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Respiratory Exposure Study for Fire Fighters and Other Emergency Responders

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Abstract. This study provides a literature review of prior research on respiratory exposure for fire fighters and other emergency responders, and includes an information collection effort that provides a summary review of field measurement technology and selected fire department Standard Operating Procedures and Standard Operating Guidelines (SOPs/SOGs) relating to respiratory exposure. The purpose of this study is to raise awareness on the need for emergency responder respiratory protection, promote and support specific fire service respiratory exposure related research, and to help develop best practice fire service guidance for determining when to use and discontinue use of self-contained breathing apparatus (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.

Keywords: emergency response, fire fighters, fire fighting, fire service, overhaul, respiratory exposure

1. Introduction

The purpose of this project is to (1) raise awareness on the need for emergency responder respiratory protection, (2) establish a research platform for others who are studying this topic, and (3) provide information for firefighters and other emergency responders to help develop best practice guidance for determining when to use and cease using self-contained breathing apparatus (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.

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 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

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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; [1]
2. Outdoor fires (e.g., brush/wildland, automobiles, dumpsters, etc.); [2]
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.) [3, 4].

A threefold approach is used to meet the objectives of this study. First, an overview and background information is provided of the respiratory exposure concerns facing the fire service, including a review of current trends, a discussion of hazard types (i.e., airborne contaminants and oxygen content), and a review of applicable regulations and recommendations. Second, a review of the literature is presented that includes a discussion on the collection methodology and summary of results. Third, the results of a data collection method are described, and which provide specific detailed information on how fire service organizations are addressing respiratory exposure concerns. This tripartite approach provides useful technical information to promote and support other specific fire service respiratory exposure related research and to help fire service organizations develop best practice fire service guidance for determining when to use and discontinue use of SCBA and other respiratory protective equipment.

2. Overview of Fire Fighting Respiratory Exposure Protection Concerns

What are the specific respiratory exposure concerns that face today's fire service? How are these concerns changing? These and other similar questions are addressed in this section by collecting and summarizing applicable information to provide a study overview, and to establish the proper context and necessary backdrop to address this overall topic. This includes a review of current trends of fire service respiratory exposure hazards, a discussion of hazard types such as airborne contaminants and oxygen content, and a review of applicable regulations and recommendations.

2.1. Trends in Fire Service Respiratory Exposure

Among the information provided by the annual US Fire Department Profile Report, there are approximately 30,000 fire departments in the US 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% (or about two of every five) US residents are protected by such a department [5].

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 [6]. 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.

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 a question in 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 1.

The percentages in Table 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% 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 [6, p. 67]. Interestingly, since about half of the 1.1 million US 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

Table 1
Percentage of US Fire Departments and Fire Fighters Using SCBA by Size of Jurisdiction

Population of protected jurisdiction[a]	Fire departments where all fire fighters on a shift are equipped with SCBA[b] (%)	Percent of total fire fighters
1,000,000 or more	100	2.9
500,000–999,999	100	3.2
250,000–499,999	96	2.4
100,000–249,999	98	4.6
50,000–99,999	95	4.6
25,000–49,999	89	6.6
10,000–24,999	77	12.0
5,000–9,999	52	12.1
2,500–4,999	33	14.7
Under 2,500	23	36.9

[a] *Source*: Ref. [6], p. iv and 68.

[b] Based on a 2005 stratified random-sample survey sent to roughly half the approximate 30,000 career, volunteer, and combination fire departments in US. 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".

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 1 provides an indication of the growth of non-fire carbon monoxide calls that fire departments have responded to in recent years [7]. An increase of 18% 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.

