FIRE SMOKE COALITION

SMOKE

Atmospheric Monitoring: The Comprehensive Guide

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Forward

By *Rob Schnepp*

The Fire Smoke Coalition is spreading the word across the world about the dangers of fire smoke, and most important, the Toxic Twins™ – hydrogen cyanide (HCN) and carbon monoxide (CO). It does not take a critical examination of scientific data to determine that fire smoke is a toxic soup of dangerous gases and a deadly enemy to firefighters and responders. What is still confusing for responders is how to decide which toxins are important to pay attention to; how to identify them amongst the other gases and particulates in fire smoke; and, at what point is the air safe to breathe without SCBA or other respiratory protection.

While gas detection is common in the hazardous material response side of the fire service, the typical line firefighter is unfamiliar with gas detection, manufacturers, gas detection devices, and methods and procedures for detecting toxic gases at every fire scene. It is important to note that there is no industry standard best practice when it comes to detection and monitoring in the fire environment, specifically during overhaul. To that end, agencies are investing in technologies for detecting toxic gases at the fire scene without a clear understanding of the mission, the limitations of the devices, or an understanding of the results. That is slowly changing due to the rising level of awareness of the dangers of fire smoke, and the need to identify the presence of toxins at fire scenes. Change is slow to occur primarily because of the strong fire service culture which includes the use, or lack of use, of self-contained breathing apparatus; an ingrained belief that breathing smoke is part of the job and unavoidable; and, the lack of familiarity with gas detection devices among non-hazardous materials personnel in the fire service.

Up until the last few years, there have been three primary uses for detection devices for a typical fire department outside of the traditional Haz Mat response team:

- Rescue response including confined space
- Building collapse and trench rescue
- CO detector responses

However, it is known that the extensive commercial and residential use of synthetic materials (plastics, nylons, and polymers such as Styrofoam and polyurethane foam) have a significant impact on combustion and fire behavior, as well as the smoke produced during a structure fire. Synthetic substances ignite and burn fast, causing rapidly developing fires and toxic smoke, making structural firefighting more dangerous than ever before.

Understanding the flurry of activity and education regarding fire gas toxicity and firefighter safety, the need for atmospheric monitoring on every scene adds an entirely new category for detection – outside of the hazmat response. Ideally, the ultimate goal is to create a new concept for the fire service: *gas detection is user-friendly for all firefighters on the scene of everyday fires.*

Gas Detection Survey Results

In 2012 the Coalition issued a national survey to assess the base level of knowledge regarding the use of gas detection devices at the scene of a fire. 244 firefighters responded. The demographics of those responding were:

25% - Volunteer
34% - Combination Career/Volunteer
40% - Career

The majority of respondents were line firefighters working in the field. When asked about standard operating procedures for using gas detection devices at fire scenes, 80% of the respondents replied they had no standard operating procedures for detecting/monitoring hydrogen cyanide in the field. 49% of the respondents had no similar operating procedures for detecting/monitoring CO on the fire scene and 79% of the respondents had no standard operating procedures for detecting/monitoring any toxic gas on the fire scene. The conclusion to be drawn is an overwhelming majority of the firefighters have no guidance when it comes to performing the task of detecting and monitoring for toxic gases on the scene of a fire.

Over 20% of the respondents replied they have been treated for smoke inhalation but more interesting is that 90% stated they have never been treated for smoke inhalation, but suffered headaches, nausea and sore throats following a fire. This indicates a lack of understanding of the signs and symptoms of smoke inhalation, which points directly back to detection and monitoring. If a firefighter does not have a reference point about the quality of air they are breathing, there is no correlation back to the fact that smoke may be the culprit for feeling ill after a fire or causing long-term health effects.

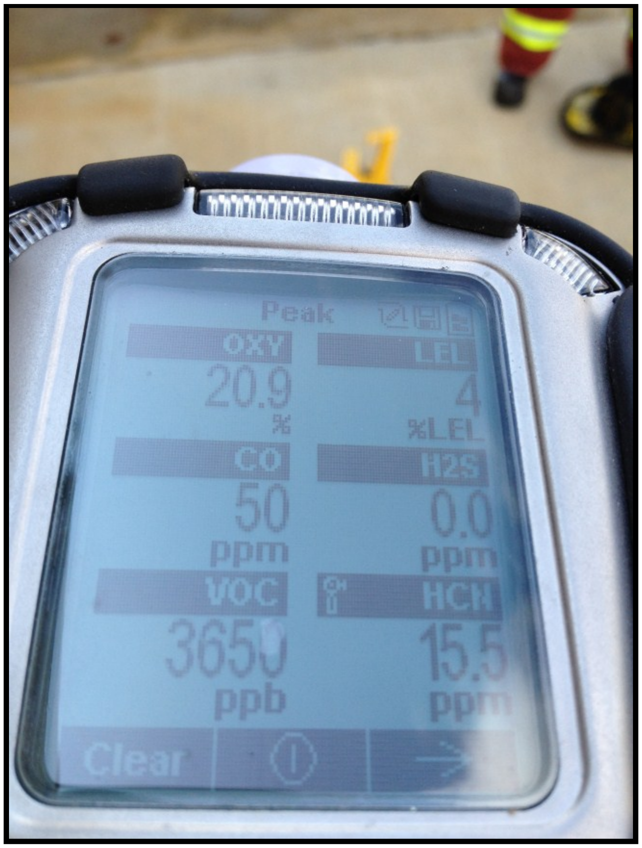
The majority of firefighters who attend the Coalition's *Know Your Smoke: The Dangers of Fire Smoke Exposure* training program go back to their departments with new education and awareness about the need for atmospheric monitoring on every fire scene, but don't know where or how to begin the process of developing *procedures* and *practices*.

The purpose of this publication is to provide the reader with a comprehensive tool to guide a fire department through the process of selecting gas detection devices, the process of atmospheric monitoring, the physiological processes the body will endure when exposed to fire gases and the actual process for implementing departmental atmospheric monitoring protocols.

To direct the educational content of this publication, the Coalition engaged the expertise of Chris Hawley, Dr. Jim Brown and Jason Krusen, all of which will share fundamental, but necessary information about the process of atmospheric monitoring from beginning to end.

There's no question the fire service has come a long way since WWII. Hopefully, the information shared in this publication will guide your department through the productive and live-saving steps of atmospheric monitoring on every fire scene.

**A new concept for the fire service:
gas detection is user-friendly for all firefighters
on the scene of everyday fires.**



Sensor Technology and Detection of Toxic Gases in Fire Smoke

By *Chris Hawley*

The intent of this article to provide the reader some level of expertise about gas detection, an overview of sensor technology, and the types of detection available with the hope of providing a more reliable means of working on every fireground scene with the additional protection and absolute understanding of what you will be breathing if not wearing and using air. Ultimately, this article is about providing greater protection and longevity to first responders.

The dangers of fire smoke can often be under appreciated in today's response community. Fire smoke contains hundreds of lethal and toxic gases, i.e., carbon monoxide, carbon dioxide, hydrogen cyanide, ammonia, hydrogen chloride, sulfur dioxide, hydrogen sulfide, and oxides of nitrogen.

