Respiratory Exposure Study for Fire Fighters And Other Emergency Responders

Final report

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FOREWORD

In 2007 the Fire Protection Research Foundation solicited proposals from NFPA TC/TCC Chairs and their assigned staff liaisons for research intended to directly benefit NFPA codes and standards. Twenty-three candidate submittals were provided; this was one of three studies chosen by an evaluation panel, and multiple NFPA Technical Committee projects stand to benefit from this final report.

The intent of this document is to assist the fire service and other emergency responders with the development and clarification of best practice guidance for determining when to use, and when to discontinue use, of SCBA and other respiratory protective equipment when exposed to atmospheres that are possibly hazardous yet tenable. Specifically, this study summarizes the available literature on this topic and provides helpful information for use by emergency response personnel to develop and clarify best practice guidance for using respiratory protective equipment on the fire ground.

Fire fighters and other emergency responders routinely use self-contained breathing apparatus (SCBA) to protect against hazardous atmospheres that contain harmful gases and particulates. However, SCBA have certain practical field limitations, including a finite supply of air and various design features that restrict a fire fighter's dexterity and vision. It is not practical to expect SCBA to be worn by fire fighters for long duration activities, and fire fighters sometimes choose to not use SCBA when the hazardous atmosphere can be readily tolerated for short term exposure. Examples of such situations include overhaul at structure fires, outdoor fires, and fire investigations.

The Research Foundation expresses gratitude to the Project Technical Panelists, NFPA staff that assisted with review and information contained in the report, and to all the fire service and emergency response personnel that contributed to the information collection effort. Special thanks are expressed to National Fire Protection Association (NFPA) for providing the funding for this project.

The content, opinions and conclusions contained in this report are solely those of the author.

Respiratory Exposure Study for Fire Fighters And Other Emergency Responders

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RESPIRATORY EXPOSURE STUDY FOR FIRE FIGHTERS AND OTHER EMERGENCY RESPONDERS

A Report for the

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December 2007

THE FIRE PROTECTION RESEARCH FOUNDATION

EXECUTIVE SUMMARY

This study provides information for firefighters and other emergency responders to help develop best practice guidance for determining when to use and discontinue use of SCBA and other respiratory protective equipment. The applications of primary focus include atmospheres that are possibly hazardous yet tenable, such as during overhaul operations, fighting outdoor fires, or limited exposure situations.

The approach used includes a literature review of research on respiratory exposure, a summary of field measurement technology currently available, and a summary review of selected fire department Standard Operating Procedures (SOPs) and Standard Operating Guidelines (SOGs) relating to respiratory exposure.

The results of the literature review provide an extensive compilation of applicable articles, reports, and other literature that provides researchers and others with a useful platform to better address the multiple facets of this topic deserving further study. The literature collected resulted in a compilation of over 200 citations that provide helpful background information on the health effects to fire fighting personnel, characteristics of the environment, and the tools that are used for respiratory protection.

The information collection form was distributed to a diverse group of fire departments and the results clarify how the fire service approaches certain field practices. The 130 unique departments provide a composite view of how the fire service uses respiratory protective equipment and hand held gas monitoring equipment to determine the conditions to remove SCBA in an environment that is questionable yet tolerable, such as during overhaul or exterior fires.

Among the findings of the literature review is an indication that the atmospheres encountered by fire fighters and other emergency responders, both at interior or exterior applications, have hazardous components that should be of concern to all who may be exposed to these atmospheres. Further, for certain applications such as those faced by fire investigators or wildland fire fighters, additional protective measures should be considered for the on-going respiratory hazards they face. The literature review also indicates that fire fighters have a higher rate of long-term adverse health effects, like cancer, than the rest of the general population, although the precise cause of these ailments is not clear, and the respiratory concerns faced by fire fighters operating at structural fires today appear to be changing from similar exposures occurring approximately 1 to 4 decades ago, based on the changing characteristics of the materials that are burning in a typical building fire.

The information collection component of this study provides additional helpful data. Most of the responding fire departments have SOPs/SOGs to indicate when to use SCBA, but fewer address when to discontinue the use of SCBA. Most also generally have hand-held portable monitoring equipment for carbon monoxide calls and hazardous materials incidents, and they're using this equipment to measure hazardous environments elsewhere, such as during overhaul.

For the fire departments that are measuring airborne contaminants, most of those responding to the information collection are measuring carbon monoxide, oxygen, flammable gases, and hydrogen sulfide. In fewer numbers, fire departments are also measuring hydrogen cyanide, sulfur dioxide, nitrous oxide and other toxic gases. A clear indication appears to be lacking of what fire departments should optimally be measuring, and guidance is needed for the measurement of multiple components of the hazardous environment for fire departments that are focusing only on individual airborne contaminants.

The content, opinions and conclusions contained in this report are solely those of the author.

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ACKNOWLEDGEMENTS

The study has been made possible through funding from the National Fire Protection Association, whose mission is to make the world safer from fire and related hazard.

Special thanks are extended to the members of the Project Technical Panel and members of NFPA staff that have provided helpful guidance and assistance with this study. Appreciation is likewise extended to the numerous individuals and organizations that have participated in providing valuable input into this report, for the cause of improving the safety of first emergency responders.

# # #

This study is dedicated to all the men and women with first emergency response organizations who face adverse respiratory environments on a daily basis and live with the question of possible long-term adverse health effects. In particular this report remembers the late Bob "Booboo" McCarthy who was a Lieutenant with the Quincy MA Fire Department, worked part-time with the NFPA Fire Analysis and Research Division, and who passed away in 2003 from respiratory complications just months after his fire department retirement.

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GLOSSARY OF TERMS

ACGIH: American Conference for Governmental Industrial Hygienists.

Air-purifying respirator: A respirator with an air-purifying filter, cartridge, or canister that removes specific air contaminates by passing ambient air through the air-purifying element. (NFPA 1404, *Standard for Fire Service Respiratory Protection Training*, 2006 Edition)

APR: See "Air-purifying respirator".

Atmosphere-supplying respirator: A respirator that supplies the respirator user with breathing air from a source independent of the ambient atmosphere, which includes self-contained breathing apparatus (SCBA) and supplied air respirators (SAR). (NFPA 1852, *Standard on Selection, Care, and Maintenance of Open-Circuit Self-Contained Breathing Apparatus (SCBA)*, 2002 Edition)

CBRN: An abbreviation for Chemical, Biological, Radiological, and Nuclear. (NFPA 1994, *Standard on Protective Ensembles for First Responders to CBRN Terrorism Incidents*, 2007 Edition)

CBRN Terrorism Agents: The term used to refer to chemical terrorism agents including both chemical warfare agents and toxic industrial chemicals, biological terrorism agents, and radiological particulate terrorism agents. (NFPA 1994, *Standard on Protective Ensembles for First Responders to CBRN Terrorism Incidents*, 2007 Edition)

Hazardous Area: The area where members might be exposed to a hazard or hazardous atmosphere. A particular substance, device, event, circumstance, or condition that presents a danger to members of the fire department. (NFPA 1500, Standard on Fire Department Occupational Safety and Health Program, 2007 Edition).

Hazardous Atmosphere: Any atmosphere that is oxygen deficient or that contains a toxic or disease-producing contaminant. [NFPA 1404, *Standard for Fire Service Respiratory Protection Training*, 2006 Edition]

IDLH: See "Immediately dangerous to life or health".

Immediately dangerous to life or health: Any condition that would pose an immediate or delayed threat to life, cause irreversible adverse health effects, or interfere with an individual's ability to escape unaided from a hazardous environment. (NFPA1670, *Standard on Operations and Training for Technical Search and Rescue Incidents*, 2004 Edition)

NIOSH: National Institute for Occupational Safety and Health, operating within the U.S. Center for Disease Control (CDC)

Open-Circuit SCBA: An SCBA in which exhalation is vented to the atmosphere and not re-breathed. There are two types of open-circuit SCBA: negative pressure or demand type and positive pressure or pressure demand type. NFPA1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services*, 2007 Edition)

OSHA: Occupational Safety and Health Administration, operating within the U.S. Department of Labor.

Powered Air-purifying respirator: An air-purifying respirator that uses a power source (usually a battery) to operate a blower that passes air across the cleansing element to supply purified air to the respiratory inlet. (Plog, B.A., "Fundamentals of Industrial Hygiene", Fifth Edition, National Safety Council, 2002, pg. 682)

PAPR: See "Powered Air-purifying respirator".

Respiratory Equipment: A positive pressure, self-contained breathing apparatus (SCBA) or combination SCBA/supplied-air breathing apparatus certified by the National Institute for Occupational Safety and Health (NIOSH) and certified as compliant with NFPA 1981, Standard on Open-Circuit Self-Contained Breathing Apparatus for Fire and Emergency Services. (NFPA 1991, *Standard on Vapor-Protective Ensembles for Hazardous Materials Emergencies*, 2005 Edition)

Respiratory Hazard: Any exposure to products of combustion, superheated atmospheres, toxic gases, vapors, or dust, or potentially explosive or oxygen-deficient atmospheres, or any condition that creates a hazard to the respiratory system. (NFPA 1404, *Standard for Fire Service Respiratory Protection Training*, 2006 Edition)

Respiratory Protection: Equipment designed to protect the wearer from the inhalation of contaminants. (NFPA 472, *Standard for Competence of Responders to Hazardous Materials/Weapons of Mass Destruction Incidents*, 2008 Edition)

Respiratory Protection Equipment: Devices that are designed to protect the respiratory system against exposure to gases, vapors, or particulates. (NFPA 1404, *Standard for Fire Service Respiratory Protection Training*, 2006 Edition)

Respiratory Protection Program: A systematic and comprehensive program of training in the use and maintenance of respiratory protection devices and related equipment. (NFPA 1404, *Standard for Fire Service Respiratory Protection Training*, 2006 Edition)

SAR: See "Supplied-Air Respirator".

SCBA: See "Self-contained breathing apparatus".

Self-Contained Breathing Apparatus: An atmosphere-supplying respirator that supplies a respirable air atmosphere to the user from a breathing air source that is independent of the ambient environment and designed to be carried by the user. NFPA 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services*, 2007 Edition)

Supplied-Air Respirator: An atmosphere-supplying respirator for which the source of breathing air is not designed to be carried by the user; also known as an airline respirator. NFPA 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services*, 2007 Edition)

1) INTRODUCTION

a) Background

Firefighters and other emergency responders are routinely exposed to hazardous atmospheres that contain harmful gases and particulates. Respiratory protection from these dangerous environments is accomplished through the use of self-contained breathing apparatus (SCBA), which provides effective respiratory protection for limited periods of time.

However, SCBA have certain practical field limitations, including a finite supply of air and various design features (e.g. weight, bulk, facepiece) that restrict a firefighter's dexterity and vision. It is not practical to expect SCBA to be worn by firefighters for long duration activities, and it is generally not used when the hazardous atmosphere can be readily tolerated for short term exposure. Situations when firefighters might not utilize SCBA when an adverse yet tolerable atmosphere may be present generally fit into three broad categories:

1) Overhaul at structural fires, which is the extended operational period after the fire has been knocked down and firefighters dig through the rubble to extinguish hot spots;
2) Outdoor fires (e.g. brush/wildland, automobiles, dumpsters, etc); and
3) Limited exposure situations to firefighters and other emergency responders (e.g. police, emergency medical service personal, utility workers, etc) who are not within the immediate hazardous space fighting a structural fire but are still exposed to limited quantities of the fire atmosphere (e.g. pump operators, incident commander, etc).

Protecting firefighters and other emergency responders from harmful atmospheres is a complex problem. Previous research has successfully addressed certain scientific and technical details of this topic, but has not resulted in the implementation of practical field guidance for direct use by the fire service and other emergency responders. This study will attempt to develop best practice guidance for determining when to use and discontinue use of SCBA and other respiratory protective equipment when exposed to atmospheres that are possibly hazardous yet can be readily tolerated for short term exposure.

b) Purpose and Scope

The purpose of this project is to raise awareness on the need for emergency responder respiratory protection, establish a research platform for others who are studying this topic, and provide information for firefighters and other emergency responders to help develop best practice guidance for determining when to use and cease using SCBA and other respiratory protective equipment when exposed to atmospheres that are possibly hazardous yet tenable, such as during overhaul operations, fighting outdoor fires, or limited exposure situations.

The scope and tasks of this project are comprised of the following five elements, with an emphasis on tasks 1 and 3:

1) Perform a literature review of research on respiratory exposure for fire fighters and other emergency responders of the available scientific, technical and field-applied literature.

2) Generate a summary of field measurement equipment currently available for use by the fire service and other emergency responders for field measurement of potentially harmful atmospheres.
3) Implement a collection of information of fire department Standard Operating Procedures (SOPs) and other information relating to respiratory exposure, with the intent to analyze and summarize the collected information in a useable format to recommend fire service respiratory exposure best practice. (Example: What are the criteria to determine when to remove an SCBA on the fire ground?)
4) Develop awareness material to better engage the fire service and other emergency responders on current and proposed respiratory exposure research, and help facilitate the transfer of research by medical researchers, industrial hygienists and others into best practice guidance for the fire service and other emergency responders.
5) Clarify further research work that is needed that will ultimately help establish best practice guidance for the fire service and other emergency responders on respiratory exposure, and provide recommendations on the prioritization of proposed research.

c) Applicable NFPA Projects

This study has been conducted under the auspices of the Fire Protection Research Foundation, whose mission is to plan, manage and communicate research in support of the NFPA mission. On this basis, this study is believed to be applicable, either directly or indirectly, to the following NFPA Technical Committee Projects and NFPA documents. While arguably this study can be extrapolated to numerous other NFPA projects and documents, those discussed here are believed to be the most pertinent at this time.

The affected NFPA Technical Committee Projects whose current scope and responsibilities most closely relates to the subject matter addressed in this study are identified as:

- Technical Committee on Fire Service Occupational Safety and Health (FIX-AAA)
- TCC on Fire and Emergency Protective Clothing and Equipment (FAE-AAC)
- Technical Committee on Respiratory Protection Equipment (FAE-RPE)
- Technical Committee on Fire Service Training (FIY-AAA)
- Technical Committee on Fire Investigation (FIA-AAA)
- Technical Committee on Gas Hazards (GAS-AAA)
- Recently approved TC project on Confined Space Safe Work Practices

The NFPA Documents whose current scope of activities most closely relates to the subject matter addressed in this study are identified as:

- NFPA 306, *Standard for the Control of Gas Hazards on Vessels*
- NFPA 921, *Guide for Fire and Explosion Investigations*
- NFPA 1403, *Standard on Live Fire Training Evolutions*
- NFPA 1404, *Standard for Fire Service Respiratory Protection Training*
- NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*
- NFPA 1852, *Standard on Selection, Care, and Maintenance of Open-Circuit Self-Contained Breathing Apparatus (SCBA)*
- NFPA 1981, *Standard on Open-Circuit Self Contained Breathing Apparatus for Fire and Emergency Services*
- NFPA 1989, *Standard on Breathing Air Quality for Fire and Emergency Services Respiratory Protection*
- New NFPA confined space safe work practices project document(s)

Of particular interest is NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*, which is administered by the Technical Committee on Fire Service Occupational Safety and Health.[1] This document provides model requirements and guidance that clarifies the use of SCBA and other respiratory equipment, although the discontinued-use of this equipment is not explicitly addressed. The following are applicable excerpts from the 2007 edition of NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*, and are summarized here for convenience (with underlines added for emphasis):

7.5* Chemical-Protective Clothing for Hazardous Materials Emergency Operations.
7.5.1* Vapor-Protective Ensembles.
7.5.1.3 All members who engage in operations during hazardous materials emergencies where there is potential for exposure to known chemicals in gaseous or vapor form that pose skin hazards, to chemicals that have not been identified, or to chemical environments that are classified as IDLH shall be provided with and shall use SCBA that meet the applicable requirements of Section 7.11.
7.5.1.3.1 Additional outside air supplies shall be permitted to be utilized in conjunction with SCBA, provided such systems are positive pressure and have been certified by NIOSH under 42 CFR 84, Approval of respiratory protective devices.

