Health Effects of Exposures
  - Single
  - Multiple
- Areas for Research

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Contaminant	Effect
Carbon monoxide	***Initial***: Headache, dizziness, nausea, diminished work capacity; ***Advanced***: Vomiting, loss of consciousness, collapse, coma death *Interferes with bloods ability to transport oxygen: Maintain COHb below 5%*
Particulates	Irritant (PNOR); may depend on particle chemistry; *Size fraction* may be most important (ultrafine vs respirable vs "total" or "inhalable")
Aldehydes	Irritants; carcinogen (formaldehyde; low molecular weight compounds suspect)
HCN / cyanides	Chemical asphyxiant inhibiting cytochrome oxidase
Hydrocarbons	Irritants (nearly all), CNS, liver, kidney, … Benzene and methylene chloride: cancer
PAHs	Carcinogenic (Benzo(a)pyrene), irritant
Free Radicals	Oxidative stress and DNA damage; Lung damage

Contaminant	8-hr (short-term) Limit ppm or mg/m^3	Reported Overhaul Exposures AIHAJ(16)636-641
Carbon monoxide	PEL: 50 (-) TLV: 25 (-) REL: 35 (200)	52.6 (260 max, N=65)
Particulates (PNOR)	PEL: 15 T / 5 R TLV: 10 I / 3 R REL: -	R: 0.71 – 25.7 mg/m^3 (26/93)
Aldehydes	HCHO- PEL: 0.75 (2) TLV: - (0.3) REL: 0.016 (0.1)	HCHO: 0.016 – 1.8 ppm (86/96) Acrolein: 0.013-0.3 ppm (7/96) C=0.1 Acetaldehyde: 0.041-1.75 (71/96)C=0.25
HCN	PEL: 10 (-) TLV: - (4.7) REL: - (4.7)	HCN: <0.94 ppm (4/25) Methylisothiocyanate: $\leq$ 2.1 ppm
Total Hydrocarbons	No limit for Total HC Need to know individual compounds C6H6 0.5 (2.5)	Benzene: 0.07-1.99 ppm (53/98)
PAHs – as CTPV (particles)	PEL: 0.2 (-) TLV: 0.2 (-) REL: 0.1 (-)	B(a)P = 18.7-50 ug/m^3 (5/88) TLV=L; CTPV= 0.2 mg/m^3
Free Radicals	none	

Contaminant	Monitoring Method(s)
Carbon monoxide	Direct-Reading: multiple brands, electrochemical reaction
Particulates	Direct-Reading: pDR (respirable), PTrak (ultrafine) Pump-Filter: respirable (Al cyclone); total (37-mm cassette), inhalable (button or stainless IOM)
Aldehydes	Direct-Reading: none with good reaction time **Passive:** many sorbent tubes; heat concerns Pump-Sorbent Tube: DNPH treated tube (EPA TO11)
HCN / Methyl Isothiocyanate	Pump-Sorbent Tube: NIOSH 6010 (soda lime tube) Pump-Sorbent Tube: OSHA 2 (silica gel tube; 24-hr hold time limit)
Total Hydrocarbons	Direct-Reading: PID (semi-quantitative) Pump-Sorbent Tube: multi-media tube (EPA T01/T02)
PAHs	Pump-Sorbent Tube: PTFE filter – Orbo tube (NIOSH 5506) → *thermal desorption to analyze*
Free Radicals	Pump-Filter: ESR on 37-mm PVC filter, cold storage and ship on dry ice

Pump-Filter for Particulates

Direct-Reading Particle

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Analyzing Multiple Exposures

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Multiple Exposures: Additive?

- When exposures have similar effects:

$$ExposureIndex = \sum \left(\frac{Conc_i}{Limit_i} \right)$$

- Recommended Irritant Index (Wildland Fires)

$$IrritantIndex = \left(\frac{HCHO}{0.3} \right) + \left(\frac{Acrolein}{0.1} \right) + \left(\frac{PM4}{3} \right)$$

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Contaminant	Effect
Carbon monoxide	*Initial*: Headache, dizziness, nausea, diminished work capacity; ***Advanced***: Vomiting, loss of consciousness, collapse, coma death *Interferes with bloods ability to transport oxygen: Maintain COHb below 5%*
Particulates	Irritant (PNOR); may depend on particle chemistry; *Size fraction* may be most important (ultrafine vs respirable vs "total" or "inhalable")
Aldehydes	**Irritants**; carcinogen (formaldehyde; low molecular weight compounds suspect)
HCN / cyanides	Chemical asphyxiant inhibiting cytochrome oxidase
Hydrocarbons	**Irritants** (nearly all), CNS, liver, kidney, … Benzene and methylene chloride: cancer
PAHs	Carcinogenic (Benzo(a)pyrene), **irritant**
Free Radicals	Oxidative stress and DNA damage; Lung damage

Multiple Exposures: Additive?

- For Overhaul Exposures
  - Irritant exposures include
    - Aldehydes (all; HCHO and Acrolein are most common)
    - CTPV (to account for all PAHs)
    - Respirable dust
    - Total hydrocarbons
  - Index with:
    HCHO… Acrolein … Benzene … CTPV … PM
    - Max Reported values
      6 + 3 + 0.8 + <0.17 + 8
      → 18 (which is much larger than "1")

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Exposure Correlations?

- Wildland Fires
  Acrolein = 9.48E-4(CO) + 4E-3
  Benzene = 1.01E-3(CO) + 6E-3
  HCHO = 7.99E-3(CO) + 6E-3
  Resp. Particulates = 0.114(CO) - 3E-2
  Reinhardt, Ottmar, Hanneman (2000), Smoke Exposure Among Firefighters in the Pacific Northwest, USDA-Forest Service, PNW-RP-526
- Overhaul Fires
  - CO does not predict other contaminants
    Bolstad-Johnson *et al.*, (2000) Characterization of Firefighter Exposures During Fire Overhaul, AIHAJ(61):636-641
    Current bench-top studies

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Research Needs

- SCBAs not consistently used during overhaul
- Currently investigating respirator cartridge breakthrough
  - P / POV / POVF evaluations in Wildland
    DeVos, *et al.* (2006): Effect of protective filters on fire fighter respiratory health during simulated bushfire exposure, AJ Ind Med 49:740-750
  - Current work: Scott 642, MSA FR-15
    Not sufficient in reducing HCHO
- *Monitoring methods*

NPPTL Respirator Tests

Phase 1: Method development

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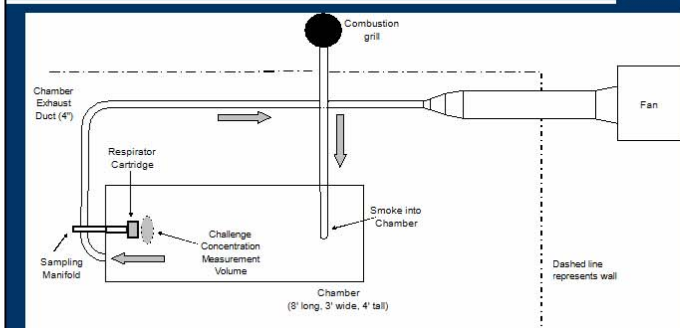
Experimental Set-Up



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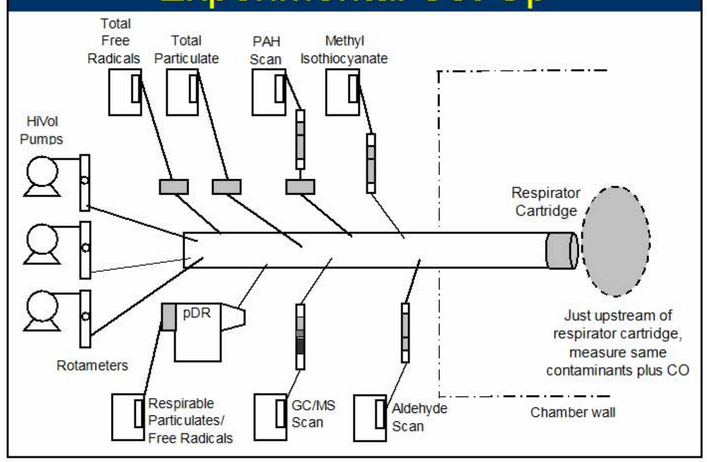
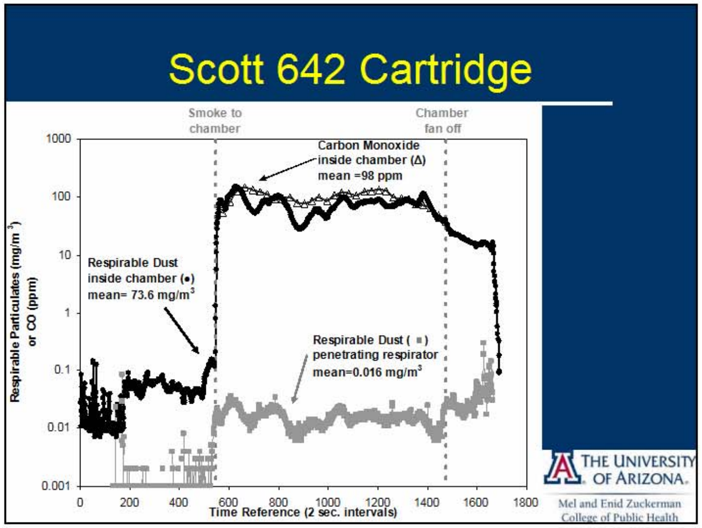
Experimental Set-Up




Scott 642 Cartridge
Smoke to chamber
Chamber fan off
Carbon Monoxide inside chamber (Δ) mean =98 ppm
Respirable Dust inside chamber (•) mean= 73.6 mg/m³
Respirable Dust (▪) penetrating respirator mean=0.016 mg/m³
Respirable Particulates (mg/m³) or CO (ppm)
Time Reference (2 sec. intervals)
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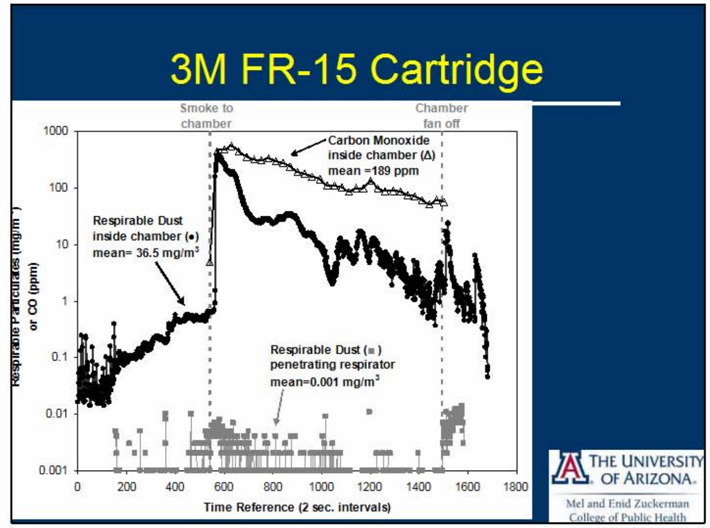
3M FR-15 Cartridge
Smoke to chamber
Chamber fan off
Carbon Monoxide inside chamber (Δ) mean =189 ppm
Respirable Dust inside chamber (•) mean= 36.5 mg/m³
Respirable Dust (▪) penetrating respirator mean=0.001 mg/m³
Time Reference (2 sec. intervals)
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APPENDIX 3.D – No Smoke, No Fire, No Hazard: A Firefighter's Perspective on the Hazards of Fire Overhaul and How to Protect Against Them

Dawn Bolstad-Johnson, City of Phoenix Fire Department

Firefighters know that the SCBA provides the best respiratory protection available in known or unknown hazardous environments. A high level of training attempts to endow the new recruit with an appreciation for the need for respiratory protection. OSHA mandated respirator training is given annually. The training does not instill permanent habits, however, and when the smoke disappears during overhaul the sense of danger disappears as well. The use of respiratory protection depends on the insistence of the commanding officer, and is highly variable within a fire department and from one fire department to another. Overhaul is an opportunity to discuss/review what transpired in fighting the fire, and the SCBA masks are often removed for better communication. Department-wide enforcement and education based on scientific evidence are needed to keep SCBAs on during overhaul. The fire service is comfortable with using four-gas meters, which monitor oxygen, hydrogen sulfide, carbon monoxide, and combustible gas, as a way to assess for flammable conditions or conditions of respiratory hazards.