Think about it this way: if any *one* of these gases were leaking from a tanker or cylinder on a highway, first responders would establish a perimeter and only personnel in hazardous materials suits would be allowed in the area. Now combine all of these dangerous gases and dump them into the high-temperature environment of the everyday house fire with firefighters running toward the situation − sometimes with and sometimes without proper protective clothing. Structural fires, vehicle fires, dumpster fires and, frankly, any type of fire will produce toxic gases – it is the type and amount of gases that will vary from fire to fire. Merely heating certain items, such as plastics can produce toxic gases. If you are a firefighter with a few years of experience, at some point you've probably suffered from a headache or nausea following a fire, which is indicative of exposure to one or more of the toxic gases. These exposures can add up over a firefighter's career and create long-term health issues and even death. It is critical to the safety of the emergency response community to determine what dangers are present and at what level they exist at every incident scene. This can present a significant challenge for the emergency response community, primarily considering that current technologies are not able to accurately distinguish between the components of the toxic soup known as fire smoke.

Exposure Levels

The toxic mixture contained in fire smoke is comprised primarily of carbon monoxide, carbon dioxide, hydrogen cyanide, ammonia, hydrogen chloride, sulfur dioxide, hydrogen sulfide, and oxides of nitrogen. The National Institute for Occupational Safety and Health (NIOSH) establishes safe levels for chemical exposures in the workplace. However, the values are for average worker exposure and can only be *estimated* for the rigors of firefighting. High heat, increased vital signs, open pores, and dehydration are just some of the factors that would add to the intake and effects of these toxic gases on responders. For the purpose of this article the more conservative NIOSH levels will be used to guide suggested operations and assist in the evaluation of whether a situation is safe or not safe for responders. The exposure levels used are:

- **IDLH** (Immediately Dangerous to Life and Health)
- **STEL** (Short Term Exposure Limits)
- **REL** (Recommended Exposure Limits)

Levels at or above IDLH require immediate withdrawal from the environment or the use of breathing apparatus. To determine STEL and REL the average levels are calculated for a particular time period, even though during that time period, the levels of the toxic substance can rise and fall. A STEL is for a 15-minute exposure no more than four times a day, and a REL is for a 10-hour exposure. The Occupational Safety and Health Administration (OSHA) also has set comparable levels, and, in many cases, uses the NIOSH values. OSHA uses Permissible Exposure Limit (PEL) instead of REL and the PEL is an average calculated over an 8-hour period. The values for the toxic gases commonly present in fire smoke are listed in Table 1.

Table 1: Exposure Values and Density

Gas	REL	STEL	IDLH	Density
Ammonia (NH_3)	25 ppm	35 ppm	300 ppm	Lighter than air
Carbon dioxide (CO_2)	5,000 ppm (0.5% vol.)	30,000 ppm (3% vol.)	40,000 ppm (4% vol.)	Heavier than air
Carbon monoxide (CO)	35 ppm – no higher than 200 ppm allowed (ceiling)	NR	1200 ppm	Lighter than air
Hydrogen chloride (HCl)	No higher than 5 ppm (ceiling)	NR	50 ppm	Heavier than air
Hydrogen cyanide (HCN)	4.7 ppm (15 minutes only)	4.7 ppm – 1 time only	50 ppm	Lighter than air
Hydrogen sulfide (H_2S)	10 ppm (10 minutes only)	10 ppm – 1 time for 10 minutes	100 ppm	Heavier than air
Oxides of Nitrogen (NO_x)(NO_2) (NO)	NO_2 - 3 ppm NO - 25 ppm	NO_2 – 5 ppm NO - NR	NO_2 – 20 ppm NO - 100 ppm	Heavier than air
Sulfur dioxide (SO_2)	2 ppm	5 ppm	100 ppm	Heavier than air

There are a number of methods to detect toxic fire gases, but the most common method involves the use of single gas or multiple gas detection devices. When monitoring for toxic fire gases, responders can use the levels listed in Table 1 to determine if an area is safe or not safe. The IDLH for CO is 1200 ppm. Therefore, if responders obtain meter readings that indicate levels at or above 1200 ppm, the environment or situation should be considered immediately dangerous to the life and health (IDLH) for those in the environment or situation.

The use of the term "immediately dangerous" in IDLH imparts a sense of risk, but what can be more difficult to navigate are the situations where levels are below the IDLH. The REL is the most conservative of the remaining levels, and therefore safer, so it will be used for examples herein. The REL is an average over a 10-hour period, so to get a REL on an emergency scene would involve calculations of the dose of the toxic gas over time. Considering the dynamic nature of fire scenes and that time isn't typically available for emergency responders, this isn't a real possibility. The easiest and also safest route is to use the REL level itself as the safe point. For example, the REL for CO is 35 ppm, so any level above 35 PPM would be considered dangerous.

From a personal standpoint, during hazardous materials responses, a building or area was never safe until gas detection readings were below the REL. The strategy for dealing with environments thought or known to have potential toxic gases was simple: below REL **-** breathing apparatus could be removed; levels at the REL and above **-** breathing apparatus were left on. Long-term exposure to toxic gases is detrimental to the health of all first responders. At your first fire you may not anticipate much exposure, but when you catch that second, third and fourth fire you are increasing the risk of illness, disease and even death through cumulative exposures. The common sense approach is simply this. Why inhale any toxic gases? It just isn't worth the risk to your health, your livelihood, and your family.

Unfortunately, the simple philosophy of using the REL to determine the use of breathing apparatus may be considered somewhat controversial. Some current schools of thought advocate wearing breathing apparatus masks the entire time on a scene since the potential for exposure to toxic gases is so great. But, in reality, these philosophies are no different. The safest means of operation is to keep breathing apparatus mask in place for the duration of an incident, but it is well known that first responders on fire scenes throughout the country remove their masks during overhaul. There are situations where the REL is low enough to remove breathing apparatus masks, which can make the strenuous work on an incident scene easier for responders. If the equipment is available to detect and monitor for toxic gases, using the REL to determine whether an area is safe or not safe is a viable option that still protects the safety of the responders.

Detecting Toxic Gases

Part of the challenge in detecting toxic fire gases relates directly to the volatility of a given situation and the limit of technology. The atmosphere is not consistent, and the type and amount of gases present will vary. In most cases on a fire scene, the toxic gases common in fire smoke will be present, but the levels may be below the threshold of detection. There are eight main toxic gases that are usually present, but many fire departments only try to detect CO and/or HCN. Responders that are only looking for CO could be missing at least seven other gases and some are significantly *more* toxic than the CO. It is also possible that there are more than the standard eight gases present, depending on what is burning or smoldering. Using detection methods to search for CO and HCN is a good place to start as these two are or can be immediately lethal. While looking for CO and HCN does offer some level of protection and can be a good first step, truly effective detection and monitoring would mean that responders would check for all of the eight gases that are most likely present.