Figure 1-1a: NFPA 1500 Excerpt on Respiratory Protection for Vapor-Protective Ensembles.

7.5.2* Liquid Splash-Protective Ensembles and Clothing.
7.5.2.3 All members who engage in operations during hazardous materials emergencies that will expose them to known chemicals in liquid-splash form shall be provided with and shall use either SCBA that meet the applicable requirements of 7.11.1, or other respiratory protective devices that are certified by NIOSH under 42 CFR 84 as suitable for the specific chemical environment.
7.5.2.3.1 Additional outside air supplies shall be permitted to be utilized in conjunction with SCBA, provided such systems are positive pressure and have been certified by NIOSH under 42 CFR 84.

Figure 1-1b: NFPA 1500 Excerpt on Respiratory Protection for Liquid Splash-Protective Ensembles and Clothing.

7.5.3* Protective Ensembles for CBRN Terrorism Incidents.
7.5.3.3.1 All members who engage in operations for incidents involving CBRN terrorism agents and who are required to wear vapor-protective ensembles that meet NFPA 1991 shall be provided with and shall use either of the following respiratory protection:
(1) SCBA that meet the applicable requirements of 7.11.1, provided that the SCBA is fully encapsulated by the protective ensemble
(2) Open-circuit SCBA that are certified by NIOSH as compliant with NIOSH Standard for Chemical, Biological, Radiological, and Nuclear (CBRN) Open Circuit Self-Contained Breathing Apparatus (SCBA)
7.5.3.4.1 All members who engage in operations for incidents involving CBRN terrorism agents and who are required to wear NFPA 1994 Class 2 ensembles shall use open-circuit SCBA that are certified by NIOSH as compliant with NIOSH Standard for Chemical, Biological, Radiological, and Nuclear (CBRN) Open Circuit Self-Contained Breathing Apparatus (SCBA).
7.5.3.5.1 All members who engage in operations for incidents involving CBRN terrorism agents and who are required to wear NFPA 1994 Class 3 ensembles shall use one of the following types of respirators:
(1) Open-circuit SCBA that are certified by NIOSH as compliant with NIOSH Standard for Chemical, Biological, Radiological, and Nuclear (CBRN) Open Circuit Self-Contained Breathing Apparatus (SCBA)
(2) Air-purifying respirators (APRs) with a minimum rated service life of at least 30 minutes that are certified by NIOSH as compliant with NIOSH Standard for Chemical, Biological, Radiological, and Nuclear (CBRN) Full Facepiece Air Purifying Respirator (APR)

7.5.3.6.1 All members who engage in operations during chemical and biological terrorism incidents and who are required to wear NFPA 1994 Class 4 ensembles shall use one of the following types of respirators:
(1) Open-circuit SCBA that are certified by NIOSH as compliant with NIOSH Standard for Chemical, Biological, Radiological, and Nuclear (CBRN) Open Circuit Self-Contained Breathing Apparatus (SCBA)
(2) APR with a minimum rated service life of at least 30 minutes that are certified by NIOSH as compliant with NIOSH Standard for Chemical, Biological, Radiological, and Nuclear (CBRN) Full Facepiece Air Purifying Respirator (APR)

Figure 1-1c: NFPA 1500 Excerpt on Respiratory Protection for Protective Ensembles for CBRN Terrorism Incidents.

7.8 Protective Ensembles for Technical Rescue Operations.
7.8.3 Members engaged in technical rescue operations that require respiratory protection shall be provided with and shall use respirators that are certified by NIOSH to 42 CFR Part 84.
7.8.3.1* Where air-purifying respirators (APRs) and powered air-purifying respirators (PAPRs) are selected to provide the respiratory protection, the APRs and PAPRs shall be provided with the chemical or particulate filter elements that provide protection against the specific contaminants based upon the anticipated level of exposure risk associated with different response situations.
7.8.3.2* Where it cannot be determined that an APR or PAPR will provide effective protection against the contaminant, or if the identity of the contaminant is not known, SCBA shall be worn until it can be determined that other respiratory protection can be used.

Figure 1-1d: NFPA 1500 Excerpt on Respiratory Protection for Protective Ensembles used with Technical Rescue Operations.

7.9 Respiratory Protection Program.
7.9.1 The fire department shall adopt and maintain a respiratory protection program that addresses the selection, care, maintenance, and use of respiratory protection equipment (RPE), medical surveillance, training in respirator use, and the assurance of air quality.
7.9.7* When engaged in any operation where they could encounter atmospheres that are IDLH or potentially IDLH, or where the atmosphere is unknown, the fire department shall provide and require all members to use SCBA that has been certified as being compliant with NFPA 1981, Standard on Open-Circuit Self-Contained Breathing Apparatus for Fire and Emergency Services.
A.7.9.7 Hazardous atmospheres requiring SCBA can be found in, but are not limited to, the following operations: structural fire fighting, aircraft fire fighting, shipboard fire fighting, confined space rescue, and any incident involving hazardous materials.
7.9.8* Members using SCBA shall not compromise the protective integrity of the SCBA for any reason when operating in IDLH, potentially IDLH, or unknown atmospheres by removing the facepiece or disconnecting any portion of the SCBA that would allow the ambient atmosphere to be breathed.
A.7.9.8 The required use of SCBA means that the user should have the facepiece in place, breathing air from the SCBA only. Wearing SCBA without the facepiece in place does not satisfy this requirement and should be permitted only under conditions in which the immediate safety of the atmosphere is assured. All members working in proximity to areas where SCBA use is required should have SCBA on their backs or immediately available for donning. Areas where the atmosphere can rapidly become hazardous could include rooftop areas during ventilation operations and areas where an explosion or container rupture could be anticipated.
A hazardous atmosphere would be suspected in overhaul areas and above the fire floor in a building. Members working in these areas are required to use their SCBA unless the safety of the atmosphere is established by testing and maintained by effective ventilation. With effective ventilation in operation, facepieces could be removed under direct supervision, but SCBA should continue to be worn or immediately available.

Figure 1-1e: NFPA 1500 Excerpts on Requirements for Respiratory Protection Programs.

8.6 Control Zones.
8.6.1 Control zones shall be established at emergency incidents.
8.6.1.1 The perimeters of the control zones shall be designated by the incident commander and communicated to all members.
8.6.1.2 If the perimeters of the control zones change during the course of the incident, these changes shall be communicated to all members on the scene.
8.6.2* Hazard control zones shall be designated as hot, warm, and cold.
8.6.2.1 All members shall wear all of the PPE (SCBA, flash hood, etc.) appropriate for the risks that might be encountered while in the hot zone.
8.6.2.2* All members operating within the hot zone shall have an assigned task.
8.6.2.3 Where an exclusion zone is designated, no personnel shall enter the exclusion zone due to imminent hazard(s) or the need to protect evidence.

Figure 1-1f: NFPA 1500 Excerpt on Respiratory Protection for Control Zones.

2) OVERVIEW OF FIRE FIGHTING RESPIRATORY EXPOSURE PROTECTION CONCERNS

a) Problem Summary

The fire ground atmosphere encountered by fire fighters and other emergency responders as part of their normal work routine is highly variable, changes rapidly with time, is a combination of multiple respiratory hazards, and is frequently IDLH.[2] Respiratory exposure protection is an essential part of the portfolio of the equipment used by the fire service.

Respiratory protective equipment is used by a wide range of emergency responders. This study is focused toward fire fighters, but it's recognized that the same incidents in which they are primarily engaged typically also involve other first emergency responders who, at times, share these same respiratory protection concerns. An example is the response of law enforcement personnel for crime scene control and evaluation, which may involve equal exposures or exposures to lesser hazardous concentrations but for longer periods of time.[3, 4]

Respiratory protection from these dangerous environments on the fire ground is accomplished through the use of equipment such as self-contained breathing apparatus (SCBA), which provides effective respiratory protection for limited periods of time. However, SCBA has certain practical field limitations, including a finite supply of air and various design features (e.g. weight, bulk, facepiece) that restrict a firefighter's dexterity and vision. It is not practical to expect SCBA to be worn by firefighters for long duration activities, and it is generally not used when the hazardous atmosphere can be readily and reasonably tolerated for short term exposure.

Aside from non-fire incidents such as those involving hazardous materials, CBRN events, or confined space entry, fire ground situations when firefighters might not utilize SCBA when an adverse yet tolerable atmosphere may be present generally fit into three broad categories:

1) Overhaul at structural fires, which is the extended operational period after the fire has been knocked down and firefighters dig through the rubble to extinguish hot spots and/or investigate the post-extinguishment fire scene;
2) Outdoor fires (e.g. brush/wildland, automobiles, dumpsters, etc); and
3) Limited exposure situations to firefighters and other emergency responders (e.g. police, emergency medical service personal, utility workers, etc) who are not within the immediate hazardous space fighting a structural fire but are still exposed limited quantities of the fire atmosphere (e.g. pump operators, incident commander, etc).

Each of these three application categories generally requires full respiratory protection when fire fighters are faced with unknown respiratory hazards. For example, a typical automobile fire will generally require full SCBA during the extinguishment phase of the fire since, despite being an exterior fire event, the products of combustion in the vicinity where extinguishment is occurring are unknown and assumed to be IDLH.

During certain phases of fire fighting, such as during overhaul when the atmosphere may still be hazardous yet can be tolerated for short term exposures, fire fighters are tempted to shed bulky respiratory protection that limits their dexterity and vision. Overhaul is considered to be the process of searching and extinguishing any pockets of fire that remain after a fire has been brought under control.[5] It is a physically demanding and time-consuming process that is required for almost all types of fires, whether they are structure fires, or non-structure fires such as automobile and wildland fires.

Respiratory exposure to harmful environments during overhaul that are obvious following the knock-down of structure fires are equally a cause for concern with the overhaul of exterior fires such wildfire, brush fires, vegetation, car fires, bulk piles of rubber tires or wood chips, etc. While it is relatively obvious when to use respiratory protective equipment, such as in an IDLH or unknown atmosphere, it is less clear when its use can be discontinued. Certain fire fighting applications, such as wildland fire applications, are for very long durations in remote areas and full SCBA is not practical. This study hopes to help further mitigate fire fighter respiratory injuries by providing a better understanding of the respiratory hazards faced by fire fighters, and the associated long term implications of their exposure.

b) Trends in Fire Service Respiratory Exposure

Among the information provided by the annual U.S. Fire Department Profile Report, there are approximately 30,000 fire departments in the U.S. with roughly 1.1 million fire fighters. Just under three-fourths (73%) of the 1.1 million fire fighters are volunteers, and nearly half of these volunteers serve in communities with less than 2,500 population. Only one in 15 fire departments is all-career, but 43 percent (or about 2 of every 5) U.S. residents are protected by such a department.[6]

One of the more useful documents providing a clear, overall understanding of the magnitude of the U.S. fire service is the 2005 Fire Service Needs Assessment Survey.[7] This is an update of a similar needs assessment done in 2001, and it provides a measure of multiple facets of fire service activities, equipment and personnel.

Table 2-1: Percentage of U.S. Fire Departments Using SCBA by Size of Jurisdiction

Population of Protected Jurisdiction[1]	Fire Departments Where All Fire Fighters on a Shift are Equipped with SCBA[2]
1,000,000 or more	100 %
500,000 - 999,999	100 %
250,000 - 499,999	96 %
100,000 - 249,999	98 %
50,000 - 99,999	95 %
25,000 - 49,999	89 %
10,000 - 24,999	77 %
5,000 - 9,999	52 %
2,500 – 4,999	33 %
Under 2,500	23 %

1) Source: U.S. Fire Administration, "*Four Years Later – A Second Needs Assessment of the U.S. Fire Service*", A Cooperative Study by U.S. Public Law 108-767, Title XXXVI, FA-303, October 2006, Available for NFPA, Quincy MA, Pg 68.
2) Based on a 2005 stratified random-sample survey sent to roughly half the approximate 30,000 career, volunteer, and combination fire departments in the United States. Results are based on response to a question asking "How many emergency responders on-duty on a single shift can be equipped with SCBA", with possible answers of "All", "Most", "Some", or "None".

The 2005 Fire Service Needs Assessment is based on a stratified random-sample survey sent to roughly half the fire departments in the United States. Of particular interest to the topic of respiratory exposure protection is question 28a of the survey, which asked "how many emergency responders on-duty on a single shift can be equipped with SCBA", with possible answers of "All", "Most", "Some", or "None". The results of this survey question are summarized in Table 2-1.

The percentages in Table 2-1 indicate that larger fire departments generally have SCBA for all the fire fighters on a shift. For fire departments that are protecting communities with a population of at least 50,000 people, at most 5 percent do not have enough SCBA to equip all fire fighters on a shift. Conversely, roughly three-fourths of all fire departments protecting jurisdictions under 2,500 populations do not have SCBA for all fire fighters on a shift.[8] Interestingly, since about half of the 1.1 million U.S. fire fighters serve in departments protecting populations of 5,000 or less, this suggests that an appreciable number of fire departments do not have SCBA for all their fire fighters on a shift.

In addition to the respiratory protective equipment used by the fire service, the other applicable piece of fire service equipment for respiratory concerns are portable hand-held gas or atmospheric monitoring devices. Unlike the prior discussion on SCBA, an inventory of available equipment for portable hand-held gas or atmospheric monitoring devices is not readily available.

The application of portable hand-held gas or atmospheric monitoring equipment is becoming more prolific based on its use for hazardous materials incidents and carbon monoxide calls, and this is allowing this equipment to be more commonplace on the fire ground and to be available for other tasks such as measuring overhaul environments. Figure 2-1 provides an indication of the growth of non-fire carbon monoxide calls that fire departments have responded to in recent years.[9] An increase of 18 percent was seen for the time period from 2003 to 2005, and this provides an indication that the fire service has a growing need for equipment to measure gas atmospheres.

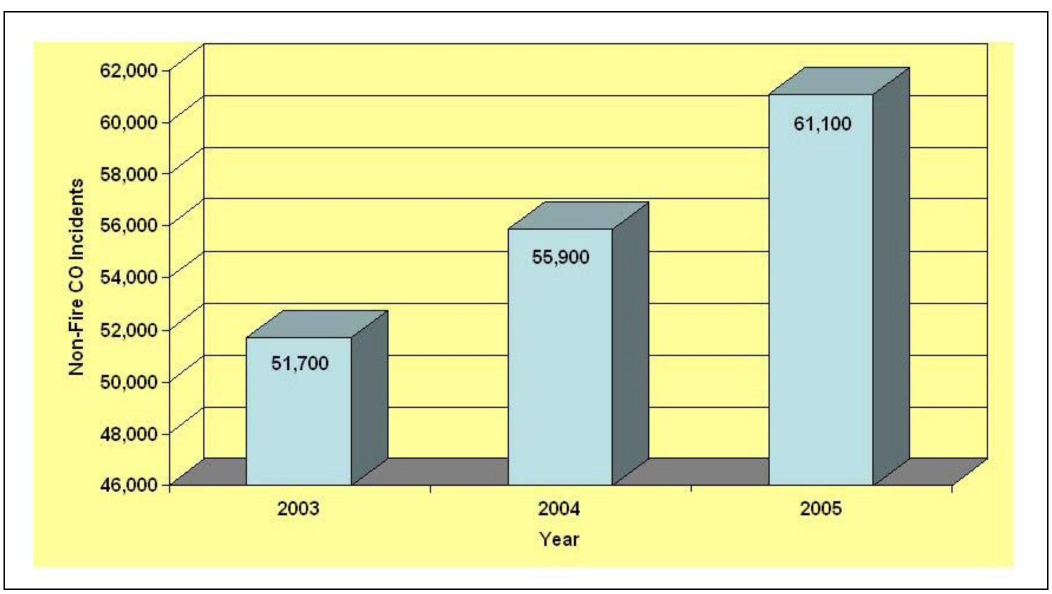


Figure 2-1: Non-Fire Carbon Monoxide Incidents Reported

by Responding U.S. Fire Departments from 2003 to 2005

Aside from the equipment assessment of the U.S. fire service, what is the trend for respiratory injuries to U.S. fire fighters? Through the time period of 1981 through 2006, fire fighter fire ground injuries due to smoke, gas inhalation or respiratory distress have declined.[10] This decline was more precipitous during the beginning of this time period, and during the last decade has stabilized. It's noted that this is partly due to the drop in overall structure fires during this same time period, as illustrated in Table 2-2 and Figure 2-2. Fewer structure fires notwithstanding, this data suggests that in the last decade the rate of respiratory injury per fire incident has remained relatively stable.

