Understanding the Toxic Twins: HCN and CO

Dangerous individually, significantly more harmful together

This paper describes the nature of fires today, examines the progressive effects of CO and HCN on the body, and describes best practices for firefighter safety – including a new gas monitoring technology that can provide early warning of danger by simultaneously measuring the presence of both gases.

ABSTRACT

Smoke from structural fires produces many toxic gases that put firefighters at risk, including carbon monoxide (CO) and hydrogen cyanide (HCN). Together, CO and HCN – known in the fire industry as the "toxic twins" – create a deadly chemical asphyxiant that can put the firefighter or fire victim into cardiac arrest at the time of the fire and cause cancer decades later.

Because the combination of CO and HCN is exponentially more harmful than exposure to these agents individually, measuring each gas against its single alarm threshold is not ideal for overhaul operations.

BACKGROUND

In the 1970s, the fire service began to recognize the danger of inhaled toxic gases from smoke. Soon after, investigators became aware of the dangers of toxic gases found during overhaul. Now, the industry is learning of the long-term health dangers such as cancer from toxic gases.

In the 1950s and before, home furnishings were made of natural products such as cotton, wool and wood, which give off about 8,000 BTUs per pound when burned. But in the 1960s, they began to be made of synthetic materials. Today, the vast majority of furniture, carpeting, bedding, clothing, appliances, electronics and building materials inside the average home or office is made of synthetic materials.

Polyurethane, the plastic often used in today's soft materials such as cushions and carpeting, gives off 12,000 BTUs per pound when burned. Polystyrene, the hard plastic used in TVs, toys, and other plastic items in modern homes, gives off 18,000 BTUs per pound when burned.[1] Insulation – both rolled and spray foam – is the single product known to produce some of the highest levels of HCN and other toxicants during combustion.

All these synthetics are making fires burn two to three times hotter than those with natural materials and creating faster flashovers. The temperature of most house fires today is between 932 to 1,112 degrees Fahrenheit, although flashover temperatures can peak at about 2,000 degrees Fahrenheit.[2]

Because synthetics burn hotter than natural materials and produce quicker flashovers, they also speed up the release of HCN. Radiant heat from the fire source quickly heats all of the materials around it. The materials incur what is called quantitative decomposition – where they spread toxic gas through the structure before they ignite.

One of the most tragic examples of quantitative decomposition occurred in 2003 at the Station Nightclub in West Warwick, Rhode Island. Two pyrotechnic devices were set off during a band performance, creating an exothermic reaction that threw sparks over a distance of 15 feet for about 15 seconds. These sparks ignited a substandard sound suppression foam board that was wrapped around the stage to project sound into the audience. As temperatures soared from the initial flames, thermal decomposition of the foam board began to produce high quantities of smoke filled with HCN.

Subsequent investigations and a simulation of this event by NIST concluded that with no sprinkler system in the building, the performance area was uninhabitable within 90 seconds. Many of the 462 people in the room were overcome by the HCN/CO in the smoke before they could get out of the structure. 100 people lost their lives and more than 200 were severely burned or injured as a result of this event.[3]

WHERE THERE IS SMOKE, THERE ARE TOXIC GASES

In residential fires today, the leading cause of death is from smoke inhalation – not burn injuries. A 2011 study by the NFPA shows an 8-to-1 ratio of smoke inhalation to burns for deaths in home fires.[4]

Gases Produced by Burning Synthetics[6]

- Carbon monoxide
- Carbon dioxide
- Hydrogen cyanide
- Hydrogen chloride
- Nitrous gases
- Phosgene
- Hydrogen sulfide
- Sulfur dioxide
- Acrolein
- Ammonia
- Formaldehyde
- Glutaraldehyde
- Acetaldehyde
- Benzaldehyde
- Benzene
- Various polynuclear aromatic hydrocarbons (PNAs)

During a fire, oxygen levels decrease and the environment is likely to contain high levels of carbon monoxide and many other toxins. Moreover, smoke produces toxins regardless of its thickness, color or movement. It is impossible to tell from looking at smoke how much toxic gas is coming out of the structure. It's pretty obvious that there are toxins in heavy, turbulent smoke – but they can also be present in light colored smoke or even haze.