Detection devices typically use electrochemical sensors filled with a chemical reagent that reacts with the target gas and results in a meter reading. There are a number of sensors that can be used for fire gas sampling. For example, a carbon monoxide sensor is filled with sulfuric acid and has two electrical poles within the sensor. When carbon monoxide enters the sensor there is a chemical reaction that changes the electrical balance in the sensor. The poles detect the change which results in a reading. However, one of the challenges in detecting toxic gases is how precise the sensor is in detecting the target gas. The carbon monoxide sensor will react to quite a few other gases, some of which are listed in Table 2.

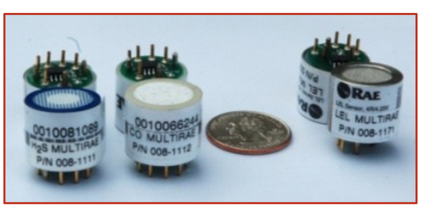


Table 2: Common Interferents to CO and H2S

Electrochemical Sensors		
Acetylene	Hydrogen	Methyl Sulfide
Ammonia	Hydrogen cyanide	Nitric oxide
Carbon disulfide	Hydrogen sulfide	Nitrogen dioxide
Dimethyl Sulfide	Isobutylene	Phosphine
Ethyl alcohol	Isopropyl alcohol	Propane
Ethyl Sulfide	Mercaptans	Sulfur dioxide
Ethylene	Methyl alcohol	Turpentine

Typical electrochemical sensors used by firefighters include oxygen, hydrogen cyanide, carbon monoxide, hydrogen sulfide, ammonia and chlorine. These sensors are commonly found in single gas devices. There are several issues that arise with electrochemical sensors, specifically those used to detect O_2, CO, H_2S, and HCN, which are detailed below:

- Toxic sensors react to other gases and you cannot be sure you are reading a level of the intended gas or an interfering gas. For example, if you are reading levels of both CO and H_2S there is probably an acidic gas present that is causing the reaction and resulting in the readings displayed. Most of the interfering gases are also toxic, so when readings are found on the detection devices firefighters should be aware that there are toxic gases present. Some of these gases are also flammable which means you may also get a reading in your flammable gas sensor. There are ways to determine which gases are present through the use of detection devices your hazardous materials team carries.

- Electrochemical sensors can be easily overwhelmed and will max out with regard to their readings. For example, most HCN sensors will max out at 50 ppm and won't tell you if you are in levels higher than the maximum. CO sensors usually have a maximum reading of 500 ppm. High exposures to a gas that causes a reaction will result in the sensor failing sooner than its intended life.
- Electrochemical sensors fail to the "0" (zero) point. With O_2 that's not necessarily a problem since 0% oxygen is dangerous and you would not enter a potentially hazardous environment. But when a CO or HCN fails and reads 0, it may not indicate it has failed, and that can set-up responders for believing a toxic gas is not present – a dangerous situation.

  Some detection instruments will indicate that a sensor has failed, while others may not. Responders should ensure their devices are calibrated according to manufacturers' recommendations and should at least be bump tested prior to use. Many companies recommend the devices be calibrated before use, which is not practical in an emergency response environment, but it should be bump tested at a minimum. To bump test a device, it is exposed to a known quantity of gas to see if the meter responds appropriately. It may not read exactly to the levels of the target gas, but it should respond reasonably close to the level indicated in the bump test bottle. You can use the calibration gas to bump test your instrument and it only takes a few seconds once a device is warmed up.
- Responders must be mindful of the reaction time of electrochemical sensors as they can take as little as 20 and as much as 200 seconds based on the type of sensor to react based on the type of sensor.

Flammable Gas Sensors

There are other types of detection devices besides electrochemical sensors that are available to responders. One of the more common flammable gas sensors is a catalytic bead sensor, and may also be known as a Lower Explosive Limit (LEL) sensor. Flammable gas sensors are used to determine how dangerous a flammable gas release is in an area. Flammable gas sensors will have a portion of their systems that are heated so when a flammable gas crosses the sensor there is a measurable increase in heat that results in a meter reading. Most of the flammable gas sensors measure how close you are getting to the LEL level. When dealing with flammable gases and vapors, in order for them to burn or explode they must be mixed with the proper amount of air. Once in the proper mixture, and if an ignition source is present, ignition can occur. There are two levels that are relevant to the responder: the lower explosive level (LEL) and the upper explosive level (UEL). The range between the LEL and the UEL is known as the flammable range, and it is in this range when present gases can burn or explode. Above the UEL or below the LEL combustion is not likely. Most gas detection devices utilized by first responders are used to detect proximity to the LEL. and are set to detect methane accurately, and the LEL for methane is 5% (95% air). When the LEL sensor reads 100% there is 5% methane in the air, as you have reached 100% of the LEL for methane. The situation is dangerous long before your detection device reaches 100%. The detection device will alarm at 10% of the LEL, which is a good warning point. When the meter alarms for LEL, actions should be taken to make the atmosphere safe or responders should retreat.

Photoionization (PID) Sensor

Another type of sensor that may be used by first responders is a photoionization (PID) sensor. The PID sensor uses an ultraviolet light to ionize the gases that move through the sensor. When gases are ionized sensors are able to determine the electrical components of the molecules. When electrical charges are found a reading is generated based on the calibration gas, which is isobutylene. The PID sensor generally detects common toxic materials such as benzene, acetone, toluene, ammonia, and many others. It is primarily a sensor that detects organic materials (materials that contain carbon as part of the molecular structure). Ammonia is the most common inorganic chemical detected by a PID. The PID does not identify the material that is present; it only alerts the user of its presence. A PID in a smoke situation will detect the toxic soup that is in the air and alert you that something is present, but will not identify what toxic gas is present.

Responders should be aware of differences in the reaction time of the various detection devices: electrochemical sensors react within 20-200 seconds, LEL sensors in 7-10 seconds, and the PID reacts within 1-2 seconds.

Another consideration with any electronic detection device is the dirt and filth created in the fire environment. There is a lot of particulate matter in the air, and many detection devices have an internal pump, which is drawing the gas into the device for analysis so any particulates in the air will be drawn in as well. To combat this problem most devices have a protective filter, which keeps out particulate material and will offer some limited protection against liquids. The devices are not usually water resistant, and if there is any chance water can be drawn in to the device it should be shut off as quickly as possible. New filters will be required on a regular basis depending on how often the device is used and how dirty the sampling environment is. If the device has a PID it is possible the PID will alert when the filter is dirty, as you will get readings on the PID in what should be a clean environment. With devices that have an internal pump you can hear the pump change to an increased draw when the filter is removed and when you place the filter back on the pump it will bog down. You may also be able to see the filter is dirty, and if you can see dirt then the filter should be replaced. You should always use a filter with a detection device, otherwise the device may require repair.