The respiratory protective technologies that are in widespread use today have existed since the early 1800's, but did not become mainstream until refinements made them more practical and manufacturing mass production made this technology readily available for fire fighters following World War II.[11] Prior to its application and widespread use by the fire service, this type of respiratory protection was implemented for use during the late 1800s and throughout the 1900s in underground mines, and for high altitude flights during the World War II era. Today, the use of SCBA-based technology is common throughout the North American fire service as well as in other parts of the developed world. Overall progress in reducing fire fighter respiratory injuries is, however, only partly dependent on advances in technology, and another important factor is the attitude and culture of individual fire service users.[12]

Table 2-2: Annual U.S. Fire Fighter Respiratory Related Injuries
In Relation to Number of Fire Calls

Year	Fire Incident Calls	Fire Fighter Smoke, Gas Inhalation or Respiratory Distress
1981	2,893,500	12,485
1982	2,538,000	10,880
1983	2,326,500	11,470
1984	2,343,000	10,105
1985	2,371,000	9,625
1986	2,271,500	8,090
1987	2,330,000	8,040
1988	2,436,500	7,400
1989	2,115,000	7,220
1990	2,019,000	7,095
1991	2,041,500	7,525
1992	1,964,500	6,335
1993	1,952,500	5,540
1994	2,054,500	6,175
1995	1,965,500	5,700
1996	1,975,000	5,400
1997	1,795,000	3,820
1998	1,755,500	3,745
1999	1,823,000	4,435
2000	1,708,000	3,725
2001	1,734,500	5,115
2002	1,687,500	3,765
2003	1,584,500	3,870
2004	1,550,500	3,500
2005	1,602,000	4,140
2006	1,642,500	4,330

One trend that is not clear from the data illustrated in Table 2-2 and Figure 2-2 is the attitude and culture of individual U.S. fire fighters toward embracing a more rigorous implementation of appropriate respiratory equipment. Prior to the advent of today's modern respiratory protective equipment, fire fighters generally faced challenging hazardous environments with little or no respiratory protective equipment.[13] Traditions, however, do not disappear quickly. To an extent, a carryover of the fire service "eating smoke" mindset exists in various forms today. Because fire fighting is a very complex and dynamic process, many of the particular risks that are taken on the fire ground can be as much the choice of the individual as they are institutional policy.[14]

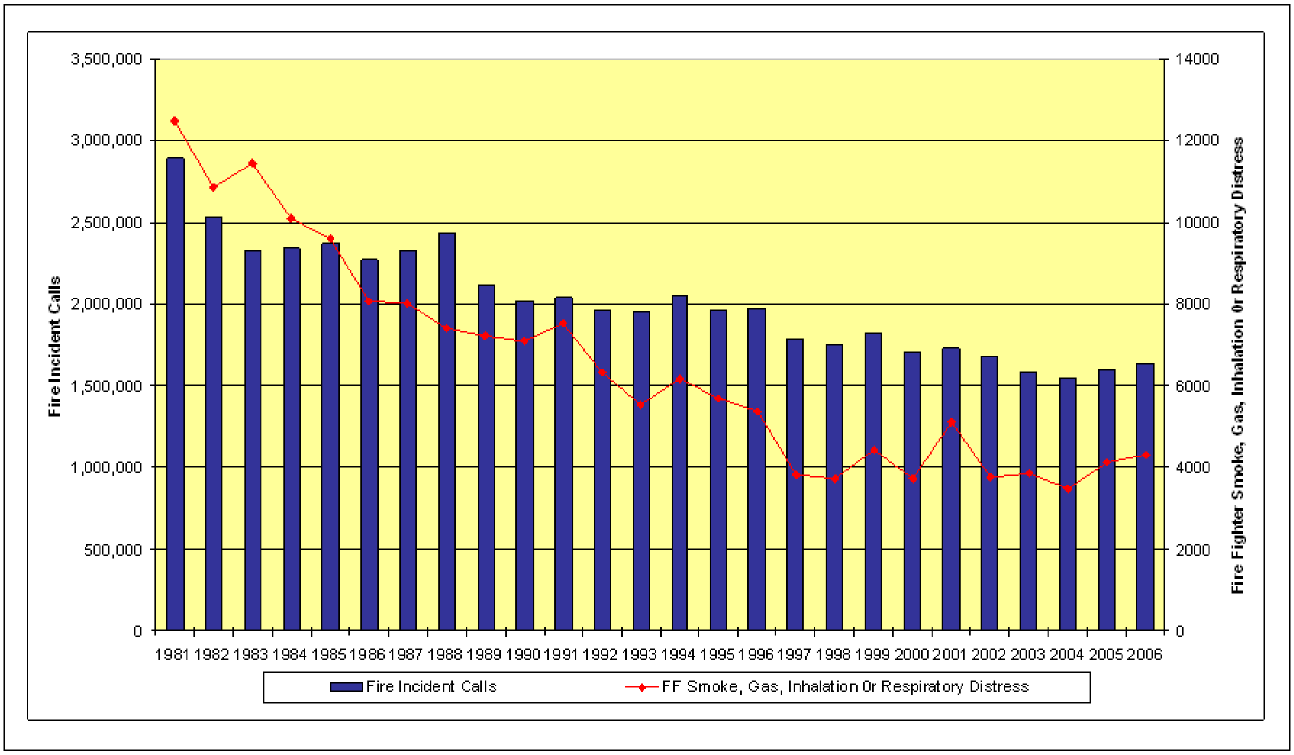


Figure 2-2: Annual U.S. Fire Fighter Respiratory Related Injuries
In Relation to Number of Fire Calls

Although immediately recognized respiratory exposure injuries do not account for a large percentage of overall fire ground injuries to fire fighters (approximately 10 %), the number of injuries that occur each year is nevertheless appreciable. Based on a study of fire fighter injuries during the period of 2001 through 2004, approximately 2,000 U.S. fire fighters annually suffered fire ground injuries that were related to respiratory exposure.[15]

The statistical information illustrated in Table 2-2 and Figure 2-2 is based on injuries that occur on the fire ground that is immediately recognizable for its effect, and this data does not directly address the long term health impact of numerous tolerable exposures occurring over a long period of time, such as a fire fighter's career. A number of projects identified in the literature review of this study have addressed this topic (see Annex A), but questions remain due to the challenging nature of identifying long term effects and ruling out possible other causes of long term health problems.[16, 17, 18, 19, 20, 21]

More specifically, a number of previous studies provide an indication that fire fighters have higher rates of cancer and other specific health implications as compared to the general population.[22] These studies have been conducted with a diverse geographic focus, and have included countries such as Canada, Croatia, France, Japan, New Zealand, Switzerland, Sweden, and the United States (see literature review documents 145 thru 149, and 151 thru 170).

While this implies that health hazards are associated with fire fighting, it does not directly link the effect with a cause. For example, one study of San Francisco fire fighters from 1940 to 1970 indicate a higher occurrence of cirrhosis and other liver diseases, which might be related to alcohol consumption as part of a cultural lifestyle choice outside the normal expected hazards of fire ground activity.[23]

Further, even with concerns focused on respiratory exposure, questions remain as to the cause of various adverse health effects. For example, one study on Philadelphia fire fighters from 1925 to 1986 which raised questions about the exposure to diesel exhaust among the other possible respiratory hazards.[24] Today, just under three-fourths of existing fire stations are not equipped for exhaust emission control, raising questions for how this less obvious particular respiratory hazard is exposing fire service personnel.[25]

c) Airborne Contaminant Hazards

Hazards in the workplace that can cause impaired health, sickness or significant discomfort are generally recognized in one of the following hazard classifications: biological, ergonomic, chemical, psychological, and physical.[26]

Fire fighters face all of these types of hazards, but this study is primarily concerned with respiratory exposure concerns as a result of chemical hazards, and also to a certain extent biological hazards. Chemical hazards are the result of excessive airborne concentrations of mists, vapors, gases or solids in the form of dusts or fumes, which are commonly faced by fire fighters while fighting fires and during overhaul. Biological hazards involve any living organism or its properties that can cause an adverse health effect in humans. Fire fighter exposure to biological hazards is less common than chemical exposure, but still a consideration as a result of CBRN events and fire ground situations where biological hazards are present.

The types of airborne contaminants recognized by industrial hygienists are dusts, fumes, smoke, aerosols, mists, gases, and vapors.[27] These terms each have precise meanings and are not interchangeable. Table 2-3 provides a summary explanation of these commonly used terms.

How an airborne contaminant affects the human body is dependent on how the substance enters the human body. The three routes of entry are inhalation, absorption through the skin, and ingestion. Inhalation is the primary route of entry in the human body for harmful respiratory hazards affecting fire fighters. Absorption and ingestion are other routes of entry, but are outside the scope of this study. The degree of hazard from exposure to harmful airborne contaminants depends on the nature of the energy or material involved, the intensity of the exposure, and the exposure duration.[28]

There are three basic categories of harmful airborne contaminants that affect the lungs: (1) toxic vapors and gases, (2) aerosols, and (3) toxic aerosols or gases that pass through the lungs into the bloodstream.[29] All of these can be found in the atmospheres encountered by fire fighters at any particular fire event. Toxic vapors and gases directly affect the lung tissue, and in some cases cause chemical burns. Aerosols, such as silica dust and other particulates, can produce local lung tissue damage that is rapid or long-term. Toxic aerosols or gases that pass through the lungs and affect the bloodstream generally do not damage the lung itself, and the most common contaminant of this type to fire fighters is carbon monoxide.

Table 2-3: Types of Airborne Contaminants

Type of Airborne Contaminant	Size Range in Diameter[1]	Method of Generation
Dusts	0.1 μm - 25 μm	Handling, crushing, grinding, rapid impact, detonation, decrepitation, of organic and inorganic materials.
Fumes	< 1.0 μm	Formed when the material from a volatized solid condenses in cool air.
Smoke	< 0.1 μm	Consisting of carbon and soot resulting from the incomplete combustion of carbonaceous materials, sometimes as droplets as well as dry particles.
Aerosols		Liquid droplets or solid particles fine enough to remain dispersed in air for a prolonged period of time.
Mists		Finely divided liquid suspended in the atmosphere, caused by condensation of liquids from a vapor state back to a liquid state, or by dispersing a liquid through splashing, foaming or atomization.
Gases		Formless fluids that expand to occupy the volume to which they are confined.
Vapors		Volatile form of substances that are normally in the solid or liquid state at room temperature and pressure.

Note 1: 1 μm = 0.0001 centimeter or 1/25,400 inches

The respiratory hazards faced by fire fighters in battling unwanted fires are numerous and highly variable. This study is primarily focused on airborne contaminants and oxygen depletion because the hazards most commonly encountered by fire fighters. However, it is highly unlikely that any particular fire environment will be well defined, and thus danger from other possible chemical or biological respiratory hazards should always be considered.

The overhaul phase of structure fires is a period of time when the likelihood of respiratory exposure to fire fighters and others is arguably more likely to increase since it is a transitional phase of fire extinguishment with dangers that are less obvious. When an uncontrolled fire rages at its peak energy output, the buoyant forces of the hot gases in the fire plume generally flow upward, and during overhaul this upward buoyancy is not as pronounced resulting in a more stagnant hazardous environment due to the less energetic production of the fire by-products. Thus, the products of combustion occurring during overhaul, despite being generated at a lower rate than the peak fire energy output, can be deceptively hazardous due to the loss of a buoyant fire plume sending the products of combustion skyward.

A number of studies have identified toxic chemicals in fire smoke, [30, 31, 32] and of significance for this study, a few have additionally provided classification of the environment during the overhaul of the fire scene.[33, 34] One study clarifies that the atmosphere during overhaul is deceptively worse than what seems obvious to fire fighters and others exposed to these environments, suggesting that need for a higher level of attention for respiratory protective equipment for this phase of fire fighting.[35]

Also of interest is the changing nature of the fire ground environment that fire fighters face today versus what they faced several decades ago. Prior to and during the World War II era, the materials of construction and interior furnishing involved in a typical structure fire were mainly wood and non-synthetic materials. Today, this has changed considerably with the introduction of many synthetic products, such that the airborne contaminants in a fire situation are different, more complex and potentially more lethal. Several studies examine the changing nature of airborne contaminants that fire fighters are exposed to today.[36, 37]

Reinforcing this perspective of a new challenge in the airborne contaminants facing fire fighters is a specific focus on hydrogen cyanide poisoning. Several studies have identified this as a special threat to the fire service, and especially urban fire fighters engaged with fighting structure fires as opposed to wildland events.[38, 39, 40, 41, 42, 43, 44, 45, 46] In particular, one thorough study by the fire department in Providence, RI provides a detailed analysis of three fires that resulted in cyanide poisoning to their firefighters, and as a result each firefighter carries a separate monitor specifically to monitor HCN levels.[47]

d) Oxygen Content Hazards

Hazards relating to oxygen content occur when the percentage of oxygen being inhaled is at a level that causes temporary or long-term health concerns.[48] Oxygen is a clear, colorless, odorless, and tasteless gas and a primary component of Earth's atmosphere. Oxygen supports combustion and is necessary for plant and animal life.

The hazard to fire fighters involving oxygen content is most commonly an atmosphere that is deficient in its percentage of oxygen, which is a typical occurrence during interior fire fighting since fires consume oxygen during the combustion process.[49] The oxygen thresholds required for proper fire service operations are similar whether it is at a fire, a confined space entry event, or similar activity. According to OSHA, in situations of confined space entry, oxygen levels of less than 19.5 percent should be considered IDLH, and an oxygen level greater than 21 percent by volume should alert the competent person to look for the cause of the oxygen-enriched atmosphere and correct it prior to entry.[50]

Oxygen content hazards are different from the hazards of airborne contaminants faced by fire fighters. Oxygen is required to sustain human life, and ambient air at sea level is comprised of approximately 20.9 percent oxygen. Variations in this percentage result in physiological affects on humans, and a decrease in the percentage of oxygen in air, such as occurs during a fire, can drastically affect the ability of a fire fighter to function. This presents a respiratory hazard to fire fighters that is different than the airborne contaminants previously discussed.[51]

Table 2-4 provides a summary of the physiological effects of oxygen content for atmospheres generally encountered by fire fighters.[52] The physiological effect of oxygen concentrations on the human body is different for each person, and is dependant on multiple factors, including presence of lung disease, blood hemoglobin, kinetics of oxygen-hemoglobin bonding, cardiac output, local tissue blood flow, and oxygen concentration. Table 2-4 is based only on oxygen concentration for a normal healthy human at sea level, and ignores health differences in humans. For example, one would observe a distinct physiological difference between a person who has lived their entire life at sea level and a healthy native Sherpa who regularly lives and works in the extreme altitudes of the Himalaya Mountains.