While firefighters are exposed to harmful substances both through their lungs and their skin, lungs are 300 times as efficient in getting toxins into the body.

HCN: THE SILENT KILLER

While the threat of CO has been known for years, a study by Jacksonville, Florida Fire Rescue's Capt. Rick Rochford showed that HCN was present at every fire he investigated. As Rochford points out, the effects of HCN and CO inhalation can last for days or even weeks after exposure.[5]

Firefighters are trained to watch for symptoms of carbon monoxide poisoning – including headaches, nausea, and drowsiness. Exposure to high levels of carbon monoxide can be fatal, but what is often overlooked is the presence of cyanide. While many associate cyanide with chemical weapons and hazardous material (hazmat) scenarios, research has shown that cyanide is a significant contributor to the thousands of fire-related deaths each year.

HCN IS UP TO 35 TIMES MORE TOXIC THAN CO

Studies have shown that in fire smoke, hydrogen cyanide can be up to 35 times more toxic than carbon monoxide. (See charts on next page.)

The NIOSH short-term exposure limit (TLV-STEL) for HCN is 4.7, above which concentration a worker should not be exposed (averaged over 15 minutes). Exposures cannot be repeated more than four times per day. The American Conference of Governmental Industrial Hygienists (ACGIH) has assigned 4.7 ppm as a worker ceiling limit (TLV-C), above which concentration a worker should never be exposed.[6]

CO CONCENTRATION IN THE AIR	VOL. %	INHALATION TIME AND TOXIC SYMPTOMS
35 ppm	0.0035%	Maximum workplace concentration for 8-hour workday
200 ppm	0.02%	Mild headache within 2-3 hours
400 ppm	0.04%	Headache in the forehead within 2-3 hours, extending to the entire head within 2.5-3.5 hours
800 ppm	0.08%	Dizziness, nausea and limb twitching within 45 minutes, coma within 2 hours
1,600 ppm	0.16%	Dizziness, nausea and limb twitching within 20 minutes, death within 2 hours
3,200 ppm	0.32%	Dizziness, nausea and limb twitching within 5-10 minutes, death within 30 minutes
6,400 ppm	0.64%	Dizziness, nausea and limb twitching within 1-2 minutes, death within 10-15 minutes
12,800 ppm	1.28%	Death within 1-3 minutes

HCN CONCENTRATION IN THE AIR	VOL. %	TOXIC SYMPTOMS
2.1 ppm	0.00021	Max workplace concentration for 8-hour work - Europe
2-4 ppm	0.0004	Perception threshold
4.7 ppm	0.00047	NIOSH REL: STEL
10 ppm	0.001	OSHA PEL: TWA
20-40 ppm	0.004	Slight symptoms after several hours
45-54 ppm	0.0054	Immediate and subsequent damage within one hour
100-200 ppm	0.02	Deadly after 30-60 minutes
300 ppm	0.03	Immediate death

Physical effects of exposure to increasing amounts of CO and HCN

Rochford's studies showed HCN levels of 200 ppm common in normal structural fires: That is lethal in 10 minutes.[7]

The prevailing thought had been that if you get a person out of the smoke and into fresh air, the toxins will be replaced by the fresh air. It is now known that the toxins are stored in the body and can be difficult to displace. Cancer has now become the #1 long-term cause of firefighter death.[8]

Because of the extreme toxicity of HCN, firefighters who experience dizziness, weakness, and rapid heart rate after a fire may actually be feeling the effects of HCN. It is theorized that many firefighter heart attacks and cardiac arrest during or following fire operation may be HCN-related.

HCN also has a narcotic-like effect and can result in irrational and bizarre actions, causing the firefighter or victim to make life threatening decisions.

Here are some examples of observed behavior:

- A trapped firefighter passes windows suitable for bailout, but walks past them.
- A firefighter walks through the fire to the entrance door, then turns around and goes back into the fire. He is recovered badly burned, goes into cardiac arrest, and is not revived.
- A firefighter becomes separated from crew members, radios Mayday, but does not activate his PASS and pushes RIT team members away twice before running away from them. He is overcome, goes into cardiac arrest and is not revived.