Colorimetric Tubes

Another option for the detection of toxic gases is colorimetric sampling using colorimetric tubes. Colorimetric tubes can also be used to confirm the readings of the electrochemical sensors. The colorimetric tubes are designed to determine the levels of a known gas but can also be used to help determine what unidentified gases may be present. The tubes are set-up to detect chemical families, but they can also be used to detect a specific chemical. For example, the ethyl acetate tube is designed to detect ethyl acetate but if the test is positive it could mean that there is an organic material in the air. The acetone tube detects acetone as well as all the other aromatic hydrocarbon vapors. The process for colorimetric sampling requires that a certain amount of sample air moves through the tube. To accomplish this, a responder can use a piston-style pump or a bellows pump. Both of these styles have long sampling (draw) times; however, the piston pump is the easiest to use. Each tube is different but, as an example, CO tubes may have a sampling time of one to three minutes. When using the piston-style pump, draw back the plunger to introduce the air sample into the tube. It will then take one to three minutes for the air sample to be drawn into the tube. When using the bellows-style pump you squeeze, release, and wait for the bellows to expand fully before squeezing again. This method requires the user to track the number of pumps it takes to draw the proper amount of air through the tube. Most sample pumps and piston pumps have an indicating mechanism that alerts the user that the pump stroke is complete.

Colorimetric tubes are a point source sampling tool - meaning that they will only indicate the presence of a material right at the intake of the tube. The colorimetric tubes are easy to use and are accurate devices that do not require calibration immediately prior to use. For the most part, the tubes are one-time use only, but the pump can be reused a number of times. There are standard hazardous materials detection kits that use colorimetric tubes and can help responders detect the range of toxic fire gases. These kits are a bit more complicated and are usually carried by hazardous materials response teams rather than fire engines or truck/rescue companies. They do require additional training and experience to effectively use them.

Detection, Usage and Strategy

Although we have already discussed some of the issues with detection devices, they are the best tools for detecting toxic gases at the first responder level, even with their respective challenges. Responders should develop a strategy for the use of detection devices. The use of detection devices during active firefighting is not a good idea as heat and water can be immediately or cumulatively detrimental to the instruments. Many are water resistant, but most are not waterproof and can be damaged in temperatures above 100° F. Air monitoring should be conducted when active firefighting has ceased and there is a possibility that personnel may remove their facemasks. The important factor is that air monitoring should be conducted *prior* to any personnel removing their masks and monitoring should continue the entire time responders are operating in an area in case the situation changes.

Where to sample for the toxic gases can also present a challenge for responders as it is largely dictated by the size and configuration of the fire building. The best strategy for the protection of the responders is to have air monitoring occur at any location where personnel are operating and monitoring should be done throughout the building to make sure no "toxic hot spots" are present. The Toxic Twins™ will be present, but in most cases CO will be found throughout the building. HCN will not be as prevalent at high levels in most cases, but there will be areas where HCN may have accumulated. Any room or area that has a high concentration of plastic will typically have more HCN. Some forms of insulation will off-gas HCN, so it is possible that the HCN could be throughout the building. Both CO and HCN are lighter than air in normal conditions, so they will be found in higher concentrations on upper floors. Even in a basement fire personnel could be exposed to high amounts of CO and HCN in the attic space. Situations where there is little actual fire, but large quantities of smoke could also indicate CO and HCN are present. It is worth repeating that standard electrochemical sensors have a delayed response of 20-200 seconds, so when checking for toxic gases it is important that responders using the devices move slowly. The level at which people will be breathing the air in a space is the best place to do the monitoring.

Even though the Toxic Twins™ are lighter than air, when going below the fire area, monitors should always be used. There are only 11 toxic gases that are lighter than air –the remaining gases and vapors (and there are lots of them) are heavier than air. Table 1 provides the density of some of the fire gases and where they will be found in relationship to the air.

It is important for responders to monitor continuously as conditions on an incident can change. During overhaul, crews may initially identify the presence of a toxic gas at a relatively low level, but during the course of normal events on the scene, they may uncover hot smoldering debris, which could then emit higher levels of CO, HCN or other toxic gases. Consider also that ventilation of scenes, or the lack thereof, can easily change the atmosphere inside buildings and result in the build-up of toxic gases in areas that were previously identified as safe.

Operating in well-ventilated areas will obviously reduce the risk to the firefighters. The use of positive pressure ventilation (PPV) fans will increase the air flow, thus improving the air quality. However, responders must exercise caution when using PPV fans in situations where there are low levels of CO as the PPV fan will add to the CO levels. In fire situations this isn't a concern as the fire smoke will have higher levels of CO, but in situations where PPV is used and there are low levels of CO or other gases initially, the CO level will increase depending on how well the PPV engine is operating. A fan that is not operating well can introduce CO levels above the REL that previously did not have any CO.

Making Sense of Detection Findings

So what can responders make of all this information? The question becomes: "Once toxic gases are identified, at what level is it safe for responders to remove SCBA?" The easy answer, and the one that affords the highest level of safety for responders, is that since responders are dealing with a toxic mess, you can take your mask off when you are getting ready to leave. This stance offers the highest level of protection from acute and chronic health hazards. Realistically this may not happen. If that is the case, the detection methods outlined in this article can be used in concert with the NIOSH recommendations to make decisions about when to don or remove breathing apparatus masks.
Table 3 lists the recommended levels at which SCBA should be used for the specific gases listed.

Remember just measuring for CO and finding low levels does not mean there isn't a large quantity of HCN present.

Table 3: Recommended SCBA Use Levels

Gas	Recommended Levels for SCBA
Carbon Monoxide (CO)	35 ppm
Hydrogen Cyanide (HCN)	4.7 ppm
Hydrogen Sulfide (H_2S)	10 ppm (10 minutes)
Oxygen (O_2)	<20.8% or <21%

There are many fire departments that set detection devices to alarm at lower levels for CO, such as 20-25 ppm which increases the safety of their personnel. Even at those levels it would not be uncommon to have a headache after an exposure if the exposure is more than a few minutes.

When you look at the tasks being performed when masks are commonly removed, it is typically done in an environment with an increased temperature, so firefighters' core temperatures are higher, pores are open, and pulse and respirations are increased. Each of these factors enables toxicants to enter the body at a faster rate. The oxygen levels are set for action at 0.1% which, at first look, may seem a bit low since it is a common belief that only oxygen levels below 19.5% are dangerous since that is when the meter alarms. However, an oxygen drop/increase of 0.1% means that there is 5,000 ppm of something in the air that caused that drop. A drop/increase of 1% means there is as much as 50,000 ppm of something causing that drop. Usually it's carbon dioxide that causes the drop, which is fine at low levels, but at the higher levels would be concerning. It could also be a number of other toxic gases and you would have to figure out what that gas is to determine if the levels are safe. Consider also that oxygen sensors are not the most accurate and at that 20.8%-21% area will fluctuate a bit.

A lot of technical information is contained in this article and when someone starts to discuss hazardous materials-related topics with firefighters their minds tend to wander off to a warm and sunny place far away from any chemical hazards, other than ethyl alcohol. But fire smoke is serious business and it kills firefighters. It can not only be dangerous and deadly at the time of an incident, but cumulative exposures over the course of a responder's service can be equally as dangerous and deadly over a longer period of time. In other words, it may not always be a quick killer, but, over time, it can kill you if you don't wear your SCBA.

Technology is improving so that we are better able detect the hazards at fires, but it isn't perfect. Most of the toxic gases are odorless and invisible so even if you can't see smoke it doesn't mean there isn't a toxic soup waiting for you. Only detection devices can tell you if the intended target gas is present. Sampling for just one is not enough as there are many present that can cause harm. To accomplish those goals you need to use detection devices to identify potentially hazardous environments and wear your SCBA.