No Smoke, No Fire, No Hazard:

A firefighter's perspective on the hazards of overhaul and how to protect against them.

Dawn Bolstad-Johnson, MPH, CIH
Industrial Hygienist
Phoenix Fire Department
May 3, 2007

Phoenix Fire Department

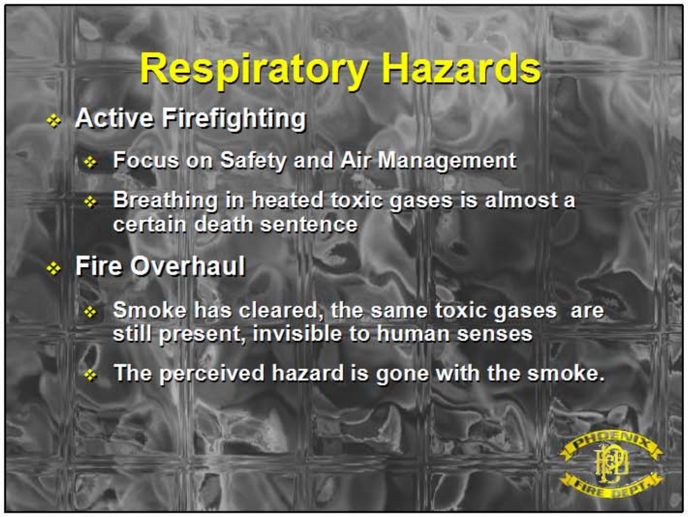
- 1600 Firefighters
- 54 Fire Stations
- 500 Pieces of Rolling Stock
- Response Area = 500 Square Miles.
- Respond to Over 280,000 Calls Per Year
- 28,000 Fire Related Calls
- We Are BUSY!!!

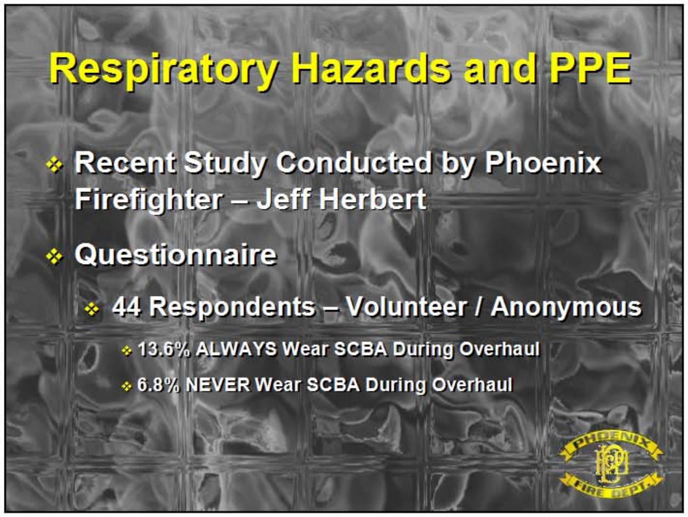
What Firefighters Know

- **SCBA provides the best respiratory protection available in known / unknown hazardous environments.**

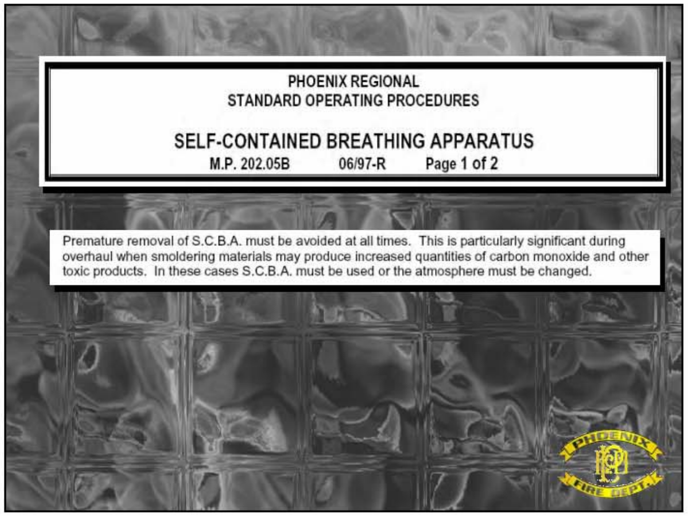
Protecting Firefighters

- Protecting Firefighters From Unknown Hazards
  - Begins at Day One
  - 12 Weeks in the Training Academy
  - 1 Probationary Year
  - After the probationary year the rigid training structure begins to unravel
  - The responsibility is placed on the company officer – Captain.


Respiratory Hazards
Active Firefighting
Focus on Safety and Air Management
Breathing in heated toxic gases is almost a certain death sentence
Fire Overhaul
Smoke has cleared, the same toxic gases are still present, invisible to human senses
The perceived hazard is gone with the smoke.


Respiratory Hazards and PPE
Recent Study Conducted by Phoenix Firefighter – Jeff Herbert
Questionnaire
44 Respondents – Volunteer / Anonymous
13.6% ALWAYS Wear SCBA During Overhaul
6.8% NEVER Wear SCBA During Overhaul


Training on Respiratory Threats
New Recruit Training
Review of the two overhaul studies previously mentioned
Annual OSHA mandated Respirator Training*
Company Training
Annual Respirator Fit Testing
PFN
Terrorism Drills
Company Drills
Safety Messages
Buckslip
Table topping
SOPs


PHOENIX REGIONAL
STANDARD OPERATING PROCEDURES
SELF-CONTAINED BREATHING APPARATUS
M.P. 202.05B 06/97-R Page 1 of 2
Premature removal of S.C.B.A. must be avoided at all times. This is particularly significant during overhaul when smoldering materials may produce increased quantities of carbon monoxide and other toxic products. In these cases S.C.B.A. must be used or the atmosphere must be changed.

Procedural Changes to Address Potential Overhaul Exposures

- Created Industrial Hygienist position.
- Company Officer Role has changed to more of a leadership position.
- Department wide re-enforcement of keeping SCBA on during overhaul.

Evidence Used to Justify Change

- Fire Overhaul Study – 1998 *Characterization of Fire Fighter Exposures to Fire Overhaul*
- Fire Overhaul Study – 1999 *Adverse Respiratory Effects Following Overhaul in Firefighters*
- Aftermath of 9/11
- Terrorism
- FEMA Team Observed Health Effects
  - Northridge, Oklahoma, 9/11, Katrina

Slow to Change

- Phoenix Fire Headed up the First Study on Characterizing Firefighter Exposures During Fire Overhaul Nearly 10 Years Ago.

Implementing Change

- **Change is on-going**
- **Generational factors both impede and assist Change.**
  - **Old Generation**
    - **Remembers when there was only one SCBA on a truck, in a box, and were told that "Real Firemen Don't Need SCBA" (1978-79)**
    - **1979-80 – SCBA's were provided to all members in Phoenix Fire**
    - **Remembers a time before OSHA and EPA existed.**

Implementing Change

- New Generation
  - Born After OSHA and EPA
  - More safety/environmentally conscious
  - Feels invincible—not going to happen to them
  - Comprise the majority of our department.
    - Recently hired 500 new recruits as 500 members retired.

Things Fire Departments Can Do NOW

- Talk About It – RECOGNIZE that there is a hazard
- Educate members
- Hire or consult with an Industrial Hygienist
- Overhaul Threats may not just be from the aftermath of a fire..i.e.. Katrina
- Ensure that Members have Annual Respirator Training and Fit Testing
- Implement a SOP for FF to Wear SCBA until they are out of the Hot Zone. The Hot Zone should include all aspects of Fire Overhaul.

Metering Challenges

- Historically, Firefighters have used CO meters to measure overhaul environments to determine when it is "Safe" to remove respiratory protection.
- CO is not the biggest hazard during overhaul.
- Meters that are typically used by fire were designed for mining industries or monitoring in confined spaces.

References

- Bolstad-Johnson DM, Burgess JL, Crutchfield CD, Storment SB, Gerkin RD. Characterization of firefighter exposures during fire overhaul. *AIHA J* 2000;61:636-641.
- Burgess JL, Nanson CJ, Bolstad-Johnson DM, Gerkin R, Hysong TA, Lantz RC, Sherrill DL, Crutchfield CD, Quan SF, Bernard AM, Witten ML. Adverse respiratory effects following overhaul in firefighters. *J Occup Environ Med* 2001;43:467-473.
- Herbert, Jeff. *Structure Fire Overhaul: Respiratory Hazards and Personal Protective Equipment* (Submitted for publication Fire Engineering 2007)
- Interview with Deputy Chief David Vera, Phoenix Fire Department – April 10, 2007

APPENDIX 3.E – Detecting Particulates in Real-Time: Optical Techniques

Da-Ren Chen, Washington University in St. Louis

Optical techniques for detecting particulates take advantage of the changes to an incident light beam caused by interaction with particles. Refraction, reflection and diffraction are the three types of elastic scattering mechanisms, which redirect the incident beam without changing its wavelength. Refraction is the bending of light within a particle; reflection redirects the light from the particle surface; and diffraction bends light external to the particle. Diffraction works best for large particles. Single particle detection requires the sensing volume to be small compared to the inverse of the particle number concentration. Detectors using this method count individual particles and may measure particle size distribution. Multiple particle detection works for larger sensing volumes. Photometers are simple, inexpensive, and robust but need to be carefully calibrated. For measurements of mass, the accuracy depends on the particulate size distribution.