Table 2-4: Physiological Effect of Oxygen Content in Atmospheres Encountered by Fire Fighters[1]

Altitude	Equivalent Percent Oxygen[2]	Barometric Pressure[3]	Oxygen Partial Pressure[4]	Equivalent Geographic Location[5]	Equivalent Physiological Effect based on Rapid Change from Sea Level[6]
-1,371 Feet (-418 meters)	22.1 %	801 torr (106.4 kPa)	177 torr (23.5 kPa)	Dead Sea, Jordan (Lowest land point)	
0 Feet (0 meters)	20.9 %	760 torr (101 kPa)	159 torr (21.2 kPa)	Sea Level	None
+ 1000 Feet (305 meters)	20.1 %	731 torr (97.4 kPa)	153 torr (20.4 kPa)	Roundwood, Ireland	
+ 2000 Feet (610 meters)	19.3 %	704 torr (93.8 kPa)	147 torr (19.6 kPa)	Mastraszentimre, Hungary	
+ 3000 Feet (914 meters)	18.7 %	677 torr 90.0 kPa)	142 torr (18.9 kPa)	Hogvalen, Sweden	
+ 4000 Feet (1219 meters)	18.0 %	652 torr (86.9 kPa)	137 torr (18.3 kPa)	Finse, Norway	
+ 5000 Feet (1524 meters)	17.2 %	627 torr (83.6 kPa)	131 torr (17.5 kPa)	Cabramurra, Austalia	None in healthy adults
+ 6000 Feet (1829 meters)	16.6 %	603 torr (80.4 kPa)	126 torr (16.8 kPa)	Obergurgl, Austria	Loss of dark adaptation
+ 7000 Feet (2134 meters)	16.0 %	580 torr (77.3 kPa)	121 torr (16.1 kPa)	Sestriere, Italy	Impaired attention/coordination, increased pulmonary and cardio output
+ 8000 Feet (2438 meters)	15.4 %	559 torr (74.5 kPa)	117 torr (15.6 kPa)	Addis Ababa, Ethiopia	Risk of high altitude sickness with rapid exposure to low O2 levels
+ 9000 Feet (2743 meters)	14.7 %	537 torr (71.6 kPa)	112 torr (14.9 kPa)	Assekrem, Algeria	
+ 10,000 Feet (3048 meters)	14.2 %	517 torr (68.9 kPa)	108 torr (14.4 kPa)	Alma, Colorado, USA	
+ 11,000 Feet (3353 meters)	13.7 %	498 torr (66.4 kPa)	104 torr (13.9 kPa)	Raices, Mexico	Abnormal fatigue, faulty coordination, impaired judgment, emotional upset
+ 12,000 Feet (3658 meters)	13.2 %	479 torr (63.8 kPa)	100 torr (13.3 kPa)	Apartadero, Venezuala	
+ 13,000 Feet (3962 meters)	12.8 %	461 torr (61.5 kPa)	98 torr (12.9 kPa)	Gaite, India	
+ 14,000 Feet (4267 meters)	12.2 %	443 torr (59.1 kPa)	93 torr (12.4 kPa)	Parinacota, Chile	Impaired respiration, very poor judgment/coordination, tunnel vision
+16,728 Feet (5100 meters)	11.0 %	399 torr (53.2 kPa)	44 torr (5.8 kPa)	La Rinconada, Peru (Highest Settlement)	
+29,028 Feet (8848 meters)	6.8 %	248 torr (33.1 kPa)	17 torr (2.2 kPa)	Mt. Everest (Highest Land Point)	

Footnotes:

1) Source of values adapted from: (1) "TLVs® and BEIs® Based on Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices", 2006, ISBN 1-882417-62-3, ACGIH Worldwide, 1330 Kemper Meadow Drive, Cincinnati OH 45240-4148; (2) (Brown, JR, Antunano, MJ, "Altitude Induced Decompression Sickness" FAA Publication AM-400-95/2, Federal Aviation Administration, Civil Aerospace Medical Institute, Aeromedical Education Division, Oklahoma City OK, 1995; and (3) McManus, N, "Safety and Health in Confined Spaces", Lewis Publishers, Boca Raton FL, 1999.
2) Equivalent Percent Oxygen based on dry air at sea level. Calculated from $P_{\%O2} = 20.948 \times e^{-(\text{altitude in feet}/25970)}$.
3) Barometric Pressure based on dry air. Calculated from $P_{\text{re: sea level}} = 760 \times e^{-(\text{altitude in feet}/25970)}$.
4) Oxygen Partial Pressure based on dry air at 20.948% O_2. Calculated from $P_{\%O2} = 20.948 \times e^{-(\text{altitude in feet}/25970)}$.
5) Equivalent Geographic Location is based on an approximated elevation only.
6) Equivalent Physiological Effect is based on a healthy adult and depends on multiple factors, including: pulmonary acclimatization, time exposed to oxygen deficient atmosphere, breathing rate, temperature, work rate, health status, and age.

Oxygen partial pressure is an important parameter when considering the physiological effects of oxygen depletion. The effects of a lower concentration of oxygen can be compensated for by a higher partial pressure, such that the human body will still receive the necessary oxygen flow in the bloodstream and no obvious ill effect is observable. Similarly, the effects of a lower partial pressure can be compensated for by a higher oxygen concentration. A rapid decrease in pressure, in combination with various other factors resulting in less oxygen reaching the bloodstream, can result in decompression sickness, also know by the slang term as “the bends”. This is a well-recognized danger to aircraft pilots, balloonist, scuba divers and anyone who might experience a rapid change in pressure.[53] For example, aircraft are required (by the U.S. Federal Aviation Administration) to use supplemental oxygen if they fly above 12,500 feet for 30 minutes or longer, or if they fly at 14,000 feet at any time during their flight.

The effective performance time of a person exposed to an oxygen deficient atmosphere is dependent on a variety of factors. The equivalent physiological effect indicated in Table 2-4 should be considered as a rough estimation, and other factors that will alter the effects include pulmonary acclimatization, time exposed to oxygen deficient atmosphere, breathing rate, temperature, work rate, health status, and age. Thus, normal fire fighter characteristics such as degree of physical activity at the time of exposure and general pulmonary health can cause these effects to significantly vary.[54]

In rare situations, a hazard can also occur with atmospheres that are too rich in oxygen content. Examples of such an incident might be a confined space event at an industrial, health care or research occupancy, involving an oxygen leak or occurring in an area utilizing an oxygen enriched atmosphere. In the unusual event that an atmosphere has a concentration higher than 21 percent, the hazard for fire fighters is less a respiratory concern and more a combustion concern, as the burning characteristic of materials can change dramatically and fire fighters should be extremely cautious that intense fire situations do not occur. From a respiratory standpoint, the inhalation of oxygen is appropriate if used properly for certain medical emergencies or long-term therapy under the direction of a physician. Inappropriately high and long term oxygen concentrations are, however, like any other high exposure situation and can have detrimental health effects. For example, one hundred percent oxygen at atmospheric pressure can cause pulmonary edema after 24 hours of exposure.[55] Therefore, any respiratory protective approach based on equipment that utilizes oxygen enrichment should be done under the auspices of qualified medical personnel.

e) Regulations and Recommendations

Most developed countries have occupational safety and health organizations addressing safety in the workplace. In the United States this role is handled by the U.S. Occupational Safety and Health Administration (OSHA), which operates under the Department of Labor. In addition, approximately half of the states also have state OSHA programs that perform a similar complementary function.

OSHA came into existence on April 28, 1971 when the Occupational Safety and Health Act (OSHAct) went into effect. This act also established the National Institute for Occupational Safety and Health (NIOSH). NIOSH is housed in the Centers for Disease Control (CDC) under the U.S. Public Health Service. OSHA is empowered to promulgate safety and health standards with advice from NIOSH, while NIOSH is the principal federal agency engaged in occupational safety and health research.[56]

An additional organization aside from OSHA and NIOSH involved with respiratory protection and of interest to first emergency responders is the American Conference of Governmental Industrial Hygienists (ACGIH). The ACGIH is a member based organization whose mission is to advance occupational and environmental health.[57]

Table 2-5: Threshold Concentration Values for
Certain Hazardous Gases Encountered by Fire Fighters[1]

Substance (Conversion value from ppm to mg/m^3)[5]	IDLH[6]	Exposure Time Period	U.S. OSHA[2] PEL[7]	NIOSH[3] REL[8]	ACGIH[4] TLV[9]
CO Carbon monoxide (1 ppm = 1.15 mg/m^3)	1200 ppm	TWA[10] (8 Hr Exp)	50 ppm	35 ppm	25 ppm
		STEL[11] (15 Min Exp)	---	---	---
		C[12] (Immediate Exp)	---	200 ppm	---
HCN Hydrogen cyanide (1 ppm = 1.10 mg/m^3)	50 ppm	TWA (8 Hr Exp)	10 ppm	---	---
		STEL (15 Min Exp)	---	4.7 ppm	---
		C (Immediate Exp)	---	---	4.7 ppm
H_2S Hydrogen sulfide (1 ppm = 1.40 mg/m^3)	100 ppm	TWA (8 Hr Exp)	---	---	10 ppm
		STEL (15 Min Exp)	---	---	15 ppm
		C (Immediate Exp)	20 ppm	10 ppm	---
N_2O Nitrous oxide (1 ppm = 1.80 mg/m^3)	Not Determined	TWA (8 Hr Exp)	---	25 ppm	50 ppm
		STEL (15 Min Exp)	---	---	---
		C (Immediate Exp)	---	---	---
SO_2 Sulfur dioxide (1 ppm = 2.62 mg/m^3)	100 ppm	TWA (8 Hr Exp)	5 ppm	2 ppm	2 ppm
		STEL (15 Min Exp)	---	5 ppm	5 ppm
		C (Immediate Exp)	---	---	---

Footnotes:

1) Based on regulations and widely recognized recommendations applicable to fire fighters within the United States.
2) U.S. OSHA = U.S. Occupational Safety and Health Administration, operating within the U.S. Department of Labor.
3) NIOSH = National Institute for Occupational Safety and Health, operating within the Center for Disease Control (CDC).
4) ACGIH = American Conference of Governmental Industrial Hygienists.
5) Unit conversion for each substance from ppm = "parts per million" to mg/m^3 = "milligrams per cubic meter".
6) IDLH = "Immediately Dangerous to Life and Health", as defined by NIOSH.
7) PEL = "Permissible Exposure Limit", which is the primary U.S. OSHA threshold concentration value.
8) REL = "Recommended Exposure Limit", which is the primary NIOSH threshold concentration value.
9) TLV = "Threshold Limit Value", which is the primary ACGIH threshold concentration value.
10) TWA = "Time Weighted Average", which is the weighted average concentration over an exposure time period based on a normal 8 hour workday and a 40 hour workweek to which all workers may be repeatably exposed without adverse effect. All OSHA thresholds concentrations are based on TWA. NIOSH and ACGIH likewise use TWA, but additionally provide recommendations for other exposure time periods.
11) STEL = "Short Term Exposure Limit", which is the Time Weighted Average concentration for a 15 minute short term exposure to which all workers may be repeatably exposed without adverse effect.
12) C = "Ceiling", which is the threshold concentration value which should not be exceeded at any time.
13) Source of values for OSHA and NIOSH taken from "NIOSH Pocket Guide to Hazardous Chemical Hazards", Sept 2005, DHHS (NIOSH Publication No. 2005-149, Stock No. B2005-108099, U.S. Government Printing Office, P.O. Box 371954, Pittsburgh PA 15250-7954.
14) Source of values for ACGIH taken from "TLVs® and BEIs® Based on Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices", 2006, ISBN 1-882417-62-3, ACGIH Worldwide, 1330 Kemper Meadow Drive, Cincinnati OH 45240-4148.
15) For additional useful interpretative information, see Plog, BA, Niland, J, Quinlan, PJ, "Fundamentals of Industrial Hygiene", 4th Edition, 1996, National Safety Council, Itasca Illinois.

All three organizations, OSHA, NIOSH and ACGIH, provide detailed information that fire fighters can use to measure a hazardous environment such as during overhaul or an exterior fire. During and after a fire, fire fighters will often measure the concentration of different environmental contaminants and other characteristics using hand-held portable gas monitors to clarify which respiratory protective equipment is appropriate. The first step is to compare them with the relevant standards and guidelines.

Table 2-5 provides a summary of the threshold concentrations for certain hazardous gases frequently encountered by fire fighters. The gases considered are carbon monoxide, hydrogen cyanide, hydrogen sulfide, nitrous oxide and sulfur dioxide, as these were the gases addressed in the information collection portion of this study. It is noted, however, that in addition to these airborne contaminants a relatively wide spectrum of respiratory hazards are regularly faced by fire fighters, including, for example, acrolein, asbestos, benzene, various aldehydes (acetaldehyde, benzaldehyde, formaldehyde, glutaraldehyde, isovaleraldehyde), hydrogen chloride, nitrogen dioxide, and respirable particulates.[58] This is in addition to the additional respiratory concern of oxygen depletion.

For the five airborne contaminants addressed in Table 2-5, the legally enforceable maximum allowed exposures are the OSHA "Permissible Exposure Limits" (PEL) and are from the Code of Federal Regulations, 29 CFR 1910.1000. Table 2-5 also includes the recommended exposure limits provided by NIOSH based on their "Recommended Exposure Limits", and the "Threshold Limit Values" provided by ACGIH.

Interestingly, the threshold values in Table 2-5 are consistent but not precisely the same. This is due to several factors, including the date the values were established, when they were updated, frequency of update, time span for the exposure, and other similar considerations.[59] From the perspective of fire fighters using hand-held gas monitors to measure a fire ground atmosphere, attention needs to be given to adhering to OSHA requirements (and any other applicable requirements if they exist), and then recognizing the additional guidance that is provided by NIOSH, ACGIH and others so that, in addition to the necessary factors of safety, they adopt the most appropriate and generally reasonable good field practice.

Table 2-5 also includes a value for each airborne contaminant for the IDLH (immediately dangerous to life or health) threshold measurement. An important concept for fire fighters or anyone else in a hazardous environment is that the exposure hazard is time dependent. In general, a human can withstand exposure to a particular airborne contaminant for low concentrations over long periods of time, and high concentrations for short periods of time.

A helpful analogy on the fire ground to better understand this concept is that of the temperature of a fire, where a fire fighter can generally withstand lower temperatures for long periods of time and higher temperatures for short periods of time. From a respiratory exposure standpoint, an important consideration is that the physiological health effects of each airborne contaminant are different, including their differences between high-concentration/short-term exposures versus low-concentration/long-term exposures. For example, the chronic or long-term effects on the human body by carbon monoxide and hydrogen cyanide are quite different, and these differences are used for the establishment of the IDLH values for each substance.

This section has focused on the regulatory requirements and recommendations in the United States that directly relate to airborne contaminants as faced by fire fighters and other emergency responders. Additional standardized information from a wide spectrum of organizations also relates in a less direct way to this topic, some from other government agencies (e.g., U.S. Environmental Protection Agency) and some from non-government sources (e.g., ASHRAE, ASTM, NFPA). An example would be the regulatory requirements from the U.S. Department of Transportation that apply to the pressurized cylinders of air used with SCBA.

3) REVIEW OF LITERATURE

a) Literature Review Methodology

The literature that has been reviewed and analyzed for this respiratory exposure study is summarized in Annex A. Table A-1 summarizes this information sorted in the order of the document identification number (Doc #), and Table A-2 is the same information but sorted by relevance and author.

To better assist individuals using the literature summary, several mechanisms have been introduced to facilitate the handling and use of this information. In addition to the general citation information, a note field ("notes") has been included that provides a brief indication of what the citation addresses and how it relates to respiratory exposure concerns for first emergency responders. Another field is the "# citations", which indicates the known number of citations to this particular item by other published works.

The literature generally fits into three basic categories of subject matter, and this is illustrated in Figure 3-1. These three realms are: Environment, Personnel, and Tools. In the literature review summaries (Tables A-1 and A-2), these basic realms are represented by the first initial of each term, i.e. "E", "P", and "T" under "Category". For example, if a particular article is focused more toward the acute or long term physiological health impact on humans it would be designated with "P". Similarly, if a citation focuses on measuring airborne contaminants or the make-up of smoke it would be designated by "E". Finally, citations focusing on respiratory protective equipment or devices used for measurement would have a "T" designation.