Aside from the equipment assessment of the U.S. fire service, what is the trend for respiratory injuries to US 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 [8]. 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 Figure 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 1800s, 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 [9]. 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

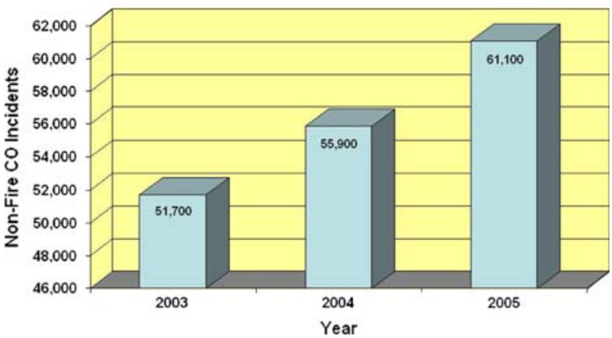

Figure 1. Non-fire carbon monoxide incidents reported by responding US fire departments from 2003 to 2005 (source: Ref. [7]).

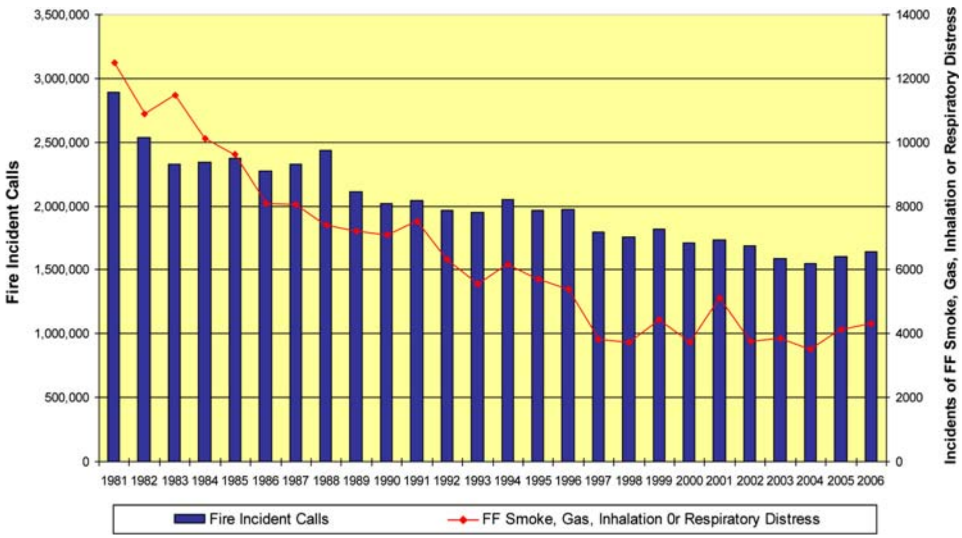

Figure 2. Annual US fire fighter respiratory related injuries in relation to number of fire calls (source: Ref. [8]).

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 [10].

One trend that is not clear from the data illustrated in Figure 2 is the attitude and culture of individual US 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 [11]. 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 [12].

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 US fire fighters annually suffered fire ground injuries that were related to respiratory exposure [13].

The statistical information illustrated in Figure 2 is based on recognizable respiratory injuries that occur on the fire ground, 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, but questions remain due to the challenging nature of identifying long term effects and ruling out possible other causes of long term health problems [14–19].

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 [20]. 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 [20–44]

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 [44].

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 [26]. 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 [6, p. 59].

2.2. 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 [45].

The types of airborne contaminants recognized by industrial hygienists are dusts, fumes, smoke, aerosols, mists, gases, and vapors [46]. These terms each have precise meanings and are not interchangeable.

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 [46, p. 27].

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 [46, p. 23]. 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.

A number of studies have identified toxic chemicals in fire smoke [47–49], and of significance for this study, a few have additionally provided classification of the environment during the overhaul of the fire scene [3, 50]. 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 [50].

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. Although not specifically addressing fire fighter respiratory exposure, several related studies (e.g., addressing smoke detector activation) examine the changing nature of airborne contaminants that fire fighters are exposed to today [51, 52].

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 [4, 53–60]. 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 [61].

2.3. 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 [62]. 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 [63]. 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% should be considered (immediately dangerous to life or health) IDLH, and an oxygen level greater than 21% by volume should alert the competent person to look for the cause of the oxygen-enriched atmosphere and correct it prior to entry [64].

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% 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 [2, p. 43].

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 [65]. 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.