Detecting Particulates in Real-Time: Optical Techniques

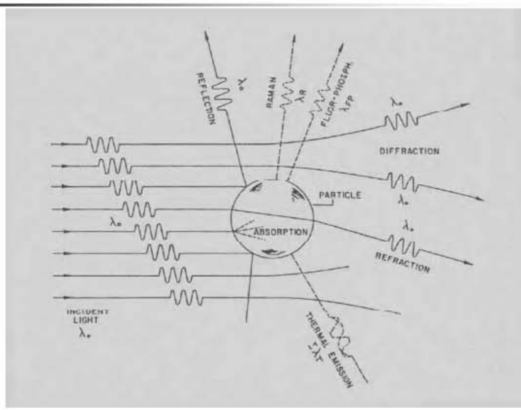
Da-Ren Chen, Associate Professor
Dept. of Energy, Environmental and Chemical Engineering,
Washington University in St. Louis,
St. Louis, MO 63130

Email: chen@seas.wustl.edu

Outline

- Light-particle interaction
- Single vs. multiple particle counting
- Laser particle counters
- Photometer and nephelometer
- Examples of instruments

Light-Particle Interaction



Elastic Scattering Mechanisms

- Definition: Redirection of incident beam without change of wavelength
- Components
  - Refraction
    - Internal to particle
    - Dependent on wavelength
    - Dependent on particle composition
  - Reflection (conductive/absorbing particles)
    - Surface of particle
    - Dependent on wavelength
    - Dependent on particle composition
  - Diffraction
    - External to particle
    - Independent of wavelength (from scattered intensity standpoint)
    - Independent of particle composition

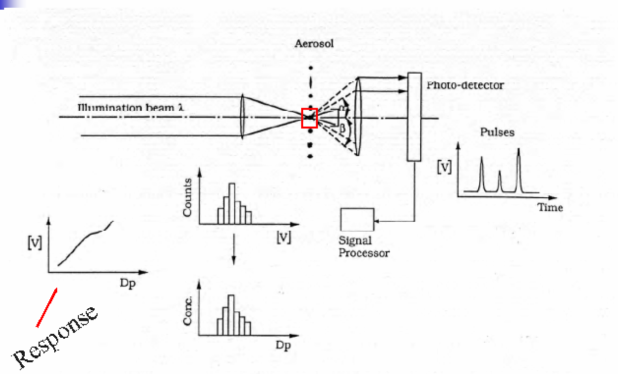
Single vs Multiple Particle Sensing

- Definition
  - Single particle detection when sensing volume V_s is small with respect to inverse of particle number concentration, N. ($V_s<0.1N^{-1}$)
  - Multiple particle detection when sensing volume Vs is equal or larger than inverse of particle number concentration, N. ($V_s>0.1N^{-1}$)
- Typical ranges of concentration
  - Single particle detection
    - $N<10^2$ #/cm^3 ; C<100 μg/m^3 (for 1 μm particles, ρ = 1.0 g/cm^3)
  - Multiple particle detection –scattering (nephelometry)
    - N> 1 #/cm^3 ; C>1-10 μg/m^3
  - Multiple particle detection – extinction (transmissometry)
    - Opacity > 1% (transmittance < 99%); C >3 mg/m^3

Single vs Multiple Particle Sensing (conti.)

- Properties
  - Single particle detection
    - Volume of sampled air must be known
    - Equivalent to counting events (precision depends on total count)
  - Multiple particle detection
    - Independent of volume of sampled air
    - Photometry (precision depends on averaging time)

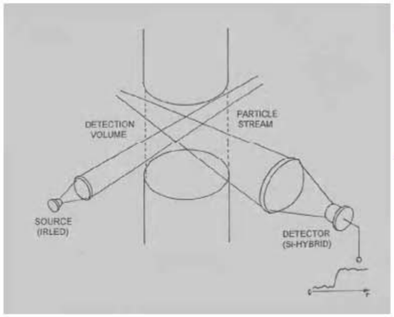
Optical/Laser Particle Counters



Pro and Con of Particle Counters

- Advantages:
  - Measuring particle size distribution
  - Counting individual particle counting– accurate number conc.
- Disadvantages:
  - Sizing depending on the particle size, refractive index and shape.
  - Low coincidence level for high aerosol sampling flowrate

Photometer and Nephelometer



- Total dust in workplaces are in the range of 0.1 to 100 mg/m^3
  - Photometers
- Typical aerosol mass concentration in the atmosphere cover the range from 10 to 200 μg/m^3
  - Nephelometers

Pro and Con of Photometers

- Advantages:
  - Simple in construction. Lower cost and robust
  - Good for relative conc. measurement if aerosols to be measured remains the same.
- Disadvantages:
  - Scattered light dominated by large particles (for the same number concentration)
  - In-accurate mass conc. measurement when applied to particles with the material different from that of calibration particles.
  - Size distribution of sampled particles inferred from the photometer reading

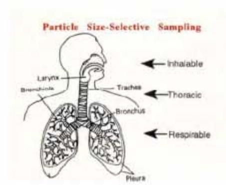
Met One Instruments, Inc.
Handheld Dust Monitors

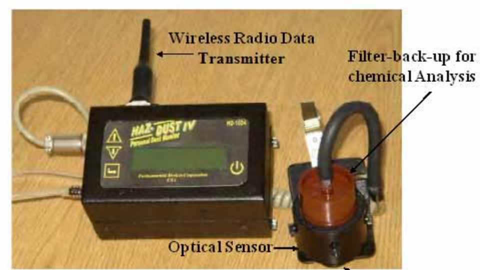
- **Aerocet Particle Counters**
  - Portable, battery-operated
  - Size-resolved particle information
  - Particle concentration range adaptable for application
  - Configurable for personal monitoring

- **Aerocet Nephelometers**
  - Portable, battery-operated
  - High concentration range: 0 to 100+ mg/m^3
  - User selectable calibration (K) factor
  - Configurable for personal monitoring

Met One Instruments, Inc.

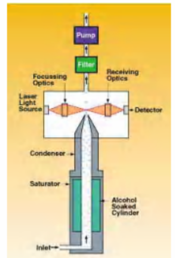
Environmental Devices Corporation
HAZ-DUST IV Real-Time Personal Particulate Monitor





- The particulate sensor design utilizes optical detection of 880nm infra-red light scattering to detect the presence of particulate concentrations in milligrams per cubic meter (mg/m^3)

TSI Inc.
P-Track Ultrafine Particle Counter



- Hand-held, portable, and battery powered
- Intuitive user interface
- Telescoping probe for stand-off monitoring
- Particle detection size range: 0.02 – 1 μm (20 – 1000 nm)
- Concentration range: 0 – 500,000 pt/cc
- What type of aerosols can be detected with a CPC?
  - Any aerosol within the detection size range
  - Examples include; combustion aerosols, incidental ultrafine aerosols, aerosols generated by chemical reactions, fumes, condensates, etc.

APPENDIX 3.F – What We Know About Particulates Resulting from Fires

George Mulholland, Building and Fire Research Laboratory, NIST

The smoke aerosol is described in more detail in this presentation. Particulates may be either solid particles or liquid droplets. Flaming results in large agglomerates of primary spheres that are roughly 30 nm in diameter, and smoldering results in liquid droplets about 2 µm in diameter. Information on smoke yield and particle size from various fuels is presented. Deposition in the lungs is a strong function of particle diameter. Non-flaming smoke scatters more than 90 % of light. Its composition is related to the fuel, and gases may adsorb to its surface. This raises the question of what materials would be appropriate for a standard smolder smoke.

What We know About Particulates Resulting from Fires

George W. Mulholland
University of Maryland
and NIST

Workshop on Real-Time Particulate Monitoring:
Respiratory Threats for First Responders
May 3, 2007

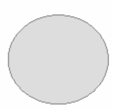
Overview of Non-flaming Smoke Aerosol Properties

- Terminology
- Demonstration of non-flaming smoke aerosol
- Production of smoke
- Light transmission through smoke
- Size and shape of smoke
- Size Distribution of smoke
- Smoke deposition in the respiratory system
- Chemistry of smoke

Terminology

- Smoke aerosol – the condensed phase component (solid and liquid) of the products of combustion. In this presentation the smoke aerosol will be simply referred to as smoke.
- Particulate matter – either solid particles or liquid droplets.

smolder smoke

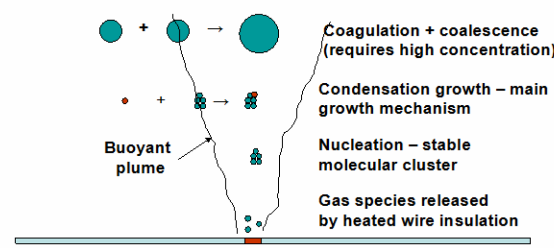


diameter = 2 µm

soot

primary sphere diameter = 30 nm

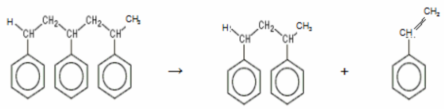
Mechanism of Smoke Formation and Growth



Insulated wire with a short resulting in a hot spot

Generation of Non-flaming Smoke

- Evaporation and condensation – candle wax
- Pyrolysis – fuel molecule undergoes reaction when heated.
  Example: pyrolysis of polystyrene



- Smolder – enough heat release via oxidation for the process to be self-propagating without external heat.
  Examples: newspaper, polyurethane foam cushion, pile of rubble with wood or paper.

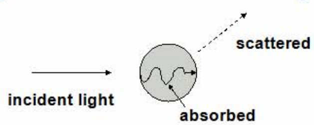
Smoke Yield

Smoke yield = mass of smoke produced per mass loss of fuel

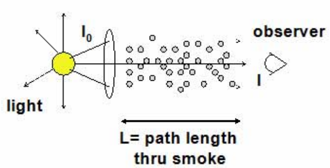
Fuel	Yield
Cellulose (paper)	0.06
Douglas fir – low flux - high flux	0.03 0.15
Polyurethane foam	0.15
PVC	0.12
Polypropylene	0.12

K.M. Butler and G.W. Mulholland, *Fire Tech.*, 40, 149-177(2004)

Light Transmission Through Smoke



For non-flaming smoke, more than 90 % of the light is scattered. For there to be significant scattering, $\pi D_m/\lambda > 1$.



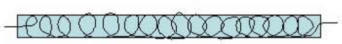
Transmitted Intensity

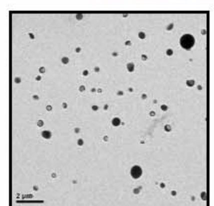
$I/I_0 = \exp(-\sigma m L)$

σ(avg) = 4.4 m^2/g for white light; Range from 2.5 m^2/g to 8 m^2/g.

TEM Images of Non-flaming Smoke

Cylinders of various materials were heated with a coiled tungsten wire. The voltage to the wire was controlled so each test was run at a fixed temperature.





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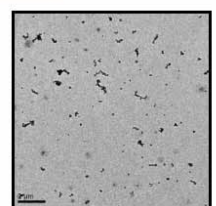
Lamp-wick smoke



B1-6-2-LLa

Kapton smoke

TEM photos by NASA Glenn Research Center

Size Distribution of Non-flaming Smoke: Lognormal Parameters

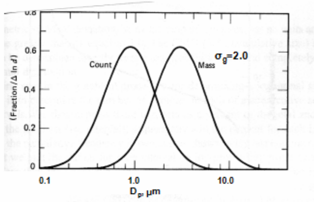
Fuel	D_{gm}, µm	σ_g
Cellulose	2-3	
Douglas Fir	0.8 – 1.8	1.9
PU foam	1.1 – 1.6	2.0
PVC	1.5	1.6
PP	2.1	1.8
Range	1 - 3	1.6-2.0

Geometric mass median diameter

$$\ln D_{gm} = \frac{\sum m_i \ln D_i}{m_t}$$

Geometric standard deviation

$$\ln \sigma_g = \left(\frac{\sum m_i (\ln D_i - \ln D_{gm})^2}{m_t} \right)^{1/2}$$

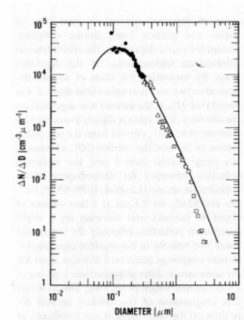


Count and mass distributions (logarithmic size scale).

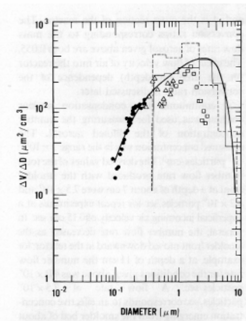
From *Aerosol Technology*, W. C. Hinds

Size Distribution of Cellulose Smoke

- Broad size distribution from < 0.09 µm to 5 µm
- Requires 2 instruments to obtain both number and volume dist.