Facts about HCN[6]

- HCN is 35 times more toxic than CO
- HCN can enter the body by absorption, inhalation, or ingestion and targets the heart and brain
- HCN can cause heart attacks and cardiac arrest, then hamper resuscitation
- HCN can cause bizarre and irrational behavior, hamper ability to perform role or to self-rescue, and can hinder or prevent rescue by others
- HCN can incapacitate a victim within a short time

HOW HCN AFFECTS THE BODY

HCN is a cellular asphyxiant that interferes with aerobic respirations. During normal respiration, the body provides nutrients to key enzymes that allow our bodies to function properly. However, when HCN is inhaled, it has a high affinity for a key enzyme called cytochrome C oxidase – which basically shuts down the aerobic respiratory path. The result is anaerobic respirations, resulting in lactic acidosis and other toxic substances that are created in the tissues and organs.

Individuals inhaling hydrogen cyanide associated with smoke often experience cognitive dysfunction and drowsiness that can impair their ability to escape or to perform rescue operations.[6] Exposure to low concentrations (or initial exposure to higher concentrations) may result in stupor, confusion, flushing, anxiety, perspiration, headache, drowsiness, and rapid breathing. Exposure to higher concentrations of HCN result in prostration, tremors, cardiac arrhythmia (which can be delayed two to three weeks after the fire exposure), coma, respiratory depression, respiratory arrest, and cardiovascular collapse.

Unfortunately, there is no quick test that be administered to individuals at the site of a fire to check for HCN toxicity. As a result, all firefighters need to be on the alert for HCN poisoning in fellow firefighters – both at the fire scene and afterward at the station. If a firefighter or victim shows significant signs of HCN toxicity, HCN antidotes can be administered to help speed the person's recovery.

SYMPTOMS OF HCN POISONING[6]

- Lethargy
- Weakness
- Shortness of breath, chest tightening, headache
- Drowsiness
- Disorientation, possibly bizarre behavior
- Cardiac issues
- Possibly bright red skin discoloration (for prolonged exposure)
- Soot or burns around the mouth and nose
- Coughing up carbonaceous sputum
- Smell of almond extract on the breath (anecdotal)

TREATMENT OF A POSSIBLE HCN PATIENT

Because cyanide gas in fire smoke can quickly become lethal, early attention to possible cyanide poisoning is critical for saving lives. The prehospital treatment of acute cyanide poisoning entails removing the person from the source of cyanide, administering 100% oxygen, and providing cardiopulmonary resuscitation, if necessary.

An antidote called hydroxocobalamin has been effectively used in France for the past 10 years. It is designed specifically for use on-scene or at the hospital for acute HCN poisoning from any source. Hydroxocobalamin neutralizes cyanide by fixing it to form cyanocobalamin (vitamin B12), which is excreted in the urine. It does not reduce the blood's capacity to carry oxygen.

If cyanide poisoning is known or suspected, some practitioners recommend CYANOKIT® (hydroxocobalamin for injection; 5g for intravenous infusion) should be administered immediately. (www.cyanokit.com)

BEWARE OF SECONDARY HCN EXPOSURE

Firefighters also need to realize that because soft body tissue acts like a sponge, fire victims absorb a lot of the combustion byproducts. When a victim is removed from a contaminated environment and brought out into clear air, their body tissue begins to outgas some of the contaminants. Therefore, emergency responders working on the victim become exposed to the same contaminants, including HCN and many other chemicals.

After the victim has been delivered to the hospital and the firefighters go back to their station, the rescuers may start to experience headaches, nausea, vomiting, and things of that nature. While these symptoms may be a result of work stress, it might also be caused by exposure to contaminants such as HCN and CO.