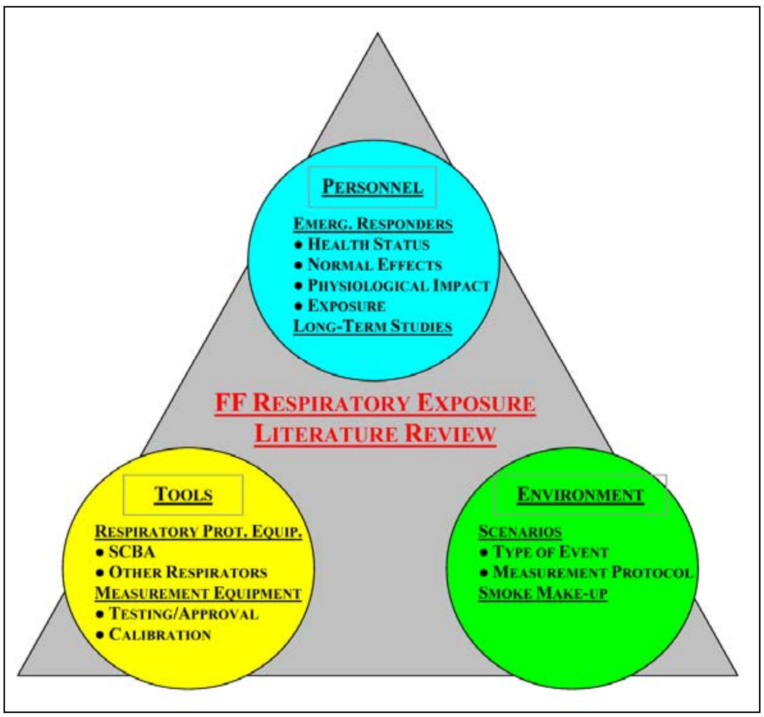


Figure 3-1: Literature Review Relevance

Numerous literature citations cover more than one of these three basic categories, and thus all three would be included, in order of which is considered most prominent. An example would be "PTE" for an article that has a predominant focus on human health effects but also addresses the equipment used and to a lesser extent touches on the composition of the environment. Admittedly this is a subjective characterization, but nevertheless it is offered to provide the user of this information with some helpful guidance.

As the literature was collected and reviewed for this study, each citation was also provided with a rating as to whether its relationship to the focus of this study was "critical", "major" or "minor". In Tables A-1 and A-2 this is referred to as the "Relevance". Like the aforementioned categories this too is admittedly subjective, but nevertheless deemed to be worthy and is included to assist others with processing this information. In addition to the three primary relevance types, two other characteristics are "reference" and "support". These are explained in Table 3-1.

Table 3-1: Definition of Literature Review Characteristics

	SCOPE RELATIVITY (Directly Related / Indirectly Related)	CONTRIBUTION (Original / Repetitious)	APPLICABILITY (Current / Outdated)	CONTENT (Shallow/ Rich)
Critical	Directly addresses project scope	Original	Current and Timeless	Rich in content
Major	Partially addresses project scope	Partially original	Somewhat current	Some applicable content
Minor	Indirectly addresses project scope	Repeat of earlier work	Somewhat outdated	Superficial or shallow content
Reference	Makes same point as other articles; superseded by other articles; potentially out of date			
Support	Describes common accepted practices; Provides background support information; Generally independent of date			

To further clarify the thought process in determining each relevance designation, the characteristics of "scope relativity", "contribution", "applicability" and "content" were all considered as illustrated by the columns in Table 3-1. "Scope relativity" addresses if the citation is directly or indirectly related to the subject of respiratory exposure to first emergency responders, while "contribution" considers if the citation is original or repetitious of earlier work. "Applicability" seeks to clarify the age of the publication, i.e. if it is current or outdated, and "content" addresses the substance of the published materials as it relates to the subject matter of this study.

b) Implementation and Results

The literature review includes more than 200 citations for documents that relate in some fashion to respiratory protection for fire fighters and other emergency responders. This review has been limited to the practical limits of addressing this subject matter, and it's acknowledged that extensive additional indirectly-related documents are available through various sources, such as regulatory documents from OSHA or recommended guidelines from NIOSH.

Of the three designated categories, the most common is "Personnel" with 136 citations, followed by "Environment" with 72 and "Tools" with 21. The primary focus of this literature review has been on published literature with a preference toward peer reviewed publications. Information such as manufacturer's literature has not been included.

In recognition that the user of this information may have preference for certain sub-topics, Table 3-2 provides a cross summary of the literature review categories by document number. This allows a focus toward the subject matter of most interest to the user of this study.

Table 3-2: Cross Summary of Literature Review Categories by Document Number

	E (Environment)	P (Personnel)	T (Tools)
Critical	001, 002, 003, 004, 005, 007, 008, 009, 012, 013, 014, 090, 119, 120, 135, 136, 137, 141, 173, 208, 219, 220, 221, 222, 224, 231	001, 002, 003, 004, 005, 007, 008, 009, 010, 011, 012, 013, 014, 016, 038, 135, 137, 145, 146, 147, 148, 151, 152, 153, 154, 155, 156, 159, 161, 162, 163, 165, 168, 169, 173, 176, 208, 224, 231	008, 009, 011, 013, 135, 208, 231
Major	006, 015, 026, 043, 067, 075, 076, 085, 093, 094, 101, 109, 124, 125, 126, 127, 128, 129, 130, 134, 139, 142, 143, 171, 172, 190, 197, 207, 210, 211, 212, 225	006, 043, 047, 067, 068, 078, 081, 091, 093, 094, 095, 100, 104, 109, 124, 125, 126, 129, 130, 134, 139, 142, 149, 157, 158, 164, 167, 170, 171, 172, 174, 175, 179, 181, 182, 183, 184, 187, 190, 194, 207, 212	015, 026, 042, 043, 067, 078, 086, 094, 101, 109, 129, 130, 139, 142, 225
Minor	049, 050, 060, 071, 074, 079, 080, 097, 098, 099, 102, 110, 111, 112, 113, 114, 115, 116, 117, 118, 132, 133, 138, 144, 150, 196, 226, 227, 228, 230	017, 018, 019, 020, 021, 027, 039, 040, 044, 045, 048, 050, 051, 052, 053, 057, 058, 059, 063, 065, 066, 069, 070, 072, 073, 079, 092, 097, 102, 103, 105, 106, 108, 110, 112, 113, 114, 115, 116, 117, 118, 121, 122, 138, 160, 166, 177, 178, 180, 185, 186, 188, 189, 191, 192, 193, 195, 196, 198, 199, 200, 201, 202, 203, 204, 205, 206, 209, 213, 214, 215, 216, 217, 223, 226, 227, 228	021, 079, 096, 097, 102, 111, 123, 216, 217, 218, 227, 228
Reference	023, 034, 041, 046, 054, 055, 064	023, 062, 229	022, 024, 025, 088, 229
Support	037, 056, 061, 087, 089, 140, 233	028, 029, 030, 031, 032, 033, 035, 036, 077, 107, 131, 233	083, 084, 232, 233

There are numerous useful articles in the literature that can assist further study on the subject of respiratory protection, depending on the specific sub-topic being pursued. Several observations are offered on this collection.

The literature survey was less robust on the subject of "Tools" than the other two categories. The design and implementation of various tools and equipment is well established by various manufacturing interests, although some of this information is proprietary or manufacturer specific, and thus not necessarily suitable for peer reviewed literature.

Several studies in the literature are attractive because of their usefulness and potential field adaptability. This includes papers such as "Characterization of Firefighter Exposures During Overhaul" that evaluates the overhaul environment and recommends SCBA during overhaul for lack of a better respirator, and also indicates that carbon monoxide should not be used to predict the presence of other contaminants found in the overhaul environment.[60] Another investigation of interest because of its utility and direct fire service application is the "Report of the Investigation Committee into the Cyanide Poisoning of Providence Fire Fighters" (Doc-013) which provides a detailed analysis of the dangers of hydrogen cyanide poisoning from today's typical urban structural fire.

Certain aspects of the literature summarized in this report are often of specific interest to certain identified constituent groups. For example, fire investigators are faced with the overhaul and post-overhaul environment, and certain dangers are still readily present, as clarified in reports like "ATF Health Hazard Evaluation Report HETA 96-0171-2692".[61] Even though the post-overhaul fire scene tends to have less off-gassing and combustion by-products than an active fire or an overhaul situation, fire investigators frequently remain at the site for longer periods of time and face atmospheres where adequate ventilation may be compromised. While many of the studies in the literature review are applicable to post-fire (i.e., overhaul) environments and apply equally to fire investigators as well as front-line fire fighters, several studies are specifically focused to fire investigators such as: Document #s 090, 110, 111, and 141.

Another sub-topic of interest to a specific constituent group is that involving wildland or bush fires. These fire events present special challenges because fire fighters can be exposed to airborne particulates for relatively long periods of time, and they are often in remote areas where respiratory protective equipment used in an urban setting is not practical. Many of the citations indicated in the literature review are applicable to wildland and bush fire fighting events. In particular, the following citations have a specific focus toward wildland and bush fire events: Document #s 004, 006, 012, 040, 041, 043, 046, 049, 055, 094, 104, 129, 130, 136, 137, 197, 206, 207, 208, 210, 211, 212, 219, 220, 221, 222, 225 and 230.

One important question for fire fighters and other first emergency responders is how repeated short term exposures to adverse respiratory atmospheres affect their long term health. A number of studies identified in the literature review have addressed this topic, but questions remain due to the challenging nature of identifying long term effects and ruling out possible other causes of long term health problems.[62, 63, 64, 65, 66, 67]

Several previous studies provide an indication that fire fighters have higher rates of cancer and other specific health implications as compared to the general population.[68] These studies have been conducted with a diverse geographic focus, and have included countries such as Canada, Croatia, France, Japan, New Zealand, Switzerland, Sweden, and the United States (see literature review documents 145 thru 149, and 151 thru 170). While this implies that health hazards are associated with fire fighting, it does not directly link the effect with a cause. For example, one study of San Francisco fire fighters from 1940 to 1970 indicate a higher occurrence of cirrhosis and other liver diseases, which might be related to alcohol consumption as part of a cultural lifestyle choice outside the normal expected hazards of fire ground activity.[69] Further, even with concerns focused on respiratory exposure, questions remain as to the cause of various adverse health effects, such as one study on Philadelphia fire fighters from 1925 to 1986 which raised questions about the exposure to diesel exhaust in the apparatus-bay among the other possible respiratory hazards.[70]

4) REVIEW OF EQUIPMENT

a) Hazardous Atmosphere Monitoring Equipment

Portable hand-held gas or atmospheric monitors are available for a wide range of emergency response applications. These are designed for a broad spectrum of performance objectives utilizing multiple technologies.[71] The various technological approaches used each have advantages and disadvantages, and the ultimate end-user of the equipment must judge which technology is most appropriate based on important considerations such as ease of use, ruggedness, maintainability, accuracy, sensitivity, real-time operability, cost, and other factors deemed important.[72]

Today, different sensing technological approaches are available, and the decision on what may be most appropriate depends on multiple factors. Manufacturers have made significant advances in recent years, and currently the problem is less about applying these technological advancements and more about clarifying what the end-user community ultimately desires.[73] Table 4-1 provides a summary of different types of gas sensing technologies, and illustrates the significant diversity of tools available for this purpose.[74]

Table 4-1: Examples of Gas Sensing Technology

Catalytic Combustible Gas Sensors	Gas Chromatographs	Photoionization Detectors
Colorimetric Method	Infrared Gas Sensors	Radioactive Ionization Detectors
Electrochemical Sensors	Luminescence-Based Analyzers	Solid-State Gas Sensors
Flame Ionization Detectors	Mass Spectrometers	Solid-State Zirconium Oxide Oxygen Detectors
Fourier Transform Infrared Analyzer	Paramagnetic Oxygen Analyzers	Thermal Conductivity Detectors

Source: Chou, J, "Hazardous Gas Monitors: A Practical Guide to Selection, Operation and Applications", McGraw-Hill Company, NY, 2000.

Certain additional features are important beyond the technology used for the gas sensors themselves, and these should also be taken into account when investigating the most optimum equipment package. For example, real-time feedback may be considered a priority feature, as has been demonstrated for wildland fire fighters to allow them to take appropriate evasive action on the fire ground.[75] Another example may be the wireless transmission of real-time details of a structure fire overhaul environment to a remote location such as incident command, which can review and store these readings.[76] Some of these additional attributes can be extremely useful during certain events that require remote monitoring (e.g. haz-mat incidents or confined space entry), or to provide documentation for post-event analysis.

Fire fighters use gas monitoring equipment to identify the composition of a particular environment by taking a sample or set of samples. How well this sample or set of samples represents the actual measured environment depends on the accuracy and precision of the measurements.[77] Accuracy addressees the relationship between a measured value its true value, while precision describes the ability to reproduce the same results each time. It's possible for instruments to have any combination of accuracy, inaccuracy, precision and imprecision levels. Figure 4-1 provides a useful visualization of the concepts of accuracy and precision. This methodology provides a means of determining the confidence of a measured sample set of the airborne environment.

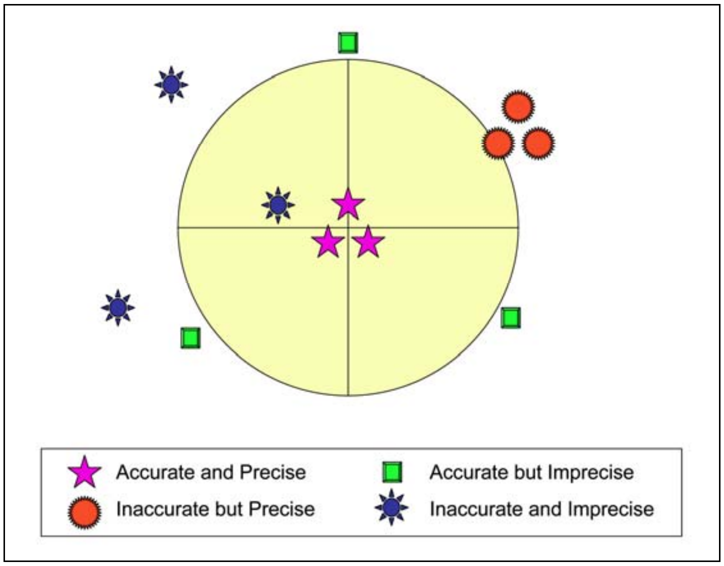


Figure 4-1: Visualization of the Concepts of Accuracy and Precision

The need for equipment that is accurate and precise is partially addressed by proper maintenance and calibration techniques. The reliable use of portable atmospheric monitoring equipment requires that they are calibrated on a regular basis to assure performance within acceptable limits. Calibration procedures vary widely between various types of equipment, and the regularity of full calibration tests depends on the type of technology used. It is important to establish the ability of an instrument to respond to the substance it was designed to detect, and calibration procedures with standardized concentrations provide this clarification.[78] Some manufacturers address the challenges of calibration with design features such as a monitor docking platform to perform routine calibration and other functions (e.g. power supply recharging) when the units are not being used.

The respiratory hazards encountered by fire fighters and other emergency responders are dynamic and complex. Every incident is unique and will present different challenges with regard to atmospheric measurement. Table 4-2 illustrates this concept by comparing the typical measurement approaches used in the following four fire service applications: structure fire, wildland fire, hazardous materials incident, and confined space entry.[79]

For any of the incidents indicated in Table 4-2 it's possible to have any combination of hazards present at any time. The probability of any type of hazard depends on the particular event and multiple factors, though some hazards are more likely in certain applications. For example, we would normally expect a radiation hazard to be more probable at a hazardous materials incident rather than a wildland fire. Nevertheless, it is important to recognize that all of these different atmospheric hazards are possible, and they all require different detection methods.

Table 4-2: Comparison of Typical Measurement Characteristics for Portable-Hand-Held-Atmospheric-Measurements Used in Selected Fire Service Applications

	Structure Fire	Wildland Fire	Haz-Mat Incident	Confined Space Entry
1	Toxic Gas	Toxic Gas	Flammable Gas	Toxic Gas
2	Oxygen Concentration	Particulates	Toxic Gas	Oxygen Concentration
3	Flammable Gas	Oxygen Concentration	Corrosive Agents	Flammable Gas
4	Corrosive Agents	Corrosive Agents	Radiation	Corrosive Agents
5	Particulates	Flammable Gas	Biological Agents	Particulates
6	Biological Agents	Biological Agents	Particulates	Biological Agents
7	Radiation	Radiation	Oxygen Concentration	Radiation

Adapted from: 1) Hawley, C, "Hazardous Materials Air Monitoring & Detection Devices", Thompson Delmar Learning, NY, Second Edition, 2007; and 2) "2006 Annual Report - 2007 Standardized Equipment List", The Interagency Board, 1550 Crystal Drive, Suite 601, Arlington, VA.