Number distribution with optical particle counter (OPC)

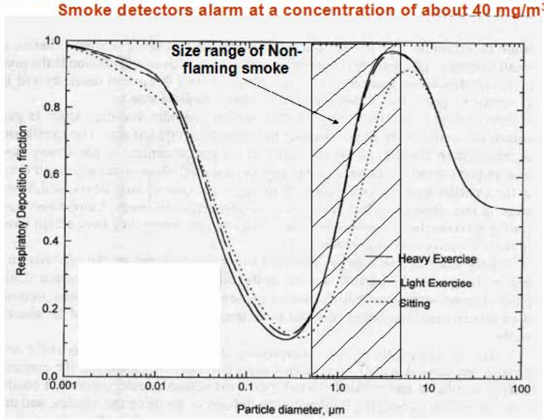


Volume distribution with OPC and 2 impactors (solid and dashed lines)

G.W.Mulholland and T.J. Ohlemiller, Aer. Sci. Tech., 1, 59 (1982).

Total Respiratory Deposition

Note: OSHA 8 hour exposure limit = 5 mg/m³ for nuisance particulate. Smoke detectors alarm at a concentration of about 40 mg/m³.

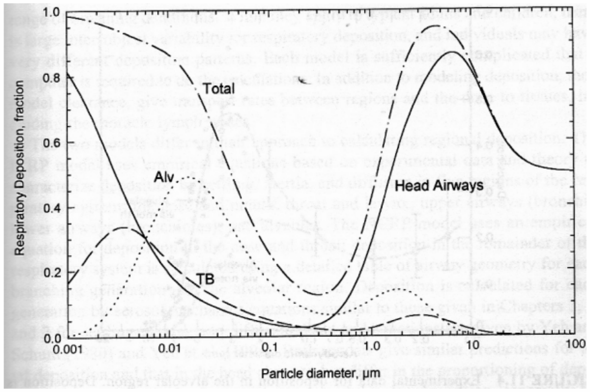


From *Aerosol Technology*, W. C. Hinds

Chemistry of Non-flaming Smoke Aerosol

- Related to fuel – each with its own set of pyrolysis products
- Possibility of adsorbed gases such as HCl from PVC
- Other materials could generate particulate from prolonged exposure to heat:
  a. metals such as lead and mercury
  b. Transformer fluids
  c. Asbestos from tiles and insulation
- Acute toxicity tests performed at NIST on a range of materials found in buildings for exposure to both particulate and gases; indication that particulate produced by pyrolyzing Teflon may be highly toxic.
- Key Question – What should be the exposure limit to non-flaming smoke aerosol?

Total and Regional Deposition for Light Exercise (nose breathing) based on ICRP Model



From *Aerosol Technology*, W. C. Hinds

Respiratory System

From *Aerosol Technology*, W. C. Hinds

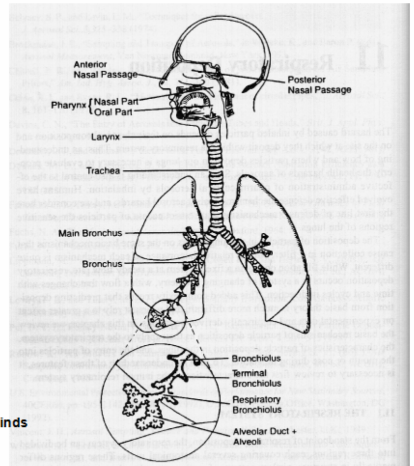
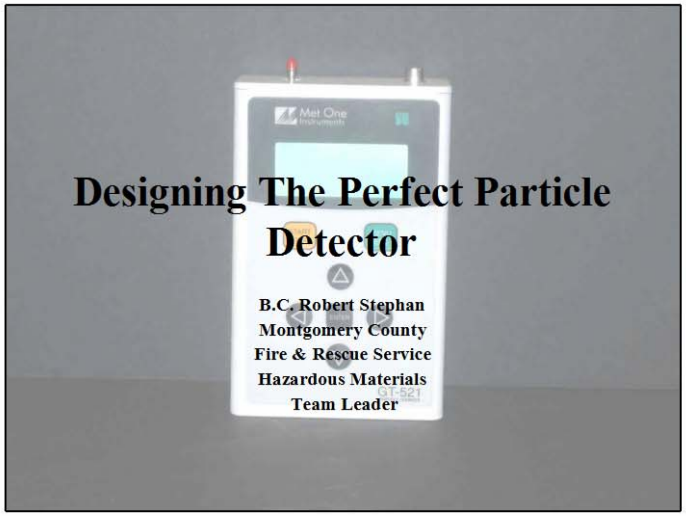


FIGURE 11.1 The respiratory system. Adapted from International Commission on Radiological Protection (1994).

APPENDIX 3.G – The Ideal Detector for the Fire Service

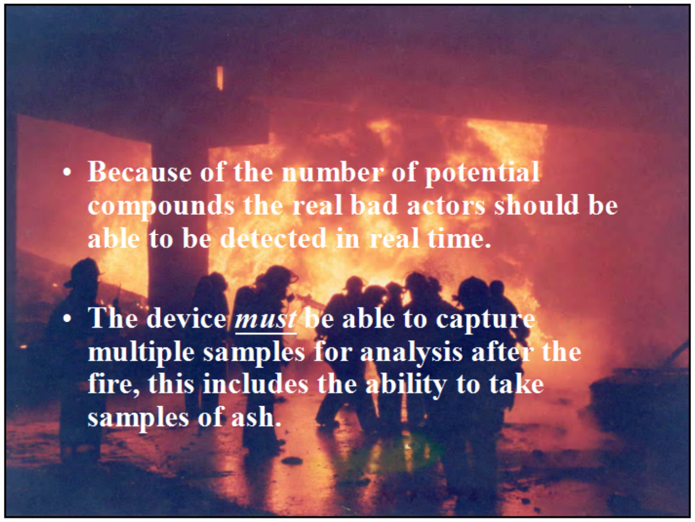
Robert Stephan, Montgomery County Maryland Fire and Rescue Service

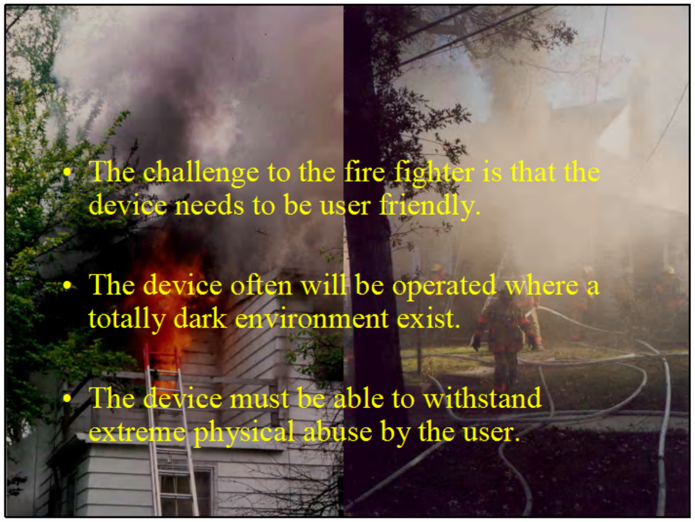
The fire environment is a highly hazardous environment that contains hundreds of unknown vapors and gases and particles of unknown size distribution and toxic composition. The ideal detector for the fire service must be functional in both high and low temperature extremes. It must be lightweight and durable, and must be operable by a user wearing heavy gloves and in the dark. It should not need frequent cleaning or be easily clogged. The detector must be able to function in the significant amounts of steam produced by firefighting. The most dangerous compounds should be detectable in real time. The device must capture multiple samples for analysis after the fire. Skin samples and nose swabs are alternative methods for getting more exposure data after firefighting. Particles can affect the respiratory tract, skin, eyes, and digestive system, although absorption of typical fire contaminants through the skin is not currently considered by the fire service.

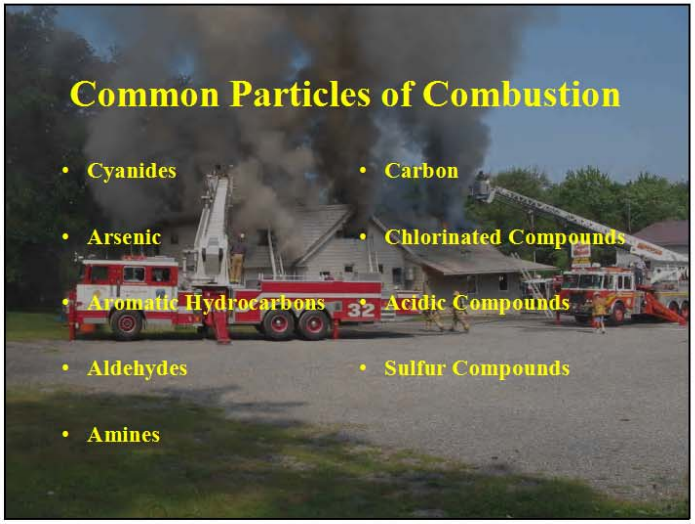


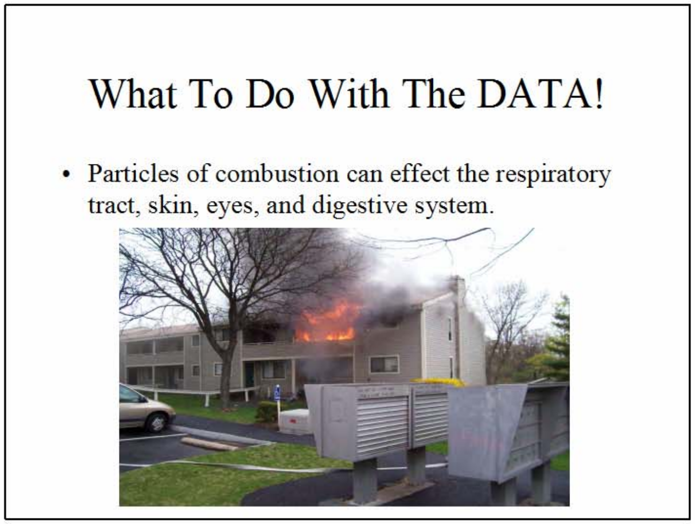
The Issues

- Sampling air inside of a fire environment presents a tremendously hazardous environment which is wrought with unknown dangers.
- Inside of a fire environment you will encounter hundreds of unknown vapors and gases in addition to particles made up of toxic compounds.


• Because of the number of potential compounds the real bad actors should be able to be detected in real time.
• The device must be able to capture multiple samples for analysis after the fire, this includes the ability to take samples of ash.


• The challenge to the fire fighter is that the device needs to be user friendly.
• The device often will be operated where a totally dark environment exist.
• The device must be able to withstand extreme physical abuse by the user.


Common Particles of Combustion
• Cyanides
• Arsenic
• Aromatic Hydrocarbons
• Aldehydes
• Amines
• Carbon
• Chlorinated Compounds
• Acidic Compounds
• Sulfur Compounds


What To Do With The DATA!
• Particles of combustion can effect the respiratory tract, skin, eyes, and digestive system.

- The synergistic affect of these suspended particles are much more dangerous than most of the elements and compound when they stand alone.

Summary

- An effectively designed particle detector is years away.
- Presently we should be drawing air samples during and after a fire to analyze and determine the most common toxic particles.

APPENDIX 3.H – NIST Fire Fighter Technology Program Overview

Nelson Bryner, Building and Fire Research Laboratory, NIST

The Advanced Fire Service Technologies (AFST) Program objectives are to

- Provide the science and performance metrics for development and implementation of new technology,
- Enable an information-rich environment, firefighter training tools, and application of innovative new technologies,
- Improve effectiveness and safety of first responders, and
- Support Fire Loss Reduction Goal and facilitate the development and transfer of BFRL research to the fire service.