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Fire Smoke Gases: Where are they, and what will they do to you?

By *Jim Brown, PhD*

The post-WWII introduction of the self-contained breathing apparatus (SCBA) to the fire service represented a significant step forward in the protection of firefighter lives. Improved SCBA design and increased regulatory pressure have now made the SCBA a standard firefighting tool in the US. This tool has made it possible for firefighters to quickly get deep into smoke-filled, burning structures and be more effective in protecting life and property.

Recent scientific examination of the fire ground has revealed hazards in addition to those made obvious by simple observation. These additional hazards are associated with the content of fire smoke, where and when it is present, and how it interacts with the human body. This article will address these issues and, where possible, make suggestions for the amelioration of the hazards. Keep in mind firefighters recognize and accept a substantial amount of risk when they come to the job and that it is not possible to eliminate all hazards. The objective herein is to bring to light some hidden hazards so that firefighters can make more educated decisions about limiting their accepted risk.

IDLH vs. Non-IDLH / Chronic Exposure

The U.S. Occupational Safety and Health Administration (OSHA) terms environments that present immediate threats to life as IDLH (Immediately Dangerous to Life and Health). Any worker exposed to threatening environments is required to wear appropriate respiratory protection. Current fire ground protocols generally require use of the SCBA inside an active fire (burning) structure. The interior environment of a burning structure may be monitored for one or more gases and declared a non-IDLH environment (SCBA not required) when threatening gas levels drop below recommended exposure limits. Further, the exterior of a burning structure is generally considered a non-IDLH environment but is not monitored. During a recent research burn we conducted in Carmel, Indiana a structure was burned intact with contents (as opposed to the 1403 training protocol). We monitored the exterior environment for carbon monoxide (CO) and hydrogen cyanide (HCN). Monitors were set up at 10, 20, and 30 feet on each of four corners of the structure. During the growth phase of the fire, HCN and CO concentrations were recorded at all points *in excess of IDLH* levels. This suggests that monitoring should be considered outside the structure as well as inside.

Overhaul operations on the fire ground are assumed to be conducted under non-IDLH conditions. Even if this assumption is valid, the environment may still present serious health risks. Although monitored toxic levels may be below IDLH levels, these toxins still exist. From a single incident perspective, these low level exposures may present a negligible threat. However, for the career firefighter who repeatedly works in these environments, the accumulated exposure may contribute to the development of chronic disease states. This effect has been shown to occur in other industries were chronic, low level exposures have been associated with the presence of heart, lung, and neurologic disease states. The facts suggest firefighters should use respiratory protection during overhaul.

Smoke Composition

Smoke generated during a structural fire is a mixture of many gases and particulates harmful to a person's health. The composition of smoke generated in structural fires is well studied [(1)] and will not be extensively discussed here. However, it is important to understand that, although the qualitative composition of smoke probably hasn't changed much, the *quantitative composition has changed drastically in recent years*. With the increased use of plastics, vinyl, and natural fibers in building construction and household goods, the relative amounts of gases and compounds present in smoke have changed. New building materials, textiles and fabrics have been shown to give off higher amounts of aldehydes, cyanide, and other toxic compounds than materials used 30 years ago [(2)]. Many of these hidden hazards, especially those in gaseous form, are not detectable by the human senses.

	Harm You Now	Harm You Later
What you see		Soot Particulates
What you don't see	CO, HCN, NOx, SO2, HCL, H2S	Aldehydes, Benzene and more

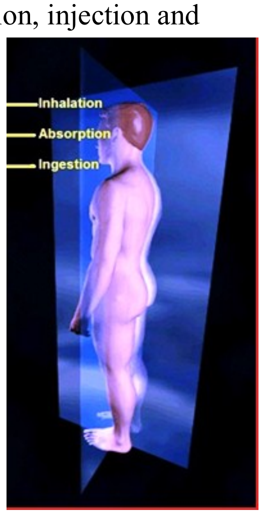
Where are the Gases?

Heat generated by a fire causes gases (including atmospheric air) to expand rapidly. This rapid expansion creates an area of high pressure which begins pushing smoke and combustion products out of its way. As a result, smoke and superheated gases are pushed throughout the structure. Ventilation of the structure provides an escape route for smoke but not all will leave the structure. An example is a recent NFPA 1403 burn conducted in Indianapolis, Indiana. All 1403 regulations were followed from preparation through burning. Between burns, we monitored the inside of the structure for carbon monoxide (CO), hydrogen cyanide (HCN), and hydrogen sulfide (H_2S). During overhaul and after the structure had been deemed safe for removal of SCBAs, we encountered a half-bath on the 1st floor that was essentially, a gas chamber. This small, non-ventilated bathroom measured 85 ppm HCN. Fortunately, the research team wears breathing protection at all times. Without a monitor, a non-protected individual would have inhaled a potentially fatal dose of cyanide. This is just one example of how these potentially toxic gases can hide in a structure, even when current safety protocols say the environment is safe.

Another factor to consider about where these gases can occur is temperature. As a gas is heated, it expands and becomes less dense. If its density becomes less than the surrounding gases, it will rise. Heat from a structural fire will not only create toxic gases but will cause them to rise in this manner. During the growth phase of a fire, these gases rise to structure's ceiling where they accumulate and begin creating high levels of gas pressure. Pressurization of the room causes smoke and gases to be pushed out of the room. More heat equals more pressure and increased velocity of gas movement, a familiar concept to firefighters. Following extinguishment however, the whole system tries to reverse. As gases cool, they become dense and move downward in the environment. This commonly occurs during overhaul and is a potential source of toxic exposure. So gases move around during overhaul make continuous monitoring necessary to protect firefighters.

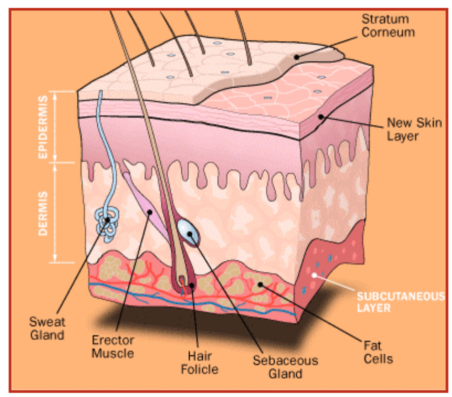
Toxic Assault on the Human Body

Toxins enter the human body by several routes including, ingestion, inhalation, injection and absorption. The total toxic load encountered by a body is the sum of all possible routes of entry. On the fire ground, only inhalation and absorption through the skin are relevant.



With an exchange surface area approximately that of a tennis court and a very small diffusion distance, the lung is designed for the exchange of gases between inhaled gas and the blood stream. Although the lung is set up this way to facilitate the exchange of oxygen and carbon dioxide as part of normal respiration, it also provides an effective pathway for toxic gases to enter the blood stream. The two most important fire ground toxic gases that utilize this pathway are CO and HCN. CO works as an asphyxiant by binding hemoglobin 200 times more effectively than oxygen. It eliminates the blood's ability to deliver oxygen throughout the body. HCN is also an asphyxiant. It attacks the cell's ability to utilize oxygen and generate energy. Significant exposure to HCN generally results in penalization of respiratory muscle and asphyxiation. More importantly, both HCN and CO are produced in a structural fire. They work synergistically to hurry death by attacking respiration from two sides, oxygen delivery and oxygen use.