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 [66]. 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 min 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 factors that will alter the physiological 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 [65].

2.4. 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.

Occupational Safety and Health Administration 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 [46, p. 6].

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 [65].

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 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 [50]. This is in addition to the additional respiratory concern of oxygen depletion [67].

For the five airborne contaminants addressed in Table 2, 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 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 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 [46, p. 517]. 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 also includes a value for each airborne contaminant for the IDLH 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

Table 2
Threshold Concentration Values for Certain Hazardous Gases Encountered by Fire Fighters

Substance (conversion value from ppm to mg/m^3)[d]	IDLH[e]	Exposure time period	US OSHA[a] PEL[f]	NIOSH[b] REL[g]	ACGIH[c] TLV[h]
CO	1200 ppm	TWA[i] (8 h exp)	50 ppm	35 ppm	25 ppm
Carbon monoxide		STEL[j] (15 min exp)	–	–	–
(1 ppm = 1.15 mg/m^3)		C[k] (immediate exp)	–	200 ppm	–
HCN	50 ppm	TWA (8 h exp)	10 ppm	–	–
Hydrogen cyanide		STEL (15 min exp)	–	4.7 ppm	–
(1 ppm = 1.10 mg/m^3)		C (immediate exp)	–	–	4.7 ppm
H_2S	100 ppm	TWA (8 h exp)	–	–	10 ppm
Hydrogen sulfide		STEL (15 min exp)	–	–	15 ppm
(1 ppm = 1.40 mg/m^3)		C (immediate exp)	20 ppm	10 ppm	–
N_2O	Not determined	TWA (8 h exp)	–	25 ppm	50 ppm
Nitrous oxide		STEL (15 min exp)	–	–	–
(1 ppm = 1.80 mg/m^3)		C (immediate exp)	–	–	–
SO_2	100 ppm	TWA (8 h exp)	5 ppm	2 ppm	2 ppm
Sulfur dioxide		STEL (15 min exp)	–	5 ppm	5 ppm
(1 ppm = 2.62 mg/m^3)		C (immediate exp)	–	–	–

Based on regulations and widely recognized recommendations applicable to fire fighters within the United States.

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, US government printing office, P.O. Box 371954, Pittsburgh PA 15250-7954, USA.

Source of values for ACGIH taken from Ref. [65].

For additional useful interpretative information, see Ref. [67].

[a] *US OSHA* US occupational safety and health administration, operating within the US department of labor.

[b] *NIOSH* National institute for occupational safety and health, operating within the center for disease control (CDC).

[c] *ACGIH* American conference of governmental industrial hygienists.

[d] Unit conversion for each substance from ppm parts per million to mg/m^3 milligrams per cubic meter.

[e] *IDLH* immediately dangerous to life and health, as defined by NIOSH.

[f] *PEL* permissible exposure limit, which is the primary US OSHA threshold concentration value.

[g] *REL* recommended exposure limit, which is the primary NIOSH threshold concentration value.

[h] *TLV* threshold limit value, which is the primary ACGIH threshold concentration value.

[i] *TWA* time weighted average, which is the weighted average concentration over an exposure time period based on a normal 8 h workday and a 40 h 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.

[j] *STEL* short term exposure limit, which is the time weighted average concentration for a 15 min short term exposure to which all workers may be repeatably exposed without adverse effect.

[k] *C* ceiling, which is the threshold concentration value which should not be exceeded at any time.

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., US 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 key part of this study is to provide a review of the applicable literature, and provide a summary of this literature review information that will facilitate other follow-on research to further address specific fire service respiratory exposure related concerns. The published report for this study contains more than 200 citations for documents that relate in some fashion to respiratory protection for fire fighters and other emergency responders, and an abbreviated version is included in the reference section of this technical paper based on the citations contained herein [68]. This section describes the collection methodology and approach used to organize this literature review information to enable and facilitate its continued use.

3.1. Literature Review Methodology

To better assist individuals using the literature summary, several mechanisms have been introduced to facilitate the handling and use of this information.