Funding is prioritized to improve equipment where no current metrics or standards exist and to improve existing metrics and standards, to integrate emerging technology with the biggest impact, and to transfer technology to the fire service through firefighting simulators and training programs. Projects in this program include the characterization of firefighter respirators using computer modeling and experiments, hose stream effectiveness, standards for thermal imaging cameras, PASS device audibility, structural collapse prediction, emergency responder and occupant locator technology, and tactical decision aids, among many others.

Workshop on Real-Time Particulate Monitoring: Respiratory Threats for First Responders 2007

Advanced Fire Service Technologies Program

Francine Amon, Rodney Bryant, **Nelson Bryner**, Kathy Butler, Joannie Chin, William Davis, Glenn Forney, Jeff Gilman, Anthony Hamins, Steve Kerber, Randy Lawson, Jack Lee, Alan Lytle, Dan Madrzykowski, Jay McElroy, Roy McLane, Nader Moayeri, Mike Molloy, Marc Nyden, Mike Selepak, David Stroup, and Robert Vettori

May 3 - 4, 2007

Gaithersburg, MD

NIST National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Overview

- Introduction
  - Technology without Standards
- AFST Program
  - Objectives
  - Approach
- Projects
- Summary

Why Invest in Advanced Fire Service Technologies ?

- Firefighter Fatalities –
  - 117 in 2004 (USFA)
- Total Injuries –
  - 80,800 in 2004 (NFPA)
  - Fireground – 37,976 injuries

- Magnitude of U.S. Annual Losses ~ $200 billion total cost

Issues- Technology without Standards

- Existing & new technology is being used without adequate metrics or standards to evaluate the performance
- Fire service is learning to exploit
  - existing technologies
    - thermal imaging, positive pressure ventilation
    - performance evaluated in a scientifically sound method
    - technology transferred to the fire service through training programs and fire fighting simulators.
  - developing technologies
    - tactical decision aids, training simulators, improved protective clothing, and real-time particulate monitors.
    - look ahead to developing innovative technologies and how new technologies can be effectively integrated into existing equipment

AFST Program Objectives

- Provide the science and performance metrics for development and implementation of new technology
- Enable an information rich information environment, fire fighter training tools, and application of innovative new technologies.
- Improve effectiveness and safety of first responders
- Support *Fire Loss Reduction Goal*,
  - facilitate the development & transfer of BFRL research
    - science, metrics, and technology
    - fire fighters, incident commanders, and other first responders.

AFST Program Approach

- Funding does not allow development of performance metrics and testing protocols for all emergency responder equipment
- FY07 funds are prioritized
  - equipment where there are currently no metrics or standards and/or at improving existing metrics and standards **50%**
    - thermal imagers
    - hose streams/nozzles
    - respirators
  - emerging technology with biggest impact is integrated first
    - National Fire Research Agenda Symposium - 50 organizations, including the fire service, IAFC, IAFF, and NVFC, manufacturers, DHS, & USFA
    - fire responder locators
    - tactical decision aids **40%**
    - respirator performance
    - improved protective clothing
  - fire fighting simulators and training programs to insure that the above science and technology to transfer to the fire service **10%**

AFST Program Projects

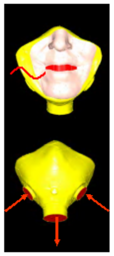
Project	PI
• Thermal Imager Technology	Amon / Bryner
• Characterization of Fire Fighter Respirators	Butler / Bryant
• Fire Fighter Protective Clothing	Gilman / Chin
• Hose Stream Effectiveness	Stroup / Amon
• Research on Hydrogen and Alternate Fuel Hazards to First Responders	Kerber / Bryner
• Monitoring and Metrology Technology for Field Scale Validation Experiments	Stroup / Kerber
• Emergency Responder and Occupant Locator Technology	Bryner / Davis Lytle / Moayeri
• Tactical Decision Aids	Bryner / Davis
• Virtual Fire Fighter Trainer	Forney

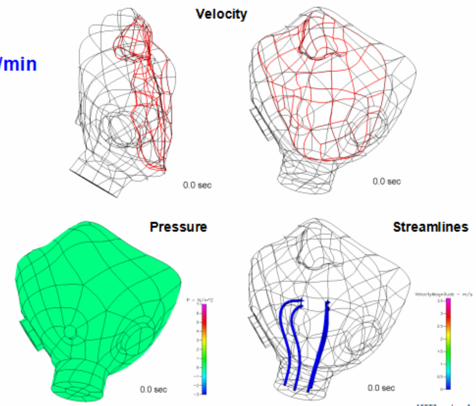
Characterization of Fire Fighter Respirators

- SCBA, Closed-Circuit SCBA, PAPR
- Standards do exist, but based on USAF data from 1960s
- Using computational fluid dynamic models to characterize flow in, out, and around respirator face pieces
- Use laser-based scanner to input
  - Head geometry
  - Respirator geometry

Gas Flow for Breathing Under Work Load

V_T = 1 L
f = 30 breaths/min





Hose Stream Effectiveness

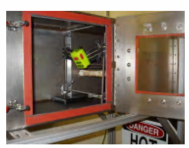
- Effectiveness for Suppressing real fires
  - never been characterized
  - performance metrics not developed
  - no testing standards exist
- Types of hose streams
  - straight stream
  - Fog
- Full-scale experiments
  - in the open and in enclosures
  - flow rate, reach, and pattern

Thermal Exposure Standards for First Responder Devices

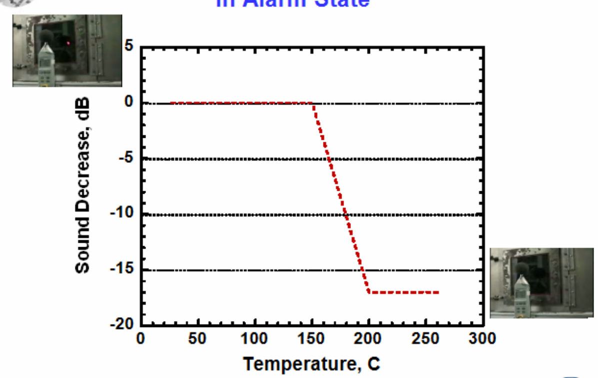
Davis, Donnelly, Selepak, & Lawson

Firefighter Equipment Evaluator (FEE)

- Survey exposure limits for electronic equipment used by firefighters.
- Define exposure conditions encountered by first responders.
- Test a number of devices for degradation of performance based on thermal and humidity criteria.
- Expose radios, gas analyzers, PASS equipment to realistic conditions



Audible Signal from PASS in Alarm State

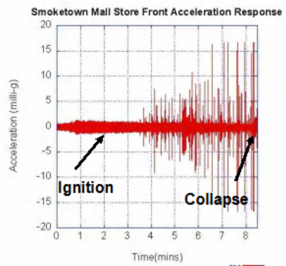


Structural Collapse Prediction

Stroup, Bryner, Madrzykowski

•Provide adequate warning to fire fighters of impending collapse
•Portable, quick, and easy to install

•Evaluated thermal imagers/cameras - unsuccessful
•Examined laser mappers - unsuccessful

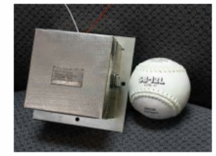


Duron - Harvey Mudd College
•Adapt acoustic sensors for detecting leaks in hydroelectric dams

Field tested prototype
•Single family home
•Industrial warehouse
•Strip shopping mall

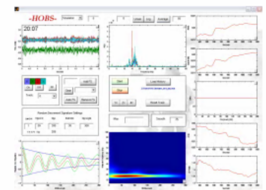
Structural Collapse Prediction

Health of Burning Structures (HOBS)



- A real-time acquisition and analysis capability
- The HOBS Panel provides real-time capabilities for
  - Multiple sensor data acquisition and storage
  - Signal processing
  - Collapse Index Analyses and Parameter adjustments
  - Fire-induced vibration and collapse index monitoring

- HOBS Indicators include
  - Root Mean Squared (RMS)
  - Power Spectral Density (PSD)
  - Frequency Bandwidth (FreqBand)
  - Shock Response Spectrum (SRS)
  - Random Decrement (RD)
  - Damping
  - Intensity



Emergency Responder and Occupant Locator Technology

- Fire fighter / occupant locator systems track first responders and occupants inside structures
- Technology must meet the performance needs
  - First responders
    - Rescue
    - Tactical
  - Public / building occupants No Performance Standards or Testing Protocols
- Technology must operate
  - Different building types
  - Different thermal conditions
- Develop Standards & testing protocols
  - Insure technology consistently performs as needed
  - Technology neutral and unbiased standards/protocols

Emergency Responder and Occupant Locator Technology

- *Precision Indoor Personnel Location and Tracking for Emergency Responders Workshop, August 2006*

WPI

Location Resolution under "severe" conditions = 3 foot

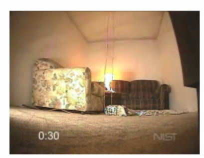
Fire Fighter "severe" conditions

Locating & Tracking - where or what building type ?

- Type I or Fire-Resistive (NFPA)
  - High rise office, shopping centers, or residential units
  - Reinforced concrete, structural steel (protected)
- Type II or Noncombustible
  - Office buildings, warehouses, auto repair shops
  - Metal frame with metal walls, metal frame with masonry walls, masonry walls with metal roof
- Type III or Ordinary
  - Office buildings, retail stores, mixed occupancy, apartment buildings
  - Noncombustible bearing walls and combustible roofs
  - Most buildings are of this type
- Type IV or Heavy Timber
  - Exterior noncombustible or limited combustible, masonry
  - Interior structural members, walls, columns, floors and roofs are large timbers
  - Common in the New England area
- Type V or Wood Frame
  - Single family dwelling, restaurants, retail stores
  - Log, post & beam, balloon, platform, and plank & beam
  - Structural members are wood and exterior walls are combustible

Under what conditions ?