Skin absorption of a toxic substance is far more complicated than inhalation. Many factors affect the rate or even whether or not a substance is absorbed through the skin. The skin can be pictured as a two layer system. The outer layer, the stratum corneum or epidermis, is a thin layer of dead cells that act as a primary barrier to absorption. Below the epidermis is a much thicker layer of living tissue that contains blood vessels, sweat glands, hair follicles and nerves. Absorption through this system is driven by diffusion alone. When a substance is deposited on, or in contact with skin surface, a concentration gradient is established that drives diffusion. This relationship is described by Fick's law of diffusion which in essence says, how much of the material reaches the blood stream and contributes to a toxic load is determined by the characteristics of both the compound and the tissue. Fick's law indicates that the rate of diffusion is determined by several factors including the surface area for diffusion (area of skin contaminated) and the concentration of the contaminant on the skin. In addition, the chemical characteristics of the contaminant are also important. The epidermis is a hydrophobic layer meaning it



repels water. Therefore, compounds similar to water will have a difficult time getting through. Organic compounds, like solvents, cross the epidermis more easily. Gases, like HCN and hydrogen sulfide (H_2S) move easily across the dermis and, in appropriate concentration, can contribute substantially to a toxic load [(4)]. Following the movement of a compound from the skin surface to the perfusion rich area of the skin, the amount of blood flow through the skin is another factor which contributes to toxic load. When the skin is hot, more blood flow is routed to the skin and provides the final sink for a contaminant's diffusion gradient. Of course, this is a common situation for the firefighter who works vigorously on the fire ground.

A firefighter's turnout gear provides substantial protection from dermal exposure during suppression operations. However, current fire ground protocols that may clear the removal of SCBA could provide an exposure risk with removal of the hood and mask.

In addition, contaminants that adhere to the exterior of the turnout gear can provide a source of exposure if handled extensively before cleaning.

In conclusion, to protect yourself and your crew, atmospheric monitoring is not a one-time exercise. To be effective, it must be continuously performed around the perimeter to protect incident command (not on air) during the initial stage of the fire and throughout the overhaul process, with the complete understanding that gases will travel throughout the fire scene. And, for absolute protection, SCBA's should be worn and used through overhaul and PPE must be kept clean, otherwise, the toxicant exposures will continue to invade your body.

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Atmospheric Monitoring: Getting Started

By *Jason Krusen*

In October 2007 the Columbia Fire Department was presented with the opportunity to test a single gas meter from a local vendor. In hindsight, this was an unplanned event that made for a positive change in the way the department would eventually start operating on fire scenes. The purpose of the test was to look at a replacement of a single gas CO meter for aging inventory. The meter received was a Rae Systems, ToxiRae II with an HCN sensor.

Because the characteristics of HCN were unfamiliar to the personnel assigned to Haz-Mat 1 the training chief asked that it be researched. There was a significant difference in the amount of information found when searching the internet for information on HCN in fire smoke as compared to CO. The department had been sporadically utilizing CO meters during overhaul for well over a decade, and was fairly familiar with the characteristics associated with CO exposure. With only a few articles and documented incidents readily available concerning HCN, a look into how the department could learn more about this unfamiliar and dangerous by-product of combustion was initiated.

Department Demographics

The Columbia Fire Department serves the 370,000 citizens of both Richland County and the City of Columbia. There are five Battalions, 31 Engines, 4 Ladders, 1 Heavy Rescue, 4 Light Rescues, 1 Haz-Mat, and 1 Rehab unit. There are 432 suppression personnel working 24/48. The minimum staffing on all apparatus in the densely populated areas is four, and two for units in the outlying areas of the county. The department covers 660 square miles including three major interstates, numerous colleges and universities, as well as some light industrial areas. The department tends to be progressive and is constantly changing the way it responds to calls and serves the community it protects.

First Step – The Research

Two notable documents were found that started the process. The first was the *Report of the Investigation Committee into the Cyanide Poisonings of Providence Firefighters,* a report from the 2006 hydrogen cyanide exposure of Providence, RI firefighters. The second document was *SMOKE: Perceptions, Myths and Misunderstandings*, an educational supplement sponsored by the Cyanide Poisoning Treatment Coalition. While there were other studies, i.e., the Dallas County Study and significant research in Paris, we felt command staff would be more acceptable of data found in South Carolina and therefore it was inevitable that local data collection would become part of the research process. After learning about HCN and the associated health risks of exposure, it was quickly decided that awareness training for HCN needed to be initiated within the department.

From the Providence report and the SMOKE publication, a concise list of key factors relative to HCN was prepared and eventually became the foundation for the final report prepared for command. Key factors included:

- HCN is 24 times more dangerous than CO
- The IDLH of CO is 1200 ppm, while the IDLH of HCN is 50 ppm.
- Low CO levels present a false security to the presence of HCN.
- HCN has a short half-life, making it difficult to fully diagnose the level of exposure.
- HCN symptoms in lower level exposures are similar to heat related illness and CO poisoning.
- HCN symptoms in severe or acute cases mirror that of a heart attack.
- Many health care facilities do not have the capability to test or treat for HCN poisoning.
- Suppression personnel are not properly trained on how to identify the symptoms of HCN.
- Statistical data is not available to help educate and protect firefighting personnel.

Along with the key factors, the first section of the research report explained the likelihood of health effects of HCN exposure if it occurred. The second section was a list of short term and long term goals the department needed to achieve.

To begin the HCN data collection process for the command staff more meters would be required. With one HCN meter already in use, two additional vendors were contacted and asked if the department could demo a meter from different manufacturers. A GasBadge Pro from Industrial Scientific and an AltairPro from MSA were quickly obtained to begin data collection and simultaneous field testing of the meters to determine which would be purchased.

Data Collection Begins

With the plan of action developed, information was presented to personnel assigned to Haz-Mat 1. It was crucial that a consistent message was delivered to all the shifts. If accurate metering was to be involved in the process, then personnel assigned to

Haz Mat 1 would have to participate. To start, a basic form was created to collect data at fires. Categories of data included:

- Type of Call
- Time of Call
- Time of Haz-Mat 1 on Scene
- Whether SCBA was used initially on scene
- Monitoring Time
- HCN Reading
- CO Reading
- Location of Reading

The last four categories were duplicated three times to enforce the process for monitoring throughout the fire scene and at different locations. Data collected was eventually transferred to a master spreadsheet.

Data collection took place over a nine month period and resulted in nearly 40 recordable incidents. There were many incidents metered but excluded because Haz Mat 1 was either late arriving or incomplete data was recorded. There were also random acts of metering, such as in the bay several hours after the fire, when we took an HCN meter around the turn-out gear and found the liner of the helmet still off-gassing 1ppm of HCN several hours after the fire.

