Dräger

HCN: A Serious Threat to Firefighters

Unmasking the threat of HCN and CO poisoning

NEXT

ABSTRACT

Research shows that over the past 50 years there has been rapid growth in the use of plastic-base products in building structures and their contents. This has drastically changed the nature of fires and the combustion byproducts that firefighters face as plastic materials burn. There is growing evidence that, along with the well-known threat of carbon monoxide (CO), life-threatening concentrations of hydrogen cyanide (HCN) gas can be present in combustion byproducts. Sometimes airborne concentrations of HCN may be high enough that they cause immediate symptoms in firefighters who are not wearing their self-contained breathing apparatus (SCBA). In other cases, lower concentrations of HCN breathed in for a long enough time may cause symptoms later, including fatal heart attacks. This e-book documents these facts through the experience of actual firefighters who have been subjected to HCN and CO exposure, and have witnessed or learned about others with similar experiences. It concludes with recommendations for improving the safety and health of firefighters.

PLASTIC POLYMERS HAVE CHANGED THE NATURE OF FIRES

It is well-known within the firefighting community that there is heavy use of plastics in today's residential and commercial building structures and their contents, including carpeting, furniture, cabinetry, etc. Firefighters have observed that when plastics catch fire, they burn hotter and produce higher quantities of toxic combustion byproducts than were seen in fires of a few decades ago. Beyond firefighters' anecdotal evidence, there are research findings that support these conclusions.

EXPERIENCE OF A FIELD INCIDENT SAFETY OFFICER

One of the researchers is Rick Rochford, a captain with the Jacksonville, Florida Fire and Rescue Department. He has been with that department for over 26 years and his current assignment is field incident safety officer. For the past four years he has been conducting atmospheric monitoring studies for HCN gas and CO accumulations at various fire applications. The CO threat has been known for years, but Rochford's studies showed that HCN was present at every fire he investigated.

Furthermore, his findings support the conclusion that the combustion creating HCN and CO has also changed the way fires burn over the past 50 years or so. During that time, plastics and other synthetics have replaced ordinary combustible materials within our society. An examination of today's building designs, construction materials, and structure contents reveals many synthetic polymers. Our society's heavy use of these synthetics, which produce HCN when they burn, includes nylon, polyurethane, synthetic rubber, melamine, resins for molding, and various laminates. Among this list of synthetics, insulation materials produce some of the highest levels of HCN and other toxicants during combustion. This includes both rolled insulation and spray foam insulations used in today's homes (Figure 1).

All these synthetics are making fires burn two to three times hotter, creating faster flashovers, and producing larger amounts of turbulent smoke during combustion, which is very toxic. The flashovers from synthetic polymer combustion can create temperatures as high as 1,000

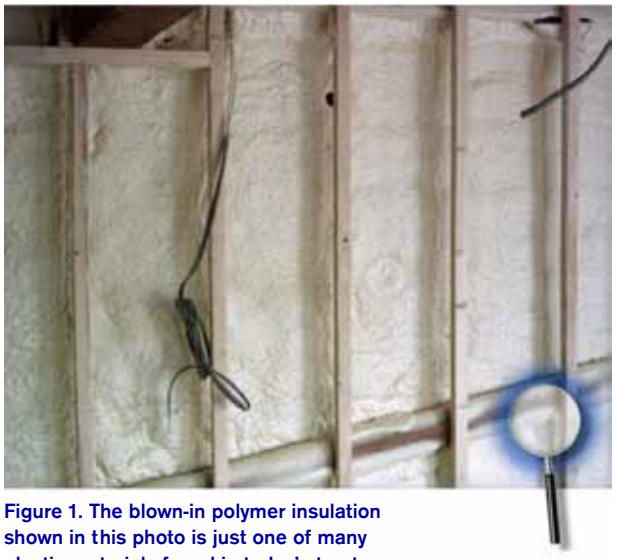

Figure 1. The blown-in polymer insulation shown in this photo is just one of many plastic materials found in today' structures.

to 1,500 degrees Fahrenheit. Because synthetics burn hotter than natural materials and produce quicker flashovers, they also speed up the release of HCN. Ultimately, this is creating acute and chronic health effects and related issues for firefighters, both inside and outside the structures.