Thermal Class	Maximum Time (min)	Maximum Temperature	Maximum Flux (kW/m^2)
I	25	100 C / 212 F	1
II	15	160 C / 320 F	2
III	5	260 C / 500 F	10
IV	<1	>260 C / 500 F	>10



Location & Tracking – Resolution

Residential Scenario

Resolution meters	Location		Escape	
	X-Y Direction	Z Direction	X-Y Direction	Z Direction
100	City Block +/-	10 floors +/-		
10	Front or rear of house	3 floors +/-	Structure +/- (Townhouse)	Floor +/-
1	Room	Floor +/-	Correct Wall	Window or Door
0.1	Location in Room	Correct Floor	Location on wall	Height of window or door

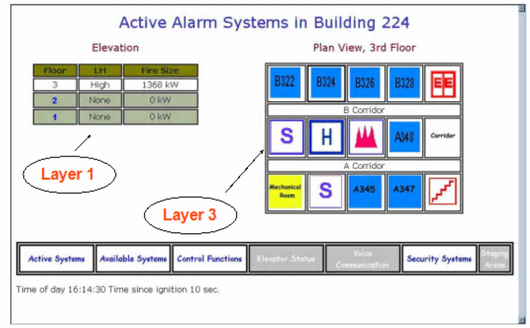
Location and Tracking Performance Standards

- Roles of NIST
  - Fundamental Science
    - Measurement or metrology (working with DHS)
    - Signal penetration (working with DHS)
    - Sensor design
    - Combustion Science
  - Building performance
  - Fire Environment
  - Performance Standards and Testing Protocols
    - Signal quality (working with DHS)
    - Sensor interfaces/performance (working with DHS)
    - Thermal exposure testing (working with DHS)
    - Network design (working with DHS)
  - Develop new technology where expertise exists

Tactical Decision Aids

- Provide fire fighters with tactical information
  - before arrival - more informed first responders
  - better and safer response to emergencies in buildings
- Information Rich Environment
  - Building sensors – data available at fire panel
  - Wireless transfer of floor plans and alarms on apparatus display
- Standards
  - What is being measured
  - How reported to fire panel – fire fighter
    - NFAC Task Group: 2002 NFPA 72 Annex Graphics Annunciator Panel Standard with Icons adopted
- Training tools
  - How to deploy search and suppression teams

Tactical Decision Aids



Display standard was published as NEMA SB30-2005 to provide standardization of displays for emergency personnel. This display standard was to be included in NFPA 72 at the June 2006 meeting

Tactical Decision Aids

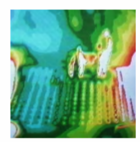
Commercial Implementation (Siemens Fire Finder)

Available Systems

Active Systems

Evaluating the Performance of Thermal Imagers and Infrared Cameras

Bryner, Amon, Hamins



- Fire service use thermal imagers and infrared cameras
  - Locate "hot spots"
  - Track spread of fire
  - Locate downed occupants and fallen fire fighters
- Currently there is no performance standard for thermal imagers or infrared cameras

Workshop Objectives

• create a research agenda and a roadmap for continued development of thermal imaging technology.

• What are the prioritized research needs for thermal imaging for first responders?
  Develop new technology?
  Use standards to develop existing technology

• What performance metrics are needed? How do they differ from current methods?
  Performance Standards?

• What standards are needed?
  Reliability Display
  Resolution Icons
  Training Batteries

• What technological advances are needed?
  New fuel cell instead of batteries

NIST Workshop on Thermal Imaging Research Needs for First Responders (12/10/04)

Standards – Performance & Testing

- A standard will be developed
  - Science based
  - Ad-hoc ....arbitrary?

- Science based standard –

  Capture, identify, address underlying issues

  Product Neutral

  Fosters the development of better equipment
    improvement of currently available
    new technology & materials

NIST Workshop on Thermal Imaging Research Needs for First Responders (12/10/04)

Evaluating the Performance of Thermal Imagers and Infrared Cameras

Bryner, Amon, Hamins

•Fire service use thermal imagers and infrared cameras
  •Locate "hot spots"
  •Track spread of fire
  •Locate downed occupants and fallen fire fighters

•Currently there is no performance standard for thermal imagers or infrared cameras

•Evaluate performance of thermal imagers and infrared cameras
  •Lab-scale experiments
  •Full-scale field tests

•Develop standard test protocol for evaluating critical performance characteristics

Identify Needs

– Fundamental science provides the foundation
  • Is the research really reaching the fire service?
    – Results in archival journals (little help to fire service)

– Need to make sure research is helping fire fighters
  • Fire service needs must be identified
  • Fire service must provide feedback

– Scientists and fire fighters need to work together

Identify and Prioritize Needs

– National Fallen Firefighters Foundation and NIST funded a National Fire Service Research Agenda Symposium - June 2005

– Workshop –
  - Priorities for performance
  - Priorities for research
  - Exposure to new tools and methods to improve safety
  - Opportunities to expand the applications of available technology
  - Sharing of ideas and future collaborations

– Potential funding sponsors can use this prioritized list in funding decisions.

Related Projects

- **Grants**

– **Structural Collapse**	Harvey Mudd
– **Fire Fighter Interface**	U Texas San Antonio
– **Positive Pressure Ventilation**	U Texas Austin

- **Other Agency Funding**

– **PASS Devices**	**USFA**
– **IR Camera Standards**	**USFA**
– **Burn Pattern Analysis**	**OLES & DHS**
– **Passive Cooling Systems**	**DHS**
– **RFID Performance Standards**	**DHS**
– **RF Linked PASS Devices**	**DHS**
– **Technology Transfer**	**USFA**
– **Structural Collapse**	**OLES**
– **Locator/Tracker**	**ATP**

Summary

AFST Program

– **Gets BFRL research directly into hands of**
  - Fire service
  - Fire protection engineers
  - Fire equipment manufacturers

– **Critical role in providing science-based**
  - Performance metrics
  - Standard testing protocols

– **Plays a leadership role**
  - Technology and standards for transfer of emergency information from buildings to fire service

– **Improve the safety and effectiveness of fire fighters**
  - Reduction of fire related fatalities and injuries
  - Both fire fighters and building occupants

Fire Research Division - 2007

Fire Fighting Technology Group
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301-975-6868
dan.madrzykowski@nist.gov
301-975-6677

Fire Metrology Group
jiann.yang@nist.gov
301-975-6662

Analysis & Prediction Group
anthony.hamin@nist.gov
301-975-6598

Integrated Performance Group
thomas.cleary@nist.gov
301-975-6858

Materials and Products
jeffrey.gilman@nist.gov
301-975-6573

Fire Fighting Technology Group - 2007

Project Leaders -

Dan Madrzykowski- (daniel.madrzykowski@nist.gov)
- Fire Fighter Safety Simulation
- Recreation of Fire Patterns
- Sim. Fire Burn Patterns w/Computer Models
- NFA Training Program
- Heat Transfer Model

Nelson Bryner (nelson.bryner@nist.gov)
- Equipment Standards for First Responders
- Fire Safety and Preparedness
- Fire Fighter Locator
- IR Camera Performance
- Structural Collapse Prediction
- Advanced PASS Devices

Fire Fighting Technology Group - 2007

Project Leaders -

David Stroup – (david.stroup@nist.gov)
- Structural Collapse Prediction
- Fire Performance of Building Design
- Hose Stream Effectiveness
- Method of Fire Resistance Determination

Robert Vettori – (robert.vettori@nist.gov)
- Heat Transfer Model
- Sprinkler Activation under Sloped Ceiling
- WTC Investigation

Francine Amon – (francine.amon@nist.gov)
- Thermal Imagers
- Thermal Imager Performance

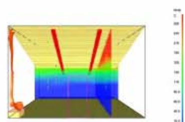
Fire Fighting Technology Group - 2007

Project Leaders -

Doug Walton – (william.walton@nist.gov)
- In-Situ Burning of Oil Spills
- Fire Reconstruction/Recreation

Randy Lawson –(james.lawson@nist.gov)
- Fire Service Technologies and Guidelines
- Firefighter Protective Clothing
- Fire Codes & Standards
- Heat Transfer Model

Stephen Kerber – (stephen.kerber@nist.gov)
- Positive Pressure Ventilation
- RI Fire Investigation



Contact Fire at NIST ?

Website - http://fire.nist.gov

FireDOC - on web

Gaithersburg, MD
Paul Reneke 301-975-6696

Fire Data - pubs/web
Models - pubs/web
Videos - call or e-mail

nelson.bryner@nist.gov
301-975-6868

dan.madrzykowski@nist.gov
301-975-6677

NIST At A Glance

"Nation's Oldest Federal Physical Sciences Laboratory"

National Bureau of Standards (1901 – 1988)

National Institute of Standards and Technology (1988 – present)

- 2,800 employees
- 1,800 guest researchers
- 1,500 field agents
- 850 users of facilities
- NIST Laboratories

- Advanced Technology Program
- Hollings Manufacturing Extension Partnership Program
- Baldrige National Quality Program

Boulder Colorado

Gaithersburg Maryland

Where We are in NIST

- Advanced Technology Program
- Manufacturing Extension Partnership
- Malcolm Baldridge National Quality Award
- Measurement & Standards Laboratories
  - Information Technology
  - Manufacturing Engineering
  - Building & Fire Research Lab
    - Materials & Construction Division 861
    - Building Environment Division 863
    - Fire Research Division 866
  - Chemical Science & Technology
  - Electronics & Electrical Engrg.
  - Material Science & Engrg.
  - Physics

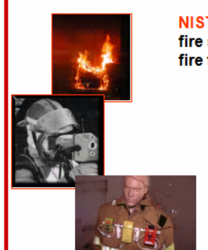
Fire Research at NIST

- Building and Fire Research Lab
  - created by Fire Act of 1974
- Budget - $44 M
  - STRS (Congress) - $27 M ($9 M)
  - Outside - $17 M ($6 M)

- 160 staff (57 Fire)
- Large Fire Facility

NIST Fire Research Mission

To conduct basic and applied fire research for the purposes of understanding fundamental fire behavior and to reduce losses from fire. *[Federal Fire Prevention and Control Act of 1974]*



NIST Fire Loss Reduction Program - to enable engineered fire safety for people, products, and facilities; and enhance fire fighter effectiveness.

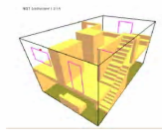
- Advanced Measurement & Predictive Methods
- Reduced Risk of Fire Spread
- Safety of Threaten Buildings
- Advanced Fire Service Technology

Fire Loss Reduction

I. Advanced Measurements and Predictive Methods

Current Projects

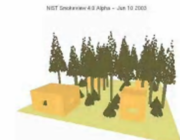
- CFAST, FDS/Smokeview Research and Development
- Smokeview and Computer Visualization
- Underventilated Comp. Fire Measurements
- HRR Uncertainty in Large Scale Fire Meas.
- Gas Velocity Measurements
- Large Fire Laboratory Operations
- Validation of Bench Scale Smoke Toxicity
- Experimental Data for Sub-Grid Fire Growth



Fire Loss Reduction

II. Reduced Risk of Fire Spread

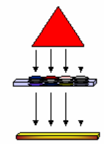
Current Projects



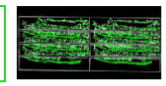
Site Specific Fire Model: quantitative planning & training tool

- Sprinkler Decision Tool for Communities
- Fire Suppression Test Method Development
- Community Fire Spread
- Fire Growth and Spread on Real Objects
- Mass Pyrolysis and Degradation of Flam. Objects
- Fault-Free Detection Test Methods and Standards
- Nanoadditive Flame Retardants for PU Foam
- Modeling Melt Flow Using Particle Methods
- Fire Retarded Polyurethane Foam Flammability

Home smoke alarm evaluation



High throughput screening methods for fire retarded nano-composites



Fire Loss Reduction

III. Safety of Threatened Buildings

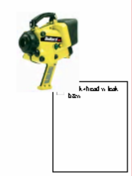
Current Projects

- Standard Test Methods for Eval. Fire Resistance of Structural Steel
- Prevention of Progressive Structural Collapse
- Fire Resistance Design and Rehabilitation of Struct.
- Complex System Failure Analysis
- Building Information for Emergency Responders
- Occupant Behavior and Egress
- Experimental Investigation of the Performance of Structural Comp. Exposed to Real Fires
- Emergency Use of Elevators and Firefighter Lifts
- Implement WTC Recommendations

Fire Loss Reduction

IV. Advanced Fire Service Technologies

Current Projects



- Computer Modeling of Respirators
- Thermal Exposure Standards for First Responder Devices
- Thermal Imaging Technology
- Emergency Responder and Occupant Locator Tech.
- Hose Stream Effectiveness
- Fire Safety and Preparedness
- Field Validation Experiments
- Fire Fighter Protective Clothing – advanced materials
- Tactical Decision Aids for First Responders
- Fire Fighter Protective Clothing – Heat Transfer Model
- Virtual Fire Fighter Trainer