Data Collection Process

Haz Mat 1 responded throughout the entire city and county in the interest of simply collecting data. Once on scene personnel would work in pairs to effectively meter the structure by strategically moving through the structure and documenting the readings from the meters. They would compare what the three meters read to check for consistency. Readings were taken at similar locations such as the front door, the fire room, and the room farthest from the fire. Personnel even monitored outside the structure where crews were staging, at the pump pane and the command post. For comparison purposes, metering also took place at various times immediately following knock down of the fire, during ventilation and following ventilation.

It was difficult to determine a pattern for HCN presence based on the data collected. There were small fires, such as a pot on the stove that generated light smoke with high levels of HCN, and there were room and content fires that should have surely produced higher levels of HCN based on the amount of smoke, but only registered in the single digits. It was difficult to explain, but it made personnel start taking note of what was heated or burned.

One fire in particular was a kitchen fire in a garden apartment which bolstered the need for atmospheric monitoring. The fire came in at 17:49 on a warm fall evening. The fire was knocked down fairly quickly after causing damage to the two end units of the two-story building containing 12 units. Approximately one hour and twenty-five minutes after the fire was under control crews were asked to check units farthest away from the fire to ensure it was safe for occupants to re-enter the structure. The ladder company that entered those units stated they had a light haze of trapped smoke in the units and a quick ventilation operation was needed.

The personnel from Haz Mat 1 entered the structure and found an alarming reading of 79 ppm of HCN and 49 ppm of CO. These numbers were not really anything new since we had been metering for a few months, but the amount of time that had elapsed since the fire was placed under control was certainly new. We had not seen any readings of that magnitude so long after the fire. With no visible smoke we began to question such high readings and suddenly realized we were looking for the gases within the smoke and not outside of the smoke. It was only through utilizing meters that the hidden dangers were formally introduced.

The visible smoke was a sure sign of a potentially dangerous atmosphere, but what was *not* seen was even more dangerous. Firefighters generally let their guard down once the active fire is controlled which allows for the dangerous perception that the atmosphere is safe. We tend to hear people say all too often - "it's just smoke." Even worse, once the visible smoke has dissipated we become even more complacent. Following this apartment fire we learned this was no longer an acceptable means of operating on the fire ground.

After only the first few fires we accepted that it was not a matter of when or where - but how much HCN could be found at a fire. It was quickly accepted that HCN had arrived in Columbia, SC.

There were few incidents where no HCN was detected. It was also realized that there was no correlation between CO and HCN. There were fires where we found high levels of CO and moderate levels of HCN. There were other incidents where we saw high levels of HCN and low levels of CO.

In May 2008 the Chief of Operations issued a memo to the department explaining the data collection and metering process conducted by Haz Mat 1 at fires. This document helped win the support of some of the more apprehensive officers. The memo further explained that personnel would continue to monitor for CO at structure fires before removing SCBA's, until meters with HCN sensors could be purchased. By the end of the nine month data collection period enough information was obtained to substantiate the need for a stronger SCBA policy and atmospheric monitoring at structure fires.

In addition to data collection, the department was fortunate enough to pilot the Department of Homeland Security training video, *To Hell and Back IV* which was the first introduction to HCN and CO, also known as the Toxic Twins™ in fire smoke. During this training session personnel on Haz Mat 1 augmented the program by presenting the data collected and suggestions for how all future calls should be handled given the new consideration and respect for HCN.

Meters

In October 2008 the command staff was presented with a list of recommendations based on the information learned during the nine month data collection period. The readings recorded were overwhelming and command quickly agreed to the need for increased protection for the personnel. By the end of 2008 the approval to purchase ten single gas meters was made, as well as the writing of a Standard Operating Guideline (SOG) for atmospheric monitoring at structure fires. The single gas meters were paired with standard four-gas meters already in use. This allowed the companies to have a CO and HCN meter at all calls they responded to.

By the spring of 2009 the meters were placed in service on four of the Rescues, the four Haz Mat Support Engines, Haz Mat 1, and one with the training chief. Metering now takes place at every fire, from a pot on the stove, to the dumpster, car fire and the two alarm multi-family dwelling fires. The SOG covers issues such as when to monitor, who is responsible for monitoring, when to calibrate, what to do if someone is expected of having a smoke exposure, and how to provide care.

The Road Ahead

Since there is so much more to learn about fire smoke the Columbia Fire Department is continuing to look for ways to protect firefighters. The first and easiest is to ensure SCBA are properly worn at every fire. The department's chief officers are seeing to this by ensuring air monitoring takes place prior to SCBA removal. The use of SCBA on all calls is being monitored, firefighter self-rescue, and department-wide air management training is now in process.

The Columbia Fire Department's path was a learning experience and resulted in live-saving changes for personnel. These changes are still taking place, and the overall reception by personnel has been well received. The changes came about from a positive and progressive movement instead of the result of a negative incident or mandate. Because of this and the persistent training and education, Columbia's firefighters are better educated and better protected.

REFERENCES:

SMOKE: Perceptions, Myths & Misunderstanding, 2005, Rob Schnepp, Chief David D. Costa, Dr. Donald Walsh, Mike Gagliano, Casey Phillips, Phil Jose, Steve Bernocco, Dr. James Augustine

To Hell and Back IV: Cyanide Poisoning, 2009, funded by Department of Homeland Security

Sample SOG – Atmospheric Monitoring

Effective: **Issued by:**

Purpose: To establish a guideline for air monitoring at structure fires.

Scope: This guideline applies to all suppression personnel.

Guideline: Fire smoke and its many bi-products of combustion present a serious health risk to responders. Hydrogen Cyanide (HCN) and Carbon Monoxide (CO) are just a few of the deadly gases that when exposed to can pose immediate and long term health effects.

I. Safety

A. Safety of responders is the first priority, therefore SCBA are required until a safe atmosphere can be determined by the use of meters.

B. HCN exposure may be difficult to determine. Its symptoms are similar to that of CO exposure, which may include headache, nausea, fatigue and dizzy spells at low levels and respiratory problems, unconsciousness, and cardiac arrest for high levels. If exposure is suspected transport to a health care facility should not be delayed.

II. Personal Protective Equipment

A. Self-Contained Breathing Apparatus (SCBA)

1. SCBA is the best preventive measure for smoke exposure, as inhalation is the primary route of entry for exposure.
2. SCBA is required on **all** structure fires that present a smoke condition, to include kitchen and cooking fires, until monitoring has taken place.
3. SCBA is required on **all** vehicle fires until completely extinguished and all smoke as dissipated, or monitoring has taken place.
4. SCBA is required on **all** large trash receptacle fires until completely extinguished and all smoke as dissipated.

B. Structural Turnout Gear

1. Turnout gear helps protect personnel from absorbing smoke through the skin, which is a secondary route of exposure.
2. Personnel are to wash turnout gear following structure fires that heavily soil and saturate gear with products of combustion.
3. If a second set of turnout gear is available personnel should switch gear as soon as possible.