Fire service organizations are often seeking a single airborne contaminant that they can conveniently measure in lieu of all others. However, there is no monitoring technique that can detect all airborne hazards, and a typical fire environment is replete with multiple respiratory dangers. For structure fire overhaul environments, some fire service organizations are using multi-channel portable meters to measure multiple toxic gases, multiple flammable gases, and oxygen concentration. Simply measuring a single gas, such as carbon monoxide, is not adequate, and the more characteristics of the airborne environment that are measured the better.[80]

A useful resource for fire service personnel and other first emergency responders to determine the most appropriate gas monitoring equipment for their needs is through the "Responder Knowledge Base" or "RKB".[81] This web-based resource serves the emergency response community and provides an integrated listing of both the Authorized Equipment List (AEL) and the Standardized Equipment List (SEL).

The Authorized Equipment List is produced by the Department of Homeland Security (DHS), and is the generic list of equipment items allowable under certain DHS grant programs. The Standardized Equipment List is produced by the InterAgency Board for Equipment Standardization and Interoperability (IAB), and contains minimum equipment recommendations for response to Weapons of Mass Destruction (WMD) incidents.

Table 4-3 illustrates a summary of the portable chemical detection equipment recognized by the Authorized Equipment List and Standardized Equipment List. This provides a convenient platform to analyze and compare different specific technologies and equipment. All but one of the twenty-one described technologies (the one exception is 07CD-01-NAA) are appropriate for use with "Fire Incident Response Support". In the Responder Knowledge Base, "Fire Incident Response Support" is the term used to describe the coordination and implementation of fire suppression operations. This includes, among other activities, search and rescue, fire containment and control, overhaul operations, and cause and origin investigation.

As an example of the usefulness of this information, an individual interested in obtaining a multi-sensor gas detection meter for point chemical detection can go to this website and perform a comparison of the products recognized by the AEL and SEL. At this time this included 40 separate products recognized by the AEL and SEL, which is not an exhaustive list. This allows a comparison of important features and operating considerations, such as calibration, shelf life, sensitivity, cost, training, etc...

Table 4-3: Portable Chemical Detection in Combined IAB Standardized Equipment List and DHS Authorized Equipment List

AEL/SEL Classification Number	Description	Number of SEL Example Products[1]
[07CD-01-CLAS]	Waste water classifier strips, pH and chemical	2
[07CD-01-DPFI]	Flame ionization detector for point detection of volatile organic compounds	2
[07CD-01-DPFP]	Flame photometry detector for point chemical agent detection	7
[07CD-01-DPIR]	Point chemical agent detector utilizing infrared spectroscopy	0
[07CD-01-DPMG]	Multi-sensor meter with minimum for point chemical detection	40
[07CD-01-DPPI]	Photo-ionization detector for point detection of volatile organic chemicals	12
[07CD-01-DPRS]	Point chemical agent detector utilizing Raman spectroscopy	5
[07CD-01-DPSI]	Ion mobility spectrometry detector for point chemical agent detection	17
[07CD-01-DPSW]	Surface acoustic wave detector for point chemical agent detection	7
[07CD-01-FTIR]	Detector utilizing infrared spectroscopy with Fourier Transform capability	0
[07CD-01-INPA]	Indicating paper, chemical warfare agent	4
[07CD-01-INTP]	Indicating tape, chemical warfare agent	1
[07CD-01-KCTC]	Colorimetric tape/tube/chip kit for specific applications	27
[07CD-01-KLSV]	Chemical classifying kit for unknown liquids, solids and vapors	1
[07CD-01-KPCB]	PCB Test Kit	0
[07CD-01-KTHG]	Mercury and mercury vapor test kit	0
[07CD-01-KWTR]	Chemical agent water test kit	9
[07CD-01-M256]	M-256(A1) detection kit for chemical agent	0
[07CD-01-MONO]	Single gas meter with point chemical detection	15
[07CD-01-PNAA]	Non-Invasive Chemical detector utilizing pulsed neutrons	0
[07CD-01-POLY]	Reactive polymer point chemical agent detector	1

1. The number of example products referenced in the Responder knowledge Base is not an exhaustive list and is cited as of 28 November 2007.

Adapted from: "Responder Knowledge Base", www.rkb.mipt.org, Memorial Institute for the Prevention of Terrorism, DHS Award Number 2007-MU-T7-K001, (public domain portion of posted web information), date cited 28/Nov/2007.

b) Respiratory Protective Equipment

While hazardous atmosphere monitoring equipment is used to detect a dangerous airborne environment, protective equipment is still needed to enter or work in atmospheres that contain the respiratory hazards. Foremost among the arsenal of equipment used by today's fire service is self contained breathing apparatus (SCBA). SCBA are required for all fire fighting operations except wildland, and are also used for various special operations such as confined space entry, hazardous materials incidents, and urban search and rescue activities.[82]

The widespread application of SCBA in the United States is due to OSHA requirements for all interior fire fighting activities that involve IDLH or unknown atmospheres. Specifically, OSHA requires that approved self-contained breathing apparatus with full-face-piece, or with approved helmet or hood configuration, be used while working inside buildings or confined spaces where toxic products of combustion or an oxygen deficiency may be present.[83]

SCBA are part of the atmosphere-supplying respirator family that includes supplied air respirators (SARs) or airline respirators, which is equipment that uses a continuous air-line supply. Two important classification sets that apply to SCBA are positive pressure versus negative pressure, and open circuit versus negative circuit. These are summarized in Table 4-4, as defined in NFPA 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services*.

Table 4-4: Types of Self Contained Breathing Apparatus (SCBA) Used by the Fire Service

Self-Contained Breathing Apparatus (SCBA). An atmosphere-supplying respirator that supplies a respirable air atmosphere to the user from a breathing air source that is independent of the ambient environment and designed to be carried by the user.

- **Open-Circuit SCBA.** An SCBA in which exhalation is vented to the atmosphere and not rebreathed.
- **Closed-Circuit SCBA.** A recirculation-type SCBA in which the exhaled gas is rebreathed by the wearer after the carbon dioxide has been removed from the exhalation gas and the oxygen content within the system has been restored from sources such as compressed breathing air, chemical oxygen, liquid oxygen, or compressed gaseous oxygen.

- **Positive Pressure SCBA.** An SCBA in which the pressure inside the facepiece, in relation to the pressure surrounding the outside of the facepiece, is positive during both inhalation and exhalation when tested by NIOSH in accordance with 42 CFR 84, Subpart H.
- **Negative Pressure SCBA.** An SCBA in which the pressure inside the facepiece, in relation to the pressure surrounding the outside of the facepiece, is negative during any part of the inhalation or exhalation cycle when tested by NIOSH in accordance with 42 CFR 84.

Source: NFPA 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services*, National Fire Protection Association, Quincy MA, section 3.3, 2007 Edition

For the SCBA characteristic of positive pressure versus negative pressure, only pressure-demand or other positive-pressure self-contained breathing apparatus should be worn by fire fighters performing interior structural fire fighting (according to OSHA regulation that became effective as of 1 July 1983).[84] The other characteristic of interest is open-circuit versus closed circuit. Open-circuit SCBA is significantly more common since it is less maintenance intensive than closed-circuit technology (closed-circuit units are also referred to as re-breathers). Some fire service organizations utilize SARs or closed-circuit SCBA in addition to their open-circuit SCBA because SARs and closed-circuit SCBA generally have long operability time, making them useful for certain specialized confined space applications (e.g., long subway tunnels).

Wildland fire fighting is the only type of fire fighting activity where respiratory protection is not required.[85] This is partly due to the logistical challenges of using SCBA, which are not practical for wildland fire fighters because they typically operate in remote locations for very long periods of time. A perception exists that the respiratory hazards of wildland fires are less in a relative sense than the respiratory hazards from urban structure fires, but the respiratory hazards nevertheless remain a concern. As one recent action toward addressing these concerns, in March 2007 by the NFPA Standards Council approved a request to develop a new document to address the respiratory hazards faced by wildland fire fighters, and assigned this activity to the project on Fire and Emergency Service Protective Clothing and Equipment.[86]

Two other types of respiratory protective equipment sometimes found within the portfolio of equipment used by the fire service are air-purifying respirators (APRs) and powered air-purifying respirators (PAPRs). An air-purifying respirator is a respirator with an air-purifying filter, cartridge, or canister that removes specific air contaminates by passing ambient air through the air-purifying element.[87] A powered air-purifying respirator uses a power source to operate a blower that passes air across a cleansing element to supply purified air to the respiratory inlet.[88] Although APRs and PAPRs may offer certain advantages such as portability and long operation times, they likewise have certain significant handicaps such as ineffectiveness against certain airborne contaminants and inability to deal with oxygen deficient atmospheres.

5) Data Collection Method

a) Information Collection Methodology

The information collection form used in this study was implemented electronically on-line using a designated page on the NFPA website, and was available for completion for an approximate a two month period starting in late summer 2007.

This study uses an interpretive qualitative approach as the method for gathering information. Qualitative methods can, at times, provide an optimal approach to prevention efforts because they provide valuable insight into the antecedents of injury that are needed to design effective interventions.[89] The information collected for this study was openly solicited using a structured collection form, and respondents were openly urged to respond through multiple media and request mechanisms.

Notification of its availability was forwarded to various fire service related outlets. Direct email requests were sent to all the fire service representatives serving on NFPA Technical Committees, and special published notices were provided through multiple NFPA related outlets, including NFPA News, and publications and/or business meetings for the NFPA Fire Service Section, the International Fire Marshals Association, and the NFPA/IAFC Metro-Chiefs Section. In addition, a multitude of other applicable organizations were made aware of the availability of the web-based information collection form, including the International Association of Fire Chiefs, International Association of Fire Fighters, the U.S. Branch of the Institute of Fire Engineers, the International Association of Arson Investigators, the National Association of State Fire Marshals, and the National Volunteer Fire Council.

Although the information collection form is focused and targeted toward the fire service, the final information collected and the final analysis is applicable to other emergency responders who may occasionally find themselves in similar respiratory exposure situations.

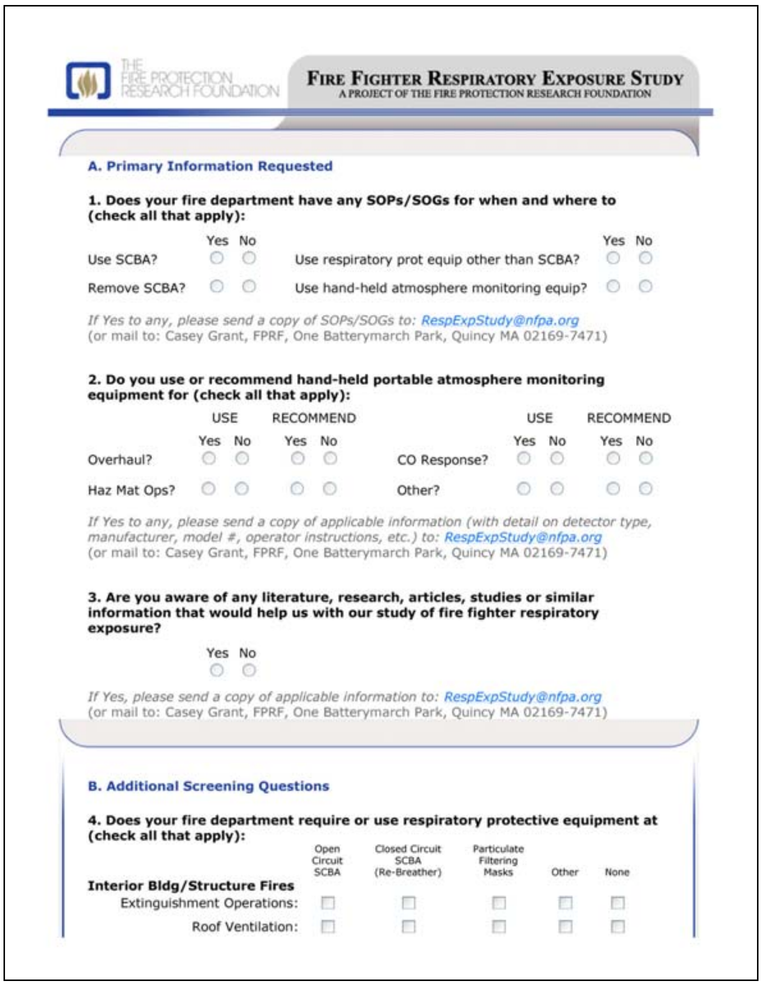
It's acknowledged that the data collected has certain inherent limitations due to the relatively small-scale of this study. Among these limitations is that multiple responses were possible from a single organization. The 9 multiple responses that were received among the 158 total responses were tracked and consolidated to reflect a single response from that particular fire service organization prior to making the final analysis. Another limitation is that each respondent may or may not have submitted their information as an official spokesperson representing their particular organization.

The approach used here intends to help provide a better understanding for how the fire service is addressing the use and discontinuance of respiratory protective equipment. The results of the information collection are based on responses from 130 unique fire service organizations. This has not been evaluated in the traditional statistical sense, since the pool of respondents is not well defined based on the open manner of this internet-based information collection. For example, it could be argued that only fire service organizations with an interest in this subject responded, and thus bias may be present in the overall results. Nevertheless, the information collected herein is considered to be a useful deliverable to assist with developing recommended best practices for using and discontinuing the use of respiratory protective equipment.

b) Design and Implementation

The information collection form was available to a wide cross section of the fire service interests, and therefore it was necessary to gather certain background information on the type of the fire department represented by a particular respondent. Further, in addition to the direct information collection form response data, an effort was made to gather Standard Operating Procedures (SoPs) and Standards Operating Guidelines (SoGs) currently used by various fire departments for additional analysis.

The information collection form is comprised of 9 questions grouped into the following three basic sections: (I) primary information; (II) additional screening questions; and (III) other applicable information. The information collection form is illustrated in Figures 5-1a, 5-1b and 5-1c.



THE FIRE PROTECTION RESEARCH FOUNDATION

FIRE FIGHTER RESPIRATORY EXPOSURE STUDY
A PROJECT OF THE FIRE PROTECTION RESEARCH FOUNDATION

A. Primary Information Requested

1. Does your fire department have any SOPs/SOGs for when and where to (check all that apply):

	Yes	No		Yes	No
Use SCBA?	○	○	Use respiratory prot equip other than SCBA?	○	○
Remove SCBA?	○	○	Use hand-held atmosphere monitoring equip?	○	○

If Yes to any, please send a copy of SOPs/SOGs to: RespExpStudy@nfpa.org
(or mail to: Casey Grant, FPRF, One Batterymarch Park, Quincy MA 02169-7471)

2. Do you use or recommend hand-held portable atmosphere monitoring equipment for (check all that apply):

	USE		RECOMMEND			USE		RECOMMEND	
	Yes	No	Yes	No		Yes	No	Yes	No
Overhaul?	○	○	○	○	CO Response?	○	○	○	○
Haz Mat Ops?	○	○	○	○	Other?	○	○	○	○

If Yes to any, please send a copy of applicable information (with detail on detector type, manufacturer, model #, operator instructions, etc.) to: RespExpStudy@nfpa.org
(or mail to: Casey Grant, FPRF, One Batterymarch Park, Quincy MA 02169-7471)

3. Are you aware of any literature, research, articles, studies or similar information that would help us with our study of fire fighter respiratory exposure?

Yes ○ No ○

If Yes, please send a copy of applicable information to: RespExpStudy@nfpa.org
(or mail to: Casey Grant, FPRF, One Batterymarch Park, Quincy MA 02169-7471)

B. Additional Screening Questions

4. Does your fire department require or use respiratory protective equipment at (check all that apply):

	Open Circuit SCBA	Closed Circuit SCBA (Re-Breather)	Particulate Filtering Masks	Other	None
Interior Bldg/Structure Fires					
Extinguishment Operations:	☐	☐	☐	☐	☐
Roof Ventilation:	☐	☐	☐	☐	☐

Figure 5-1a: Information Collection Form, page 1 of 3

The design of the questions in the information collection form attempts to take into account various baseline hypothetical assumptions, based on preliminary anecdotal feedback. These preliminary assumptions helped provide guidance in the construction and design of the information collection form, and are:

- Almost all fire departments use SCBA equipment in some manner.