Fire Division Synergism

Location & Tracking - Resolution

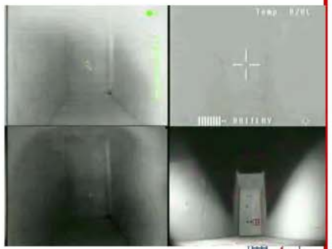
Industrial Scenario -

Resolution meters	Location		Escape	
	X-Y Direction	Z Direction	X-Y Direction	Z Direction
100	Building +/-	10 floors +/-		
10	Section of Bldg	3 floors +/-	Section of Bldg	Floor +/-
1	Room	Floor +/-	Correct Wall	Window or Door
0.1	Location in Room	Correct Floor	Location on wall	Height of window or door

Thermal Imager Technology

- •Fire service use thermal imagers and infrared cameras
  - •Locate "hot spots" or track spread of fire
  - •Locate downed occupants and fallen fire fighters
- •Currently there is no performance standard for thermal imagers or infrared cameras

- •Evaluate performance of thermal imagers and infrared cameras
  - •Lab-scale experiments
  - •Full-scale field tests
- •Develop standard test protocol for evaluating critical performance characteristics
- •Draft Standard submitted to NFPA ESE Committee



APPENDIX 3.I – DHS Standards Development Program Overview
Philip Mattson, Office of Law Enforcement Standards, NIST

The DHS Standards Development Program identifies and adopts standards and creates mechanisms to accelerate standards development. Although DHS does not have the statutory authority to issue or enforce standards, with a few legacy exceptions, it does promote the development of voluntary consensus standards. For the public safety community, the interaction with DHS is through the Office of Law Enforcement Standards (OLES). The Interagency Board for Equipment Standardization and Interoperability (IAB) has developed a Standardized Equipment List (SEL) containing items essential for responding to Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) incidents. The objective is to provide manufacturers with guidance in meeting performance requirements. The program concentrates on the tools needed to protect people and to identify the hazard. Fire departments can purchase whatever they want with their own funds, but to use DHS funding, equipment must conform to approved standards. The Standards Development Process involves the following steps in a continuous loop:

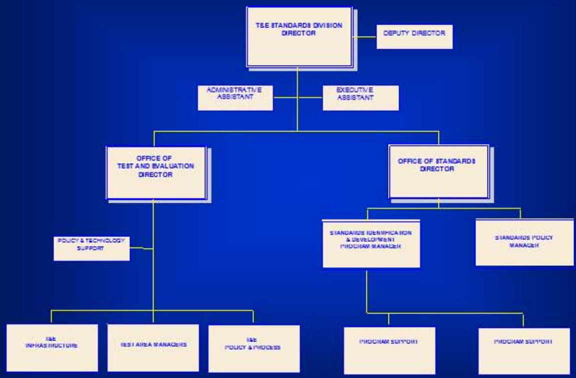
- Solicit user guidance
- Analyze the hazard and identify operational factors (Requirements Development)
- Identify existing standards, establish performance levels, and draft new standard and test methods (Standards Development & Research)
- Review & validate standard and test methods (Test Method Validation)
- Issue and adopt the standard
- Develop assessment model and conduct conformity testing (Conformity Assessment Program)

DHS Standards Development Program Overview

Workshop on Real-time Particulate Monitoring
NIST
May 3, 2007

Office of Law Enforcement Standards
National Institute of Standards and Technology

Division of T&E / Standards



DHS T&E/Standards Goals

Consistent with the Homeland Security Act of 2002 and HSPD 8

- **Develop and institute T&E policy that is centrally managed and is uniformly implemented across DHS.**
- **Integrate, coordinate, and optimize public and private sector T&E infrastructure to meet current and future technology development thrusts areas.**
- **Establish and implement streamlined procedures and infrastructures for the ongoing development and adoption of appropriate standards and evaluation methods for homeland security technologies.**
- **Develop and implement an overarching strategy for the qualification and certification of technologies and accreditation of facilities and programs.**

DHS Standards

- DHS lacks statutory authority to *issue standards* except in limited legacy programs such as
  – US Coast Guard marine safety equipment
- Public Law 104-113 (1995) - Directs that agencies will use voluntary consensus standards
  - ❑ DHS Office of Standards leverages the expertise and resources of NIST and other agencies to develop voluntary consensus standards
    – Private Sector Standards Development (ANSI)
    – Interagency Standards Coordination (ICSP)
    – Intra-agency Standards Coordination (DHS Standards Council)

DHS Office of Standards Scope

What we do…

- Lead the adoption of national Standards for homeland security technologies
- Support DHS G&T development of procurement guidelines for first responder technologies
- Develop and manage polices, procedures and infrastructure for Standards development and adoption activities
- Create and manage programs to accelerate and foster standards development activities

What we don't do….

- Promulgate standards
- Regulate compliance

Office of Law Enforcement Standards

- Weapons and Protective Systems
- Public Safety and Security Technologies
- Detection, Inspection and Enforcement Technologies
- Forensic Sciences
- Public Safety Communications Standards
- Critical Incident Technologies


The Interagency Board for Equipment Standardization and Interoperability (IAB)
Standardized Equipment List (SEL)
Items essential for responding to CBRNE incidents
"Out of Many, One"
IAB
InterOperability Board for the Interagency Local, State, and Federal Standardization


"Most commodity SubGroups have realized that equipment that falls in the individual equipment categories will not provide suitable levels of field performance."
1999 IAB Annual Report
"It is critical that compatibility issues of equipment are addressed now, through nationally recognized standards, before the advent of multi-agency, multi-jurisdictional WMD incidents."
1999 IAB Annual Report
"Out of Many, One"
IAB


SEL
Objective Evaluations
Independent Performance Testing
Performance Standards


TEAM FORMED TO TACKLE TOP PRIORITY:
NIJ
NATIONAL INSTITUTE OF JUSTICE
NFPA
INTERNATIONAL
ODP
Office for Domestic Preparedness
FBI
OSHA
TSWG
NIOSH
SBCCOM
STANDARDS FOR CBRN RESPIRATORY DEVICES

Technical Challenges

- Insufficient knowledge about threats and exposure limits
- Existing military equipment not suited for First Responder mission
- Existing commercial equipment untested against WMD
- Existing military equipment untested against Toxic Industrial Chemicals
- Urgency

CBRNE Protective and Operational Equipment Standards Development Program Goals

- Program began in 1999 with initial funding provided by National Institute of Justice (NIJ)
- Enhance public safety by promulgating standards for CBRNE protective equipment that ensure minimum performance, quality, reliability and interoperability;
- Disseminate standards and subsequent performance evaluations to the public safety community to help them make informed equipment purchases and to guide manufacturers, developers, and the test and evaluation community to ensure product compliance; and
- Link equipment certification and compliance with minimum performance standards to Federal equipment grants programs.

CBRNE Protective and Operational Equipment Standards Development Program

Respiratory Protection Equipment

Operational Equipment

Protective Equipment

Decontamination

Detection Equipment

Compendia

Communications Equipment interfaces

PPE Projects

Standards PPE Projects

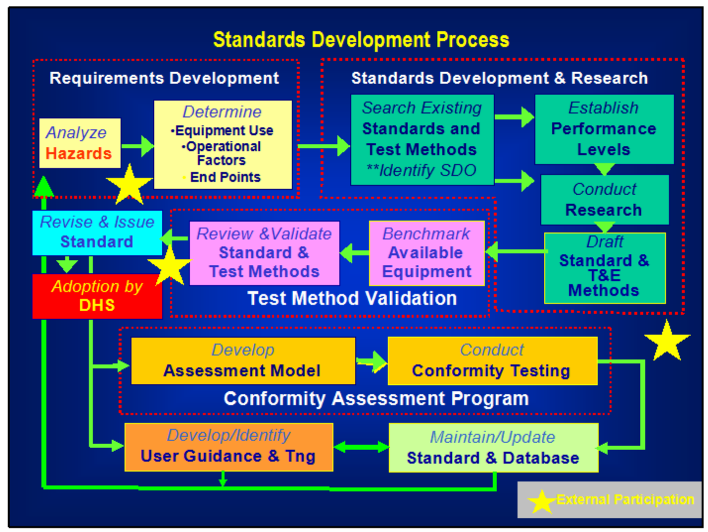
- NIOSH Development of CBRN Respiratory Protection Equipment Standards
- ECBC Support to NIOSH Respiratory Standards
- Development of Verification Method for Gas Mask Fit Test
- Permeation Through Nonporous Barrier Polymers
- Facemask Leakage Study
- Real-time Monitoring of Respiratory Threats

Standards PPE Projects

- Law Enforcement Advanced Protection (LEAP)
- Law Enforcement Specific CBRN PPE
- Emergency Responder Protection Against TIC/TIMs
- Develop CWA Simulants & Test Methods for PPE
- Evaluation & Definition of Requirements for Microclimate Cooling Systems
- Test Method for Microclimate Cooling Systems
- Radiation Protection Ensemble Test Methods

Standards PPE Projects

- Development of Bomb Suit Standard
- 1st Responder Decontamination Standards
- Testing and Measurement Methodology for Indoor Localization & User Guide
- Thermal Exposure Measurement Method for 1st Responder Locators
- Thermal Imaging Standards
- Personal Alert Safety Systems (PASS) Technology



Office of Law Enforcement Standards

at the

National Institute of Standards and Technology

Building 220, Room B208, Gaithersburg, MD 20899

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NIST Office of Law Enforcement Standards

tel: 301.975.3396

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Philip.mattson@nist.gov

Department of Homeland Security

tel: 202.254.5861

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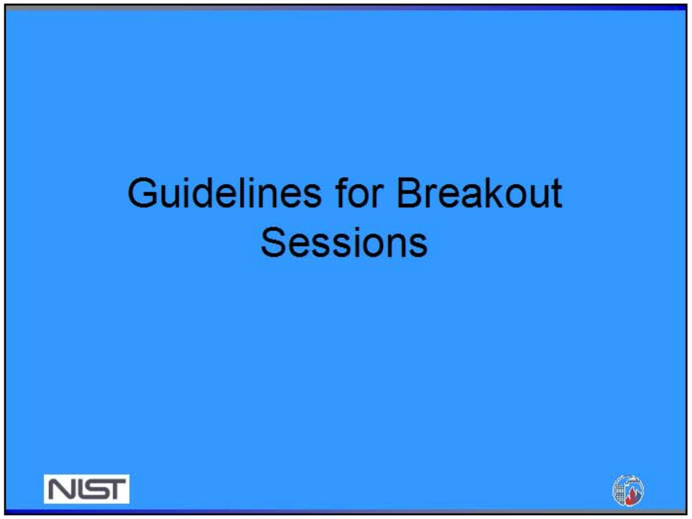
Parting Thought

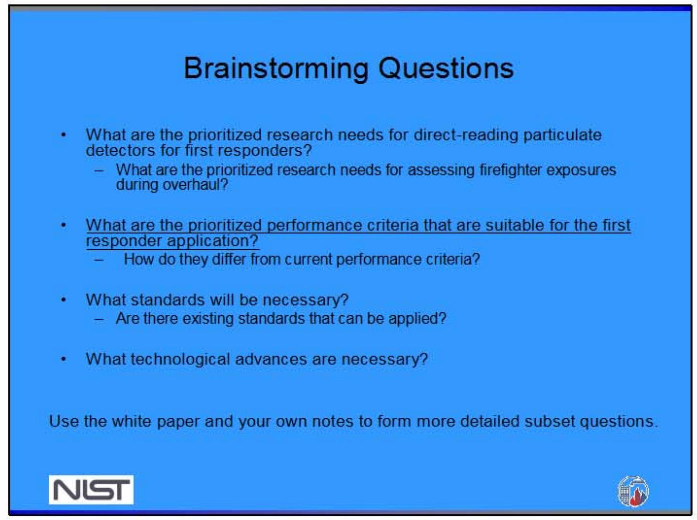
"Whether or not gas will be employed in the future is a matter of conjecture, but the effect is so deadly to the unprepared that we can never afford to neglect the question."