CO + HCN: DEADLIER TOGETHER

The fact that CO and HCN are even more toxic together has long been known. This additive effect is described and proven in the dissertation "Effects of exposure to single or multiple combination of the predominant toxic gases and low oxygen atmospheres produced in fires" by Levin, Paabo, Gurman and Harris.[9] This research showed that all animal test subjects exposed to a mixture of HCN and CO, especially in a mixture of ⅓ and ½, were significantly more often fatally poisoned than the animals who were exposed to only one of these gases at the time.

The exact proportions of the gas concentrations during or after a fire are usually different because it depends on various factors such as temperature, location, time or duration. However, the fact that HCN and CO occur together on scene during and after fire seems very clear.

HOW CAN FIREFIGHTERS PROTECT THEMSELVES?

While firefighters cannot avoid exposure to toxic substances such as HCN and CO in the line of duty, they can protect themselves by adhering to the following guidelines.

- Wear PPE: This requires an ongoing commitment on the part of the firefighter
- Monitor toxic gases: Make gas monitoring a standard procedure
- Use SCBA: Keep SCBA on until it has been determined that air is safe to breathe and make SCBA available for drivers/operators
- Shower in an hour: By showering within an hour, firefighters can reduce exposure to toxins by 90%. If they wait until they go home that night, they have received 100% exposure – so the shower does nothing to reduce their risk of cancer.
- Decon: Decontaminate PPE according to Fire & Emergency Training Institute (FETI) guidelines
- Watch out for each other: Be alert to symptoms in fellow firefighters, both at the fire scene and back at the station
- Education and training: Institute a training program that focuses on making firefighters aware of the hazards of hydrogen cyanide

The best respiratory protection firefighters have today is through their SCBAs. Firefighters frequently ask if it's OK to use an APR chemical cartridge mask during the overhaul operation instead of their SCBA. Since it is not possible to clearly identify the gases in such environments, an APR chemical cartridge is not sufficient protection during overhaul operations. There are more gases than just CO inside the structure that firefighters and investigators need to be concerned about.

NEW TECHNOLOGY PROVIDES EARLY WARNING OF TOXIC TWIN DANGER

Dräger, a leading provider of high quality safety equipment to firefighters worldwide for more than 125 years, has introduced new toxic twin signal processing technology that provides protection against the combination of CO and HCN. The standard settings for the alarm threshold are for CO 35 ppm (A1) and 50 ppm (A2); for HCN 2.5 ppm (A1) and 4.5 ppm (A2).

The previous state of the art was to treat and measure CO and HCN separately – no adjustment was made for the presence of both gases. Each alarm threshold was analyzed separately and not enough attention was paid to the toxic synergistic effect. With the toxic twins signal processing, the gas values are measured together and are added. An alarm is triggered by scaling the concentration of both substances.

Dräger has incorporated detection of the toxic twins into the Dräger X-am® 5000 and 5600 gas monitors with firmware 7.0 or later. The technology is patented by Dräger (Pub. No. US2014/0284222 A1) for the toxic substances CO and HCN.

This new gas monitoring innovation increases firefighter safety during overhaul based on scientific research conducted in the U.S. With this technology, Dräger provides the best possible safety against the toxic synergistic effect of hydrogen cyanide and carbon monoxide.

SUMMARY

Research shows that the combination of CO and HCN is more harmful than exposure to either one individually. If both gases are inhaled together, they have a toxic synergistic effect: CO prevents oxygen from reaching vital organs, HCN attacks the central nervous system and the cardiovascular system, causing people to become disoriented and confused.

Thus measuring each single gas against its single alarm threshold is not ideal for overhaul operations.

Dräger has designed a toxic twins alarm function for its Dräger X-am series of gas monitors. This patented feature increases firefighter safety during overhaul based on scientific research conducted in the United States.

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CORPORATE HEADQUARTERS
Drägerwerk AG & Co. KGaA
Moislinger Allee 53–55
23558 Lübeck, Germany

www.draeger.com

Customer Service:
USA
+1 800-4DRAGER
(+1 800-437-2437)

CANADA
+1 877-DRAGER1
(+1 877-372-4371)

Technical Service:
USA
+1 800-4DRAGER
(+1 800-437-2437)

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