The literature generally fits into three basic categories of subject matter, and this is illustrated in Figure 3. These three realms are: Environment, Personnel, and Tools. 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" for Personnel. Similarly, if a citation focuses on measuring airborne contaminants or the make-up of smoke it would be designated by "E" for Environment. Finally, citations focusing on respiratory protective equipment or devices used for measurement would have a "T" designation for Tools.

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 referred to in the report summary 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.

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. "Scope relativity" addresses if the citation is directly or indirectly related to the subject of

Figure 3. Literature review relevance.

Table 3
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			

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.

3.2. Implementation and Results

The literature review in the report published on this topic includes more than 200 citations for documents that relate in some fashion to respiratory protection for fire fighters and other emergency responders [68]. 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.

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, with tools including measuring equipment and respiratory protective equipment. 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 [50]. 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" which provides a detailed analysis of the dangers of hydrogen cyanide poisoning from today's typical urban structural fire [61].

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" [3]. 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 [3, 69, 70].

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 [71–97].

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 [14–19].

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 [20]. 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 [20–44] 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 [44]. 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 [26].

4. Data Collection Method

The third approach used to address the objectives of this study is a data collection of fire service first responders. This section describes the methodology used and the results of this data collection effort, which provides specific detailed information on how fire service organizations are addressing respiratory exposure concerns. This information is intended to assist those who are considering further research on this topic, and to help fire service organizations develop best practice fire service guidance for determining when to use and discontinue use of SCBA and other respiratory protective equipment.

4.1. 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. The questions used in the information collection form were analyzed and pre-tested for its reliability and validity using a focus group comprised of a dozen fire service representatives.

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 [98]. 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.

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 nine 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.

4.2. Design and Implementation

The information collection form was comprised of nine questions grouped into the following three basic sections: (I) primary information; (II) additional screening questions; and (III) other applicable information. In addition to the direct information collection form response data, an effort was made to gather Standard Operating Procedures and Standards Operating Guidelines (SOPs/SOGs) currently used by various fire departments for additional analysis.

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.

For SOPs/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.

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 was pursued though not considered critical.

4.3. 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 two each from nine separate responding organizations and these were consolidated resulting in nine 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 4 illustrates the populations of the 130 fire departments that responded to the request for information. 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.

Table 5 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

Table 4
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
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

combination departments. A combination fire department is defined as having emergency personnel comprising less than 85% majority of either volunteer or career membership [99]. For this study a combination fire department is taken as a mix of full-time and part-time personnel in any percentage. Table 5 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.

The primary results from the information collection form of most interest are shown in Tables 6, 7, 8, 9 and 10. Table 6 indicates the fire departments that address certain respiratory exposure protection details in their SOPs/SOGs. 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 6 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

Table 6
Fire Department SOPs/SOGs 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 7
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 8
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

Table 9
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

Table 10
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 (O_2)	63	14	9	70	9	165
Hydrogen sulfide (H_2S)	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 (SO_2)	15	4	3	44	3	69
Nitrous oxide (NO_x)	8	5	3	36	3	55
Particulates	3	3	1	17	5	29
Other	1	1	0	9	3	14

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 using SCBA also address removal (assuming that none have SOPs/SOGs only for removal).

Table 6 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 6 indicates the ratio for every fire department that has SOPs/SOGs for hand held atmosphere monitoring equipment is three to one, or in other words, for every four fire departments three 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 6 illustrates a great variety of detail and focus toward addressing these particular subjects, addressing the many aspects of this equipment. For example, almost all address care and maintenance issues, but less than a majority provides significant detail on when and where to use the equipment.

Table 7 clarifies how hand held portable atmosphere monitoring equipment is being utilized, and distinguishes between ‘use’ in any manner and if the equipment is ‘recommended’ according to the department’s operating guidelines or procedures. 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 7, 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 8 provides detail on the type of fire ground activities where different respiratory protective equipment is being used. The rows of Table 8 have been shaded to distinguish results with common responses. This 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.

One aspect of the results from Table 8 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 8 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 8 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 indicate that they use no respiratory protective equipment.