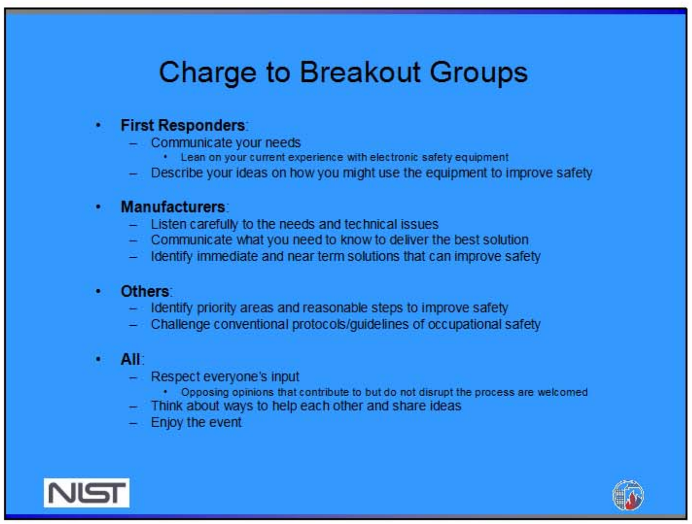
General John J. Pershing

APPENDIX 3.J – Guidelines for Breakout Sessions

Rodney Bryant, Building and Fire Research Laboratory, NIST







APPENDIX 4 –BREAKOUT GROUP DISCUSSIONS

The tables in this appendix present the results from the brainstorming sessions of each breakout group. The groups were asked to respond to the following list of questions:

- What are the prioritized research needs for direct-reading particulate detectors for first responders?
  - What are the prioritized research needs for assessing firefighter exposures during overhaul?
- What are the prioritized performance criteria that are suitable for the first responder application?
  - How do they differ from current performance criteria?
- What standards will be necessary?
- What technological advances are necessary?

These questions are categorized in the tables as Research Needs, Performance Criteria, Standards, and Technological Advances.

The next task after brainstorming was for each group to determine and rank their top five priorities in each category. In two groups (2-Blue and 3-Green), each participant was asked to vote on their top five choices. From these votes, further discussion identified and ranked the top five priorities for the group. In one group (1-Red), consensus to identify the top five priorities was achieved through open discussion but rankings were not assigned. During the discussion of the top five priorities, each group discovered commonalities among the responses that allowed multiple responses to be combined. The responses are listed in Tables 6 through 8, with the top five priorities listed first.

Table 6. Group 1 (Red) – Paul Greenberg, facilitator

<table>
<tr><th>Research Needs</th><th>Performance Criteria</th></tr>
<tr><td>1) More comprehensive data on particle environment associated with real overhaul environments, including particle size distribution (PSD), number density, composition, other moments; statistical sufficiency (local vs global micro-environment); scenarios (wildland vs residential, vehicular, dumpster, vegetative, industrial)
2) Enhanced understanding of dosimetry metrics: distinguish between acute/chronic exposure, toxicity correlations with other environmental factors (are particulates a suitable proxy for toxicity assessment?), human/animal testing, leverage off existing environmental standards
3) Improved characterization of instrument response function: PSD, number density, mixtures (variations/combinations in composition, interference with other gas-phase constituents or nuisance backgrounds e.g. H_2O vapor)
4) Comparative understanding of overhaul environment, procedures, and timeline
5) Instrument sampling efficiency and biases as a function of environmental conditions
Conceptual studies for miniaturization and/or enhanced tolerance or performance
Materials characteristics (mixtures of materials, scaling and interrelation of various “test” facilities)</td><td>1) Form factor
- Size, power, weight
- Durability (temperature, moisture, shock)
- Operability, visibility
2) Measurement performance
- Size range (emphasis on ultrafines)
- Concentration range
- Accuracy
3) Cost of ownership
- Calibration requirements
- Lifetime
- Clogging and clearance
- Maintenance protocol
4) Other
- Battery type/charging method, schedule
- Ancillary collection membrane
- Drift, correlation, interference, etc. with chemical or vapor environment
- Logging vs instantaneous
- Complexity of data display (Go/No Go vs. PSD)
5) Ability to resolve particle size distribution vs. integrated size range measurements
Cost / availability
Desorption vs composition analysis
Local information vs transmitted</td></tr>
</table>

Table 6 (cont.). Group 1 (Red) – Paul Greenberg, facilitator

Standards	Technological Advances
1) Need for a standard reflective of combustion/pyrolysis-specific materials 2) Testing standard: materials, protocols, interactions, instrument response (to what quantities or moments) and accuracy 3) Specification of operational environment requirements 4) Instrument configuration and operability 5) Linkage, buy-in, or uniformity with other certifying standards and organizations (e.g. OSHA, NIOSH, EPA, ACGIH, NFPA)	*Near-term perspective: 1-3 year horizon:* 1) Ruggedness, lifetime, environmental tolerance 2) Display visibility and information content/detail 3) Self calibration and internal diagnostics (i.e. self check and validation) 4) Emphasis on detection sensitivity in ultrafine regime 5) Data telemetry *Longer term development – not ranked:* - Ability to resolve particle size distributions, composition - Cost reduction per delivered and maintained unit - Improvements in demands and procedures for maintenance - Integrated functionality (e.g. other sensors such as gaseous species, GPS, volumetric flow measurement) - Immunity to interferences (both species e.g. H_2O vapor, interfering gases; and environmental e.g. RFI – Radio Frequency Interference, acoustic) - "Intelligent" processing (e.g. multiple moment analysis, integrated dosage vs. standard, correlations with other materials or factors) - Reduction in false positives - Reduction in size, power, mass

Table 7. Group 2 (Blue) – Kathryn Butler, facilitator

Research Needs	Performance Criteria
1) Better definition of the hazard - Relative danger of particulates and gases - Is gas riding on particulates? (carbon is a great absorber) - There is an incomplete understanding of exposure risks of firefighters, including risks over a range of activities (wildland vs. structural fires, search & rescue vs. overhaul vs. investigation) and effects of nanoparticle exposure on health - What is the timeline for safe operation? 2) Database for what fires actually generate 3) Confounders – other exposures affecting firefighter health (e.g. contaminated turnout gear, exposure to truck exhaust) 4) Water particles – are they important? How do they affect measurements? Should water be measured as a particle? Does it play a role in health effects? 5) Benefit analysis – is it worth it to do the research? At what point do you tell firefighters that they must wear the SCBA? When is it safe to downgrade PPE? Is there an indicator gas or particulate? Is the respiratory track the only route of entry to consider? (e.g. skin, eyes, ingestion) Product distribution or representative sampling – should every firefighter have a detector? How must a 40-year-old technology be hardened for firefighter use? Should all fires be treated the same? (wildland vs. home vs. big box) All-in-one or specific?	1) What is to be measured? Need to define what hazards to measure in order to build the device. 2) Where should it be measured? Personal vs. area sampler, inside vs. outside, etc. This will dictate the form of the device. 3) Environment - Temperature extremes (both hot and cold) - Vibration-proof, shockproof, waterproof - Credible measurements throughout the range of conditions experienced by the firefighter - Should not create new hazard 4) Go/no-go display – simplicity 5) Data collection and logging, and distribution of information to firefighter and incident commander; redundant system for safety No interference with communications 1-button / heavy glove operation Cost benefit analysis All-in-one meter for gas and particle identification (type of gas, what's in particle) Small Service life > 1 year Minimal training If batteries, make them regular alkaline Size distribution or total mass Measure temperature

Table 7 (cont.). Group 2 (Blue) – Kathryn Butler, facilitator

Standards	Technological Advances
1) Instrument must maintain performance over the full range of environmental insults (humidity, temperature, shock) 2) Size range of particle measurement 3) Need to quantify against accepted exposure standards (REL – Recommended Exposure Limits, TLV – Threshold Limit Values, PEL – Permissible Exposure Limits) 4) Maintenance and calibration to ensure the unit performs to manufacturer's specifications 5) Training to assure uniformity of use Electrical safety Radio frequency interference Reliability	*Long term development (5-10 years):* 1) Detection of multiple hazards 2) Wider dynamic response to meet challenges due to the wide range of concentrations and maximum concentration level in the fire environment 3) Shrink equipment (including battery and pump) to make a smaller device that would be better accepted by users 4) Knowledge of exposure in real-time (1-5 seconds) in order to make decisions 5) Data logging – event (alarm, low battery, etc.) and data Battery performance and pump efficiency Improved reliability Wireless link to incident commander Calibration – how to do this

Table 8. Group 3 (Green) – Robert Vettori, facilitator

Research Needs	Performance Criteria
1) What is physiological response to different sizes of particles? Prove to me that I need a mask or SCBA. Need to show that it is worthwhile. 2) Multi-metric method – (particle source, exposure) 3) Identify hazard of overhaul – What is the level of hazard in terms of ppm, risk, g/m^3, size 4) Design new cartridge 5) Determine composition of aerosol Location of emissions – find it, identify source – what is it? Use TIC to find hot spots Is APR or SCBA the right mask? Powered APR – is it better? Different cartridges – which cartridge is best? Put cartridges in series What is coming from wood? Combustion particles from overhaul Interest in other than overhaul Skin, dermal absorption All routes of exposure How do detectors respond to smoke/mass concentration? If higher than ambient or background, call it an action level; if measurement exceeds 5 mg/m^3 (current standard), some action is taken What is size distribution of non-flaming smoke aerosol? Equipment calibration for particles Who do we protect – all incidents or 80 % of normal stuff? Baseline of toxicity Correlation between vapor and particle Smart ticket for particles – make turnout gear of this material	1) Want it to data log 2) Hazard or No Hazard – Go or No Go for firefighter 3) Simple and easy to calibrate 4) Transmit to command post 5) What will NFPA criteria be for physical performance (e.g. temperature, humidity)? – this is mainly for manufacturers Where is the hazard? Small for everyone Color or flashing – no more sound Attach to helmet Must mean something Reliable – no false positive Physical performance On/off unless HazMat/Urban Search And Rescue (USAR)/etc.

Table 8 (cont.). Group 3 (Green) – Robert Vettori, facilitator

Standards	Technological Advances
1) Guidelines for what actions you take when the device hits a certain level (mass, number, size distribution). This is a risk management practice since we don't have a standard yet – proactive approach. 2) Standard exposure limit 3) Physical performance standards 4) Standard for calibration – calibration artifact 5) Standard smoke NIOSH guidelines OSHA best practices Need to establish limits for the firefighter workplace, e.g. 5 mg/m^3 for 8 hours for respirable dust, 15 mg/m^3 for total dust – Time Weighted Average (TWA) Standard communication protocol for data logging Standard medical checks for annual physical – HazMat teams do this already	*Near-term perspective: 1-3 year horizon:* 1) End of service life indicators for cartridges 2) Improvements to Air Purifying Respirators (APRs) 3) Real time analysis for Fire Department use. Walk outside of building with a sample and have apparatus on scene to analyze. One instrument vs. lots of instruments, need to know where you got the sample 4) From aerosol arena – What should the wavelength of the source be, what should be the detection angle, how many detectors? 5) The technology is there to do what we want. The equipment needs to be repackaged and we need to know what the specifications are. Money is needed