- Some fire departments use respiratory protective equipment other than SCBA equipment, generally for hazardous materials or confined space entry events.
- Some fire departments use hand-held gas monitoring equipment, generally for hazardous materials or confined space entry events.

Incident Command:	☐	☐	☐	☐	☐
Overhaul Operations:	☐	☐	☐	☐	☐
On-Site Fire Investigations:	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐
Exterior Fires/Incidents					
Automobile Fires:	☐	☐	☐	☐	☐
Outside Dumpster Fires:	☐	☐	☐	☐	☐
Brush or Wildland Fires:	☐	☐	☐	☐	☐
Hazardous Materials Incidents:	☐	☐	☐	☐	☐
Defensive Firefighting Incidents:	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐

If "Other", please elaborate:

5. At interior building/structure fires, who makes the decision or how is decision made when to (check all that apply):

	Use SCBA	Remove SCBA
Incident commander:	☐	☐
Safety Officer:	☐	☐
Individual Fire Fighters:	☐	☐
Pre-Established Guideline:	☐	☐
Other person:	☐	☐
Other guideline:	☐	☐

If "Other", please elaborate:

6. Does your department routinely measure the following (check all that apply):

	Interior Bldg/Struc Fire	Exterior Bldg/Struc Fire	Other Exterior Fire	Hazardous Materials Incident	Other
Carbon Monoxide (CO):	☐	☐	☐	☐	☐
Hydrogen Cyanide (HCN):	☐	☐	☐	☐	☐
Nitrous Oxide (NOx):	☐	☐	☐	☐	☐
Sulfur Dioxide (SO2):	☐	☐	☐	☐	☐
Hydrogen Sulfide (H2S):	☐	☐	☐	☐	☐
Other Toxic Gases:	☐	☐	☐	☐	☐
Oxygen:	☐	☐	☐	☐	☐
Flammable Gases:	☐	☐	☐	☐	☐
Particulates:	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐

If "Other", please elaborate:

C. Other Applicable Information

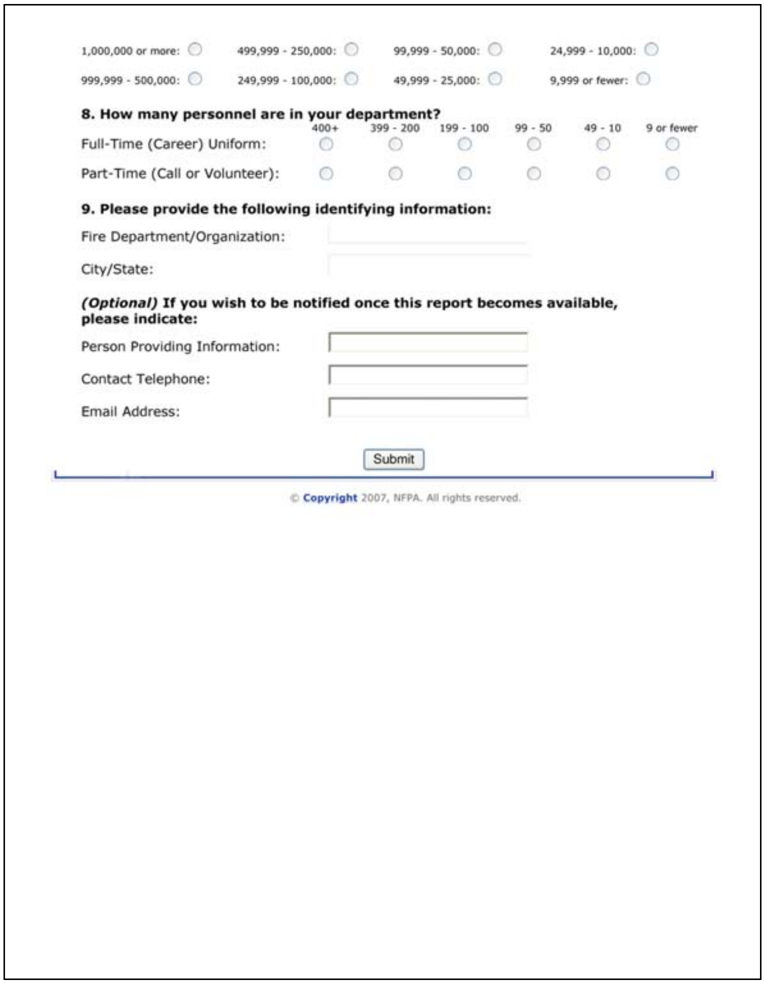
7. What is the population of the jurisdiction protected by your department?

Figure 5-1b: Information Collection Form, page 2 of 3

For standard operating procedures (SOPs) or standard operating guidelines (SOGs), the baseline assumptions used to help guide the form design are:

- Many fire departments have SOPs/SOGs addressing some aspects of SCBA purchase, care, maintenance, training and use.
- Few fire departments have SOPs/SOGs addressing use/discontinuance of SCBA or other respiratory protective equipment based on specific measured gas values.
- Some fire departments may use SCBA or other respiratory protective equipment based on specific measured gas values, but absent any applicable SOPs/SOGs.

One concept that has been intentionally omitted from the information collection form questions is to try and gather correlating information on injuries or fatalities that may have occurred from failure to properly use available respiratory protective equipment. Due to the sensitive and delicate nature of questions about fire fighter injury or loss at a particular fire department, such a line of inquiry is not included.



1,000,000 or more: ○ 499,999 - 250,000: ○ 99,999 - 50,000: ○ 24,999 - 10,000: ○

999,999 - 500,000: ○ 249,999 - 100,000: ○ 49,999 - 25,000: ○ 9,999 or fewer: ○

8. How many personnel are in your department?

	400+	399 - 200	199 - 100	99 - 50	49 - 10	9 or fewer
Full-Time (Career) Uniform:	○	○	○	○	○	○
Part-Time (Call or Volunteer):	○	○	○	○	○	○

9. Please provide the following identifying information:

Fire Department/Organization:

City/State:

***(Optional)* If you wish to be notified once this report becomes available, please indicate:**

Person Providing Information:

Contact Telephone:

Email Address:

Submit

Figure 5-1c: Information Collection Form, page 3 of 3

Fire departments with a primary jurisdiction of airports, waterfronts, industrial complexes, military bases, remote rural areas or applications that might require specialized fire fighting tactics and strategies are not excluded as long as they still address conventional structure fires, and it's assumed that all do to some extent.

The United States and Canada is the primary focus of the information collection form, and a balanced geographic representation from across the states and territories of the United States and the Canadian Provinces is desirable though not critical.

c) Summary of General Results

The results of the information collected for this study came from 158 total respondents, but this has been reduced to 130 overall respondents for the following reasons. Of these 158, 18 were duplicates of 2 each from 9 separate responding organizations and these were consolidated resulting in 9 separate responses for each organization. Also, 19 respondents submitted Procedures or Guidelines for review but did not complete the information collection form. By eliminating the duplicates and those not completing the information collection form, the net number of respondents is 130.

Table 5-1a illustrates the populations of the 130 fire departments that responded to the request for information. This is from question 7 on the information collection form. This indicates that a very well-balanced cross-section of responses was received from fire departments of all sizes, ranging from very small fire departments to those that are very large. Although this is a small fraction of the potential fire departments that could have responded (approximate 30,000 fire departments in the U.S. alone), this is an acceptable response for the purposes of this study.

Table 5-1a: Population of Jurisdiction Protected by Fire Department (Info Collection Form Question 7)

Population of Protected Jurisdiction	Responding Organizations (without duplicates)	Percent of Total Responses
1,000,000 or more	13	10.0
500,000 - 999,999	7	5.4
250,000 - 499,999	9	6.9
100,000 - 249,999	24	18.5
50,000 - 99,999	26	20.0
25,000 - 49,999	18	13.8
10,000 - 24,999	16	12.3
9,999 or fewer	17	13.1
Total	130	100 %

Table 5-1b further clarifies the demographics of the respondents by illustrating the size of each responding fire department based on the number of fire fighting personnel. This distinguishes between fire fighters that are full-time only (i.e. career or uniform), and fire fighters that are part-time only (i.e. call or volunteer).

The preferable target audience for the information collection form is a random yet balanced mix of full career departments, volunteer departments, and combination departments. A combination fire department is defined as having emergency personnel comprising less than 85 percent majority of either volunteer or career membership, as defined by 3.3.9 of NFPA 1720, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Volunteer Fire Departments*, 2004 edition. For this study a combination fire department is taken as a mix of full-time and part-time personnel in any percentage. Table 5-1b indicates that the respondents came from an even mix of full-time only departments and combination departments, with a smaller fraction coming from part-time only fire departments. For purposes of this research study, this is considered an acceptable mix of fire department types.

Table 5-1b: Fire Department Size Based on Number of Department Personnel (Info Collection Form Question 8)

Number of Department Personnel	Full-Time Only (Career/Uniform)	Part-Time Only (Call/Volunteer)	Combination Departments (at least full- or part-time)
400 or more	19	0	9
200 - 399	11	0	3
100 - 199	11	3	2
50 - 99	14	1	9
10 - 49	4	11	21
9 or fewer	0	0	12
Total	59	15	56

The primary results from the information collection form of most interest are first shown in Table 5-2a. This indicates the fire departments that address certain respiratory exposure protection details in their standard operating procedures or guidelines (SOPs/SOGs). This is based on question 1 from the information collection form, and it's worth emphasizing that this is focused on whether or not the particular department has SOPs/SOGs addressing this subject and not if they are performing the respective activity absent written SOPs/SOGs.

The results in Table 5-2a indicate that most responding departments, by a ratio of 8 to 1, have written SOPs/SOGs on when to use SCBA. Interestingly, however, the ratio is dramatically less, at 2 to 1, for departments that have written SOPs/SOGs indicating when to remove SCBA. This supports one of the underlying premises motivating this study, namely that clarity is lacking for when fire fighters determine when to remove SCBA. Countering this is the indication that three-fourths of the responding fire departments with SOPs/SOGs for SCBA use also address removal (assuming that none have SOPs/SOGs only for removal).

Table 5-2a also indicates that about the same number of fire departments have SOPs/SOGs for using respiratory equipment other than SCBA as those that do not. Further, Table 5-2a indicates the ratio for every fire department that has SOPs/SOGs for hand held atmosphere monitoring equipment is 3 to 1, or in other words, for every 4 fire departments 3 can be expected to have written procedures for using hand held atmosphere monitoring equipment.

It is noted, however, that a further review of the actual SOPs/SOGs that were submitted to support Table 5-2a illustrates a great variety of detail and focus toward addressing these particular subjects, addressing the many aspects of this equipment. As a specific example, most address care and maintenance issues, but fewer provide significant detail on when and where to use the equipment.

Table 5-2a: Fire Department SOGs/SOPs Addressing Respiratory Protection (Info Collection Form Question 1)

Does your Department have any SOPs/SOGs for when and where to:	Yes	No
Use SCBA?	115	14
Remove SCBA?	83	45
Use Respiratory Protective Equip. other than SCBA?	63	60
Use Hand-Held Atmosphere Monitoring Equipment?	90	35

Table 5-2b reflects the results of question 2 on the information collection form, and this clarifies how hand held portable atmosphere monitoring equipment is being used. The predominant use (and recommended use) is for carbon monoxide (CO) calls by a ratio of approximately 10 to 1. This is followed closely by hazardous materials calls where fire department are using hand held portable monitoring equipment by a ratio of approximately 8 to 1.

Interestingly, responding fire service organizations indicate, as shown in Table 5-2b, that their use of hand-held portable atmosphere monitoring equipment drops considerably for overhaul or other activities, where the ratio of use to non use is 2 to 1. This suggests that most fire departments have hand held portable atmosphere monitoring equipment for carbon monoxide calls and hazardous materials incidents, but a smaller percentage is using this equipment for overhaul or other operations.

Table 5-2b: Fire Department Use of Hand-Held Portable Atmosphere Monitoring Equipment (Info Collection Form Question 2)

Does your Department Use or Recommend Hand-Held Portable Atmosphere Monitoring Equipment for:	Use		Recommend	
	Yes	No	Yes	No
Carbon Monoxide (CO) Response?	115	12	53	5
Hazardous Materials Operations?	113	14	52	7
Overhaul?	87	38	48	18
Other?	49	27	23	18

Table 5-2c provides significant detail on the type of fire ground activities where different respiratory protective equipment is being used. This is based on question 4 from the information collection form, and the rows of Table 5-2c have been shaded to distinguish results with common responses. The results illustrate several observations of interest as follows.

First, Table 5-2c indicates that, not surprisingly, virtually all fire departments use SCBA for extinguishing operations at interior building or structure fires. Several departments indicate that they use SCBA other than the commonly applied open circuit type required for IDLH atmospheres. It is known that at least one responding fire department uses closed circuit SCBA (re-breathers) on their rescue squads for deployment into long tunnels and other confined spaces, and it's possible that the others of this small percentage may do so likewise or be the result of confusion by respondents on the different types of SCBA (e.g. open circuit versus closed circuit). In addition to extinguishing operations at interior building or structure fires, most fire departments also use open circuit SCBA for the following: roof ventilation, overhaul, hazardous materials incidents, automobile fires, and outside dumpster fires.

Table 5-2c: Fire Department Use of Respiratory Protective Equipment (Info Collection Form Question 4)

Does your Department Require or Use Respiratory Protective Equipment at:		Open Circuit SCBA	Closed Circuit SCBA	Particulate Filtering Masks	Other	None
Interior Building/ Structure Fires	Extinguishing Operations	126	5	0	1	0
	Roof Ventilation	118	5	0	1	5
	Overhaul Operations	102	3	23	1	15
	On-Site Fire Investigations	40	1	40	7	43
	Incident Command	11	0	0	3	76
	Other Interior Operations	14	1	5	1	20
Exterior Fire/ Incidents	Haz Mat Incident	119	9	7	2	4
	Automobile Fires	116	4	0	1	9
	Outside Dumpster Fires	99	2	0	2	22
	Defensive Firefighting	67	3	2	8	41
	Brush or Wildland Fires	14	0	20	3	64
	Other Exterior Operations	6	0	0	0	14

One aspect of the results from Table 5-2c of particular interest is the comparison of overhaul operations and on-site fire investigations at interior building or structure fires. It is interesting that Table 5-2c indicates that most fire departments are using SCBA during overhaul. Out of the 130 respondents, 102 indicate they use SCBA during overhaul, while 23 use particulate filtering masks and 15 use no protective equipment. For on-site fire investigations, the results indicate an even split among the respondents with the same percentage using either SCBA, particulate filtering masks, or no protective equipment whatsoever. It's noted that this post fire extinguishment period of time involving overhaul and fire investigations is subject to some subjective interpretation as to when it begins and ends, and future research may find value in better defining the fire and post fire extinguishment phases.

Another point of interest with the results of Table 5-2c is the very low use of SCBA at brush or wildland fires (which, it is noted, is a similar result as for incident command at interior building or structure fires). Brush and wildland fires have certain special operating characteristics such as very remote access and fire ground operations involving very long periods of time that make the use of SCBA understandably impractical. Nevertheless, it is interesting that a relatively small percentage of respondents indicate that they use particulate filtering masks (and other) respiratory protective equipment at brush or wildland incidents and most fire departments indicates that they use no respiratory protective equipment.

Table 5-2d provides clarification on who makes the decision and how the decision is made to use or remove SCBA. This is from question 5 on the information collection form. This indicates that those who decide when to use SCBA are also the same people who decide when to discontinue its use. Table 5-2d also shows that pre-established guidelines are the primary basis for making these operational decisions for use, by a ratio of 3 to 1 as compared to the decision to remove SCBA. The individual on the fire ground to actually implement this decision is most likely to be the incident commander, followed by the safety officer and by the individual fire fighter wearing the respiratory protective equipment. This suggests the possibility that multiple, and possibly overlapping, decisions may be occurring on the fire ground, although it is not clear if this is problematic or not, i.e., the decisions are contradictory or complementary for any specific situation.