Table 9 provides clarification on who makes the decision and how the decision is made to use or remove SCBA. This indicates that those who decide when to use SCBA are also the same people who decide when to discontinue its use. Table 9 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.

The final direct result from the information collection form is shown in Table 10. This clarifies when and what atmosphere components fire departments are routinely measuring, and the rows of Table 10 have been shaded to distinguish results with common responses. An analysis of this data reveals several interesting results.

First, from an overall standpoint based on the fire department response situations represented by the five columns in Table 10, 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 10 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 10, 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 Tables 6, 7, 8, 9 and 10 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.

4.4. 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 11. 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 4, 5, 6, 7, 8, 9 and 10.

The 32 fire departments indicated in Table 11 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 US OSHA CFR 1910.120, which provides the following thresholds for a hazardous work environment: CO >35 ppm; H_2S >10 ppm; $19.5\% \leq O_2 \geq 23.5\%$; and additionally, flammable concentrations $<10\%$ LEL [100]. This helps to explain the moderate consistency with the data in Table 11. 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 at 35 ppm, H_2S at 10 ppm, O_2 at 19.5–23.5%). 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 11 is also of interest, and this appears to be caused by different required or recommended values (summarized earlier in Table 2) 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.

5. Conclusions and Recommendations

The information provided in this study is intended to raise awareness on the need for emergency responder respiratory protection, promote and support specific fire service respiratory exposure related research, and to help develop best practice fire

Table 11
Selected Fire Department Hazardous Atmosphere Threshold Measurement Values

State	Population protected		Dept size career		Dept size volunteer		Threshold values referenced in SOPs/SOGs (in PPM, except "O_2" in % and "other" as applicable):				
							CO	HCN	H_2S	O_2[a]	Other
Aus	A	1M or more	A	400 or more	A	400 or more	30[b]	10		19.5/23.5	VOCs < 0.5[c]
AZ	B	1M–500K	A	400 or more	F	9 or less	10[d]			20.6	
CA	E	100K–50K	D	99–50	F	9 or less	25[e]		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[e]		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[f]		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	

Table 11
continued

State		Population protected		Dept size career		Dept size volunteer	Threshold values referenced in SOPs/SOGs (in PPM, except "O_2" in % and "other" as applicable): CO	HCN	H_2S	O_2[a]	Other
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 < 0.1/cc[g]
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[h]
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[i]			19.5[i]	

[a] Single value indicates lower limit, and two values indicate lower and upper limit.
[b] Based on Australian national occupational health and safety commission guidelines as follows: 30 ppm for TWA 8 h exposure for 40 h/week; 60 ppm for 60 min TWA exposure; 100 ppm for 30 min TWA exposure; 200 ppm for 15 min exposure; 1200 ppm for IDLH.
[c] Unspecified mixture of volatile organic compounds (VOCs) <0.5 ppm. Also acid gases (such as HCl) <5 and 50 ppm IDLH, and Formaldehyde <1 and 20 ppm IDLH.
[d] For overhaul, CO threshold = 10 ppm. For CO detector calls or CO leaks, CO threshold = 25 ppm.
[e] Based on California dept of health services and Cal/OSHA requirements, for exposure limit of 25 ppm over 8 h or 200 ppm at any time.
[f] Based on multiple CO thresholds of 9, 24, or 100 ppm depending on hazard and occupancy.
[g] Asbestos thresholds based on 0.1 fiber per cubic centimeter for 8 h TWA.
[h] Temperature required to be less than 200°F.
[i] Measurement cannot be exceeded over a 10 min continuous reading.

service guidance for determining when to use and discontinue use of SCBA and other respiratory protective equipment. The methods used to achieve the study objectives include a review of background information on this topic, a review of the applicable literature, and the collection of data from fire service organizations. The following are the key findings of this study and the recommendations for future research.

5.1. 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 trend of fewer fire fighter respiratory injuries in the last quarter of a century appears to have stabilized in the last decade.
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 one to four 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.

The key findings 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.

5.2. Future Research

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

Respiratory Exposure Study

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, including respiratory hazards and other important fire ground characteristics such as temperature. 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.

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