III. Monitoring

A. All structure fires are to be monitored by utilizing a HCN and CO meters at a minimum.

B. If a company with meters is not on scene the Incident Commander (IC) is to request a unit with a meter to respond.

C. Meters will be located on [list units in which meters are assigned].

D. Companies that have a meter are to turn on the meter and leave it at the Command Post to ensure its usage by the IC, RIT, and/or companies in staging.

E. SCBA are **not** to be removed until the atmosphere can be monitored, and deemed safe.

F. The following conditions will warrant atmospheric monitoring.

1. When SCBA have been used during a working structure fire, ventilation is complete, and the removal of SCBA is requested.
2. Any personnel are found operating inside the structure without SCBA.
    a. The IC must then determine the length of time the personnel were operating in the environment without SCBA, and the reported readings.
    b. If readings and operating time period is of sufficient length, and signs of exposure exist then personnel are to be transported to the hospital for immediate evaluation (see section VIII.A.)
3. Vehicle fires within a structure or in a parking garage.
4. Whenever deemed necessary by the IC.
5. Adjacent apartments or structures where smoke is reported.

G. The following conditions will **not** warrant atmospheric monitoring. This does not dismiss the need for SCBA, and if a meter is readily available monitoring is still encouraged.

1. Vehicle fires in the open atmosphere.
2. When a burning odor is detected and there is no visible smoke i.e. light ballast

IV. Action Levels

A. The action level in order to operate without SCBA in an environment where HCN is present will be 4.7ppm. This is the Short Term Exposure Limit (STEL) for HCN as recommended by NIOSH.

1. STEL as defined by NIOSH is a 15-minute TWA (Time-Weighted Average) exposure that should not be exceeded at any time during a workday.

B. The action level for CO will be 35ppm. The atmosphere must meet both the action level for HCN and CO in order for personnel to operate without SCBA.

C. The atmosphere must meet both the action level for HCN and CO in order for personnel to operate without SCBA.

V. Decontamination

A. Personnel should practice good personal hygiene by washing hands prior to drinking and eating in rehab or back at the station.

B. If turnout gear has a reading higher than 4.7 ppm of HCN decontaminate the gear.

1. Use a PPV fan to blow off the large particulates on the gear, and if needed use a soft bristle brush.
2. If a fan is not available briefly rinse with a soft fog pattern to prevent saturation.
3. All personnel operating inside the structure should be decontaminated.

C. Gear should be washed as soon as possible in an approved gear extractor.

1. Turnout gear, flash hood, and helmet ear flaps should be washed in extractor per NFPA 1851 at the end of the shift.
2. Gloves should be washed by hand with hose or in sink.

D. If a gear extractor is unavailable, then a garden hose and a brush can be used. Allow gear to dry out of direct sunlight.

VI. Reporting

A. The reporting officer will be responsible for recording any significant exposures during a structure fire.

B. The following information will be supplied in the narrative.

1. The HCN and CO levels during the time of operation
2. Areas monitored with corresponding reading
3. How long personnel operated in the atmosphere
4. The personnel operating in the hazardous atmosphere
5. Specifics concerning the call. i.e. major materials that burned or were greatly heated

C. Exposure reporting

1. Anytime personnel are operating outside the safe range without SCBA a notation is to be made in the report under the Fire Personnel Casualty section.

VII. Calibration

A. Calibration will be completed by personnel assigned to [enter company or person responsible for calibration].

B. Meters are to be bump tested and calibrated according to manufacturer recommendations.

C. If meters are exposed to a high concentration and register "out of range" on the LED display the meter will need to be bump tested at a minimum to insure proper operation.

VIII. Exposure

A. The following three indicators are to be used to determine if a person has been exposed to HCN

1. Exposed to fire or smoke in an enclosed area
2. Soot found around the mouth and nose
3. Altered mental status

B. If personnel are found to have been operating in an IDLH atmospheres or experiencing severe health effects it is strongly recommended they be transported for advanced medical evaluation. The safety officer that reports to hospital is to request the following:

1. HCN has a half life of one hour, therefore it is imperative that the exposed personnel be given immediate medical attention to include blood work and tested for HCN levels in the blood.
2. It is important that when transported the hospital be advised that the firefighter was operating in a known hazardous environment containing hydrogen cyanide.

C. Acute exposure symptoms including weakness, headache, confusion, vertigo, fatigue, anxiety, dyspnea, and occasionally nausea and vomiting. Respiratory rate and depth are usually increased initially and at later stages become slow and gasping. Coma and convulsions occur in some cases. If cyanosis is present, it usually indicates that respiration has either ceased or has been inadequate for a few minutes. If large amounts of cyanide have been absorbed, collapse is usually instantaneous; unconsciousness; often with convulsions, is followed almost immediately by death [Hathaway et al. 1991].

Hathaway GJ, Proctor NH, Hughes JP, and Fischman ML [1991]. Proctor and Hughes' chemical hazards of the workplace. 3rd ed. New York, NY: Van Nostrand Reinhold.

The Authors

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Dr. Jim Brown

Dr. Brown is an applied physiologist with a background in cardio-respiratory and neuromuscular aspects of work and exercise physiology. His research focuses on ambulatory measurement of human physiology, especially within the first responder population. Dr. Brown has conducted multiple, federally-funded studies in the fire service and is dedicated to the reduction of firefighter line of duty deaths. Dr. Brown's research projects can be accessed through www.saferesponder.com.

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Jason Krusen is the Chief of Special Operations for the Columbia Fire Department in Columbia, SC, with over 20 years of experience. He has an Associate's Degree in Fire Service Administration. Jason is a Planning Manager with State Urban Search and Rescue Team, SC-TF1, Team Coordinator for the Type II Collapse Search & Rescue Regional Response in Columbia, and a Planning Section Chief for the Midlands Region IMT. Jason is also the Project Manager and Instructor for E-Med Training Services, LLC in Columbia, SC.

Rob Schnepp

Chief Schnepp has over 25 years of fire service experience, currently serving as the Chief of Special Operations for the Alameda County (CA) Fire Department. He is a member of the NFPA Technical Committee on Hazardous Materials Response Personnel. He is a member of the task group charged with revising *NFPA 473 Standard for Competencies for EMS Personnel Responding to Hazardous Materials.* A published author on several fire service topics, his works include "Hazardous Materials Awareness and Operations" from Jones and Bartlett Publishers, and numerous magazine articles for *Fire Engineering* magazine. Rob is a member of the *Fire Engineering* editorial advisory board, and the executive advisory board for the Fire Department Instructors Conference (FDIC). Rob is a former hazardous materials team manager for California Task Force 4, FEMA Urban Search and Rescue program and an instructor for the US Defense Threat Reduction Agency, providing hazmat/WMD training to an international audience.

Additional Resources:

Fire Smoke Coalition:
Combustible Household and Store Material Fire Smoke Chemical Air Monitoring

Smoke: Perceptions, Myths & Misunderstandings

Smoke: Cyanide and Carbon Monoxide: The Toxic Twins of Smoke Inhalation

SMOKE The Toxic Twins: An Advance Perspective On Cyanide and Carbon Monoxide Poisoning

Cyanide in Fire Smoke: 35 Years of Data & Research

To Hell and Back: Cyanide Poisoning