Table 5-2d: Who Makes Decision and How is Decision Made to Use or Remove SCBA (Info Collection Form Question 5)

At Interior Building/Structure Fires, Who Makes the Decision or How is Decision Made When to:	Use SCBA	Remove SCBA
Pre-Established Guideline	90	28
Incident Commander	77	73
Safety Officer	60	61
Individual Fire Fighters	53	27
Other Person	15	10
Other Guideline	4	3

The final direct result from the information collection form is shown in Table 5-2e and is based on question 6 from the form. This clarifies when and what atmosphere components fire departments are routinely measuring, and the rows of Table 5-2e have been shaded to distinguish results with common responses. An analysis of this data reveals several interesting results.

Table 5-2e: Fire Department Routine Atmospheric Measurements (Info Collection Form Question 6)

Does your Department Routinely Measure:	Interior Bldg/Struc Fires	Exterior Bldg/Struc Fires	Other Exterior Fires	Haz Mat Incidents	Other	Total
Carbon Monoxide (CO)	91	19	10	77	14	211
Flammable Gases	58	18	11	76	10	173
Oxygen (O2)	63	14	9	70	9	165
Hydrogen Sulfide (H2S)	43	12	7	69	7	138
Hydrogen Cyanide (HCN)	18	6	4	45	2	75
Other Toxic Gases	15	6	4	41	4	70
Sulfur Dioxide (SO2)	15	4	3	44	3	69
Nitrous Oxide (NOx)	8	5	3	36	3	55
Particulates	3	3	1	17	5	29
Other	1	1	0	9	3	14

First, from an overall standpoint based on the fire department response situations represented by the five columns in Table 5-2e, the results indicate that the most common substance being measured is carbon monoxide. This is followed by measurements of either oxygen levels and/or flammable gases. The next most common measurement is hydrogen sulfide. A secondary tier of substances being measured are any of the following airborne contaminants: hydrogen cyanide, other toxic gases, sulfur dioxide, and nitrous oxide.

The data in Table 5-2e also reveals helpful information on how fire departments are using this equipment at certain types of incidents. By comparing the individual columns, it can be observed that for each type of fire ground situation the fire departments responding to this information collection are measuring carbon monoxide more often than other atmospheric characteristics. This observation generally holds true for each type of airborne contaminant or substance in the rows of Table 5-2e, regardless of the type of fire ground application, i.e., interior building/structure fires, exterior building/structure fires, other exterior fires, or hazardous materials incidents.

The information in Table 5-2a through 5-2e provides a helpful illustration for how the fire service approaches certain fire ground practices relating to respiratory protection. However, the user of this data should be cautious on how they apply these results and should be sensitive to the manner in which the information was collected. The approach used was to gather this information was via an open collection form where any fire service member could respond. The information may therefore not be necessarily representative of the fire service in general and may include a bias. For example, the respondents may have been from individuals who already have a particular interest in this topic, or specific responses may have been based on individual practice rather than the practice of their fire department. Nevertheless, the data obtained in the information collection is useful and should be used with an understanding for how it was collected.

d) Threshold Measurement Values

This information collection effort requested that fire departments also provide their written procedures for further analysis. Those that were provided were reviewed and the threshold measurement values that they are using to measure atmospheres on the fire ground are indicated in Table 5-3. This includes several fire service organizations that provided written procedures or guidelines, but did not respond to the information collection form and thus are not likewise reflected in the information summarized by Tables 5-1 and 5-2.

Table 5-3: Selected Fire Department Hazardous Atmosphere Threshold Measurement Values

State	Population Protected	Dept Size Career	Dept Size Volunteer	CO	HCN	H2S	O2[1]	Other
				Threshold Values Referenced in SOPs/SOGs (in PPM, except "O2" in % and "other" as applicable):				
Aus	A 1M or more	A 400 or more	A 400 or more	30[2]	10		19.5 / 23.5	VOCs<0.5[3]
AZ	B 1M-500K	A 400 or more	F 9 or less	10[4]			20.6	
CA	E 100K-50K	D 99-50	F 9 or less	25[5]		10	19.5 / 23.5	
CA	C 500K-250K	A 400 or more	E 49-10	25		10	19.5 / 23.5	
CA	D 250K-100K	C 199-100	F 9 or less				19.5 / 23.5	
CA	F 50K-25K	D 99-50	F 9 or less	35	10			
CA	A 1M or more	A 400 or more	E 49-10	25[5]		10	19.5 / 23.5	
CA	F 50K-25K	F 9 or less	E 49-10	50				
FL	D 250K-100K	C 199-100	F 9 or less	35		10	19.5 / 23.5	
IL	E 100K-50K	C 199-100	F 9 or less	10				
LA	D 250K-100K	A 400 or more	F 9 or less	35				
NC	B 1M-500K	A 400 or more	F 9 or less	35		10	19.5 / 23.5	
NC	D 250K-100K	A 400 or more	F 9 or less	34				
NV	C 500K-250K	A 400 or more	F 9 or less	35	10			
NY	D 250K-100K	A 400 or more	F 9 or less	35	10			
ON Can	A 1M or more	A 400 or more	F 9 or less	24[6]		10	19.5 / 23.0	
OR	B 1M-500K	A 400 or more	F 9 or less	35		15	19.5 / 23.5	
RI	D 250K-100K	A 400 or more	F 9 or less		4.7			
SC	G 25K-10K	C 199-100	F 9 or less	35	10			
SC	B 1M-500K	B 399-200	F 9 or less	35	10			
TX	A 1M or more	A 400 or more	F 9 or less	35				
TX	A 1M or more	A 400 or more	F 9 or less	50				
TX	B 1M-500K	A 400 or more	F 9 or less	35			19.5	
TX	F 50K-25K	E 49-10	E 49-10	30				
UT	F 50K-25K	D 99-50	F 9 or less	34				
VA	C 500K-250K	A 400 or more	C 199-100	35			19.5	
VA	D 250K-100K	B 399-200	A 400 or more	35			19.5 / 23.5	
WA	E 100K-50K	E 49-10	E 49-10	35		10	19.5	Asb<.1/cc[7]
WA	D 250K-100K	B 399-200	F 9 or less	35			19.5	
WA	D 250K-100K	C 199-100	E 49-10	35			19.5	T<200F[8]
WA	E 100K-50K	D 99-50	F 9 or less	35		10	19.5 / 23.5	
WA	E 100K-50K	C 199-100	F 9 or less	35[9]			19.5[9]	

Table 5-3 Footnotes:

1) Single value indicates lower limit, and two values indicate lower and upper limit.
2) Based on Australian National Occupational Health and Safety Commission Guidelines as follows: 30 ppm for TWA 8 hour exposure for 40 hr/week; 60 ppm for 60 minute TWA exposure; 100 ppm for 30 minute TWA exposure; 200 ppm for 15 minute exposure; 1200 ppm for IDLH.
3) Unspecified mixture of Volatile Organic Compounds (VOCs) < 0.5 ppm. Also acid gases (such as HCl) < 5 ppm & 50 ppm IDLH, and Formaldehyde < 1 ppm & 20 ppm IDLH.
4) For overhaul, CO threshold = 10 ppm. For CO detector calls or CO leaks, CO threshold = 25 ppm.
5) Based on California Dept of Health Services and Cal/OSHA requirements, for exposure limit of 25 ppm over 8 hours or 200 ppm at any time.
6) Based on multiple CO thresholds of 9 ppm, 24 ppm, or 100 ppm depending on hazard & occupancy.
7) Asbestos thresholds based on 0.1 fiber per cubic centimeter for 8 hour TWA.
8) Temperature required to be less than 200 ºF.
9) Measurement cannot be exceeded over a 10 minute continuous reading.

The 32 fire departments indicated in Table 5-3 were those that utilize actual threshold measurement to identify a hazardous atmosphere, based on a review of their procedures or confirmation of their field practice. Operating procedures and guidelines were provided by other fire departments, but they address other details relating to respiratory exposure such as the care and maintenance of equipment, and threshold measurement values.

A helpful background observation is that several procedures refer to the baseline requirements provided by U.S. OSHA CFR 1910.120, which provides the following thresholds for a hazardous work environment: CO > 35 ppm; H2S > 10 ppm;19.5% $\leq$ O2 $\geq$ 23.5%; and additionally, flammable concentrations < 10% LEL.[90] This helps to explain the moderate consistency with the data in Table 5-3. An interesting approach used by some fire departments is to simply redefine IDLH within their procedures to indicate the thresholds that they consider to be acceptable (e.g., CO @ 35 ppm, H2S @ 10 ppm, O2 @ 19.5% to 23.5%). They subsequently will re-emphasize that SCBA shall be used at all times in the presence of an IDLH or unknown atmosphere.

Aside from the consistency as noted, the variation between these values in Table 5-3 is also of interest, and this appears to be caused by different required or recommended values from federal OSHA or local OSHA requirements, and different recommended values from NIOSH, ACGIH, and other sources. Despite these variations, all these values appear to be within conservative bounds as compared to the application. Nevertheless, it would be useful for the fire service and other first emergency responders to receive clear recommendations from the industrial hygiene community as to what substances they should optimally measure in each type of emergency application, and establish definitive and uniform indication of the best measurement values to determine when to use and discontinue use of SCBA and other respiratory protective equipment.

6) CONCLUSIONS AND RECOMMENDATIONS

a) Key Findings

The key findings in this study relating to the literature review are:

1) Existing Information. Significant information exists in the literature relating to the general topic of respiratory protective exposure for fire fighters and other emergency responders.
2) Exposure to Hazardous Atmospheres. The literature provides indication that the atmospheres encountered by fire fighters and other emergency responders, both at interior or exterior applications, have hazardous components that should be of concern to all who may be exposed to these atmospheres.
3) Stabilized Trend for Fire Service Respiratory Injuries. A positive trend from a quarter of a century ago appears to have stabilized in the last decade for fire ground safety from respiratory exposure hazards.
4) Consideration of Additional Protective Measures. Certain applications, such as those faced by fire investigators or wildland fire fighters, are facing on-going respiratory hazards, and additional protective measures should be considered.
5) Higher Rate of Adverse Long-Term Health Effects. The literature indicates that fire fighters have a higher rate of long-term adverse health effects, like cancer, than the rest of the general population, although the precise cause of these ailments is not clear.
6) Changing Character of Fire Related Respiratory Hazards. The respiratory concerns faced by fire fighters addressing structural fires today appear to be changing from similar exposures occurring approximately 1 to 4 decades ago, as indicated by reports focusing on the measurement of hydrogen cyanide poisoning. This appears to be related to the changing characteristics of the materials that are burning in a typical building fire today versus a typical building fire in the past.
7) Recognition of Dynamics of Fire Related Respiratory Hazards. Respiratory exposure concerns that exist in post fire extinguishment phases of fire ground operations, such as during overhaul or fire investigations, are different than the atmospheres encountered by fire fighters during actual fire extinguishment operations. However, although these atmospheres are typically less hazardous, they can be deceptively dangerous due to off-gassing conditions and loss of natural buoyant ventilation flows that help remove harmful airborne contaminants.

The key findings in this study relating to the collection of information from fire departments are:

8) Use and Discontinuance of SCBA. Most fire departments have SOPs/SOGs to indicate when to use SCBA, but much fewer address when to discontinue the use of SCBA.
9) Use of Hand-Held Portable Atmosphere Monitoring Equipment. Fire departments have hand-held portable monitoring equipment for carbon monoxide calls and hazardous materials incidents, and they are using this equipment to measure hazardous environments elsewhere, such as during overhaul.
10) Decision Making Process for SCBA Use and Discontinuance. Those who decide when to use SCBA and other respiratory protective equipment are also making the decision when to discontinue its use, and this is most commonly determined by pre-established guidelines (written or otherwise). The individual who actually makes the decision is

generally the incident commander, the safety officer, or the individual fire fighter. In addition, multiple, and possibly overlapping, decisions may be occurring on the fire ground, although it is not clear if the decisions are contradictory or complementary for any specific situation.

11) Definition of Phases of Fire Extinguishment. The various phases of fire extinguishment are not well defined, such as when overhaul begins and ends, and when fire investigation activities begin and end.

12) Measurement Profile of Airborne Contaminants. For the fire departments that are measuring airborne contaminants, most are measuring carbon monoxide, oxygen, flammable gases, and hydrogen sulfide. In fewer numbers, fire departments are also measuring hydrogen cyanide, sulfur dioxide, nitrous oxide and other toxic gases. A clear indication appears to be lacking of what fire departments should optimally be measuring, and guidance is needed for the measurement of multiple components of the hazardous environment for fire departments that are focusing only on individual airborne contaminants.

A key finding relating to the literature review and confirmed by the collection of information from fire departments is:

13) Transition to Field Practitioners. It is not clear that the specific results of the research provided in the literature are adequately transitioning to the field practitioners that need this information for implementation.

14) Consistency of Airborne Contaminant Threshold Measurements. For fire departments that measure airborne containments and others atmospheric concerns on the fire ground, variations exist on the actual measurement thresholds due to the multiple requirements and recommendations that are available.

b) Future Research

This information points to several topical areas that are worthy of further research. These are summarized in the following list, in no particular order of priority.

1) Establish Fire Fighter Respiratory Exposure Measurement Thresholds
Currently fire service personnel are using different criteria (primarily from OSHA, NIOSH and ACGIH) to define an atmosphere to determine when it is no longer IDLH and when they can remove SCBA and use other forms of respiratory equipment. A detailed study is needed specifically for the fire service from an industrial hygiene perspective to provide clear direction for which criteria is most appropriate for which situation. The fire service needs clarification as to what airborne contaminants they should be measuring and at what threshold values. The results should be provided in a format and style that will facilitate implementation by the fire service.

2) Determine Best Detection and Monitoring Field Practice for Measuring Fire Ground Atmospheres.
Every fire ground situation faced by fire fighters is unique. The fire service would benefit from the establishment of an optimum protocol for how to best measure and monitor the fire ground environment. Providing guidance on best field practice to measure and monitor a hazardous environment would allow the development of training materials for use by the fire service, and assist in minimizing respiratory exposure to fire fighters. This should include the identification and evaluation of new technology to facilitate remote data-logging and real-time analysis.

3) Identify and Better Characterize the Fire Environments Faced by Fire Fighters During Overhaul at Structural Fires.

Generate an inventory of respiratory environments faced by urban fire fighters. Further research should be focused toward identifying and clarifying common environments. A categorization and inventory of the different environments would assist approaches that seek to provide the best respiratory protection. Include timelines that clearly indicate when fire fighters take specific actions depending on measured characteristics of the hazardous environment.

4) Evaluate and Determine the Optimum Respiratory Protective Equipment for Use by Wildland Fire Fighters

Generate an inventory of respiratory environments faced by wildland fire fighters. Further research should be focused toward identifying and clarifying common environments. A categorization and inventory of the different environments would assist approaches that seek to provide the best respiratory protection.

5) Clarify the Causes of Acute and Long-Term Adverse Health Effects in Fire Fighters

Acute exposure to products of combustion has been shown to results in adverse respiratory effects in firefighters including reduction in spirometry and increased lung permeability. In addition, various studies have established that fire fighters have a higher rate of adverse health effects (e.g. cancer) than the general population. Over half of line-of-duty deaths are cardiovascular in nature and inhalation of particulate matter in susceptible individuals among the general population is known to increase cardiovascular mortality. However, in firefighters the cardiovascular effects of acute exposure, including heat stress, and the cause of these long-term ailments are not clear. Research is needed that would define the possible causes of these adverse health effects, and clarify the linkage between certain fire fighting activities and the long-term health implications.

6) Develop a Fire Fighter Respiratory Exposure Tracking System

Establish and develop a tracking system that would inventory data from firefighters as the measurement and collection of data through gas monitoring becomes more prevalent. Certain fire departments are now collecting certain data elements on a regular basis, but this is not being coordinated on a large scale that would lend itself to future research on this subject.

7) Evaluate Existing and New Respiratory Exposure Equipment

Conduct research in support of existing technologies and new alternative technologies for respiratory protective equipment. An example of research on existing technologies might be to evaluate air purifying cartridge effectiveness from exposure to certain airborne contaminants. An example of new alternative technologies might be the evaluation of new lightweight closed-circuit re-breather approaches.

7) REFERENCES

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