At a recent seminar on these topics, Rochford posed some provocative questions:

- Do firefighters really know the combustion byproducts coming from a burning structure?
- Are they being poisoned in the performance of their fire suppression and rescue duties?
- Are they focusing on their personal health, as well as on the immediate job at hand?
- Are they diligent in wearing their SCBAs to prevent exposure to toxicants?

HCN AND CO PRODUCTION

Rochford's findings suggest that firefighters may frequently be exposed unknowingly to dangerous toxicants, including HCN. He cites the production of HCN at fires as being caused by the incomplete combustion of nitrogen- and carbon-containing substances (Table 1). The hydrocarbon nature of plastic polymers is the source of all the elements needed to form HCN during combustion. This results in much higher concentrations of poisonous HCN than, for example, combustion of natural fibers such as wool, silk, cotton, and paper.

Chemical formula identifying incomplete combustion:

4HCN Hydrogen Cyanide	+	$5O_2$ Oxygen	→	4CO Carbon Monoxide	+	4NO Nitric Oxide	+	$2H_2O$ Water

Chemical formula identifying complete combustion:

4HCN Hydrogen Cyanide	+	$9O_2$ Oxygen	→	$4CO_2$ Carbon Dioxide	+	$4NO_2$ Nitric Dioxide	+	$2H_2O$ Water

Table 1. Complete/incomplete combustion of nitrogen- and carbon-containing substances.

To put this in perspective, combustion byproducts fall into three hazard categories: irritants, asphyxiates and toxicants. These can exist in both gaseous and particulate forms. Although there are a multitude of chemical byproducts in the smoke from a structure fire, asphyxiates and toxicants are the ones we tend to focus on due to their potential effect on a firefighter's health.

CO affects oxygen-carrying capabilities within a person's bloodstream. HCN affects the tissues of internal organs, with the most serious negative effects being on the heart and brain, to the point where damaged tissue is not regenerated. This results in permanent scar tissue, so these organs can never really heal themselves again.

QUANTITATIVE DECOMPOSITION

To prove his point, Rochford likes to show his seminar audiences a video produced by the National Institute of Standards and Technology (NIST). It shows how quickly a fire that starts with the combustion of a dry Christmas tree can spread to furniture, carpeting, and other room contents. It also illustrates the quantitative decomposition that can occur in room contents before flames appear. Quantitative decomposition occurs in an object due to high temperatures generated by radiant heat from flames elsewhere in a room, before fire actually breaks out in that object. During the quantitative decomposition period, gas is emitted without the presence of any flames. It's caused by the thermal decomposition of the molecular materials in the object. This can be a real killer because of the high toxicity and the long period of time such gases are emitted inside a structure before occupants have the warning of flames.

NIST Video

PLAY VIDEO

The seriousness of quantitative decomposition was made abundantly clear by the tragic Station Nightclub fire that occurred in West Warwick, RI on the night of February 20, 2003. During the performance by the Great White band two pyrotechnic devices were set off, 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 focus sound into the audience. As temperatures soared from the initial flames, thermal decomposition of the foam board began producing high quantities of smoke filled with HCN.

West Warwick, RI. Station Nightclub fire, February 20, 2003.

PLAY VIDEO

Subsequent investigations and a simulation of this event by NIST concluded that, in the absence of a sprinkler system in the building, the performance area was uninhabitable within 90 seconds. There were 462 people in the room, and many of them were quickly overcome by the smoke before they could get out of the structure. Unfortunately, 100 people lost their lives, and more than 200 individuals were severely burned or injured as a result of this event.

At all levels, the medical community responding to this event did not even recognize the symptoms of HCN exposure. Their treatment modalities were aimed at CO poisoning. This was no fault of the responders, because up to this time the threat of HCN produced by fires was not widely publicized.

If you are a firefighter, you may be asking yourself, "Could this happen in my jurisdiction?" If you are realistic, the answer should be, "Definitely, yes." And this is why you need to be aware of this type of situation, and protect yourself while fighting a fire.

SECONDARY HCN EXPOSURE

With regard to firefighter HCN poisoning, we must also consider secondary exposure. In the left view of Figure 2, firefighters are working aggressively to save the life of a victim that was removed from a structure fire. This victim was suffering from acute HCN poisoning. In the right view of this figure you see firefighters who have also been exposed to HCN, and some of it may have occurred while working on the victim.

Firefighters need to realize that soft body tissue acts like a sponge. Fire victims absorb a lot of the combustion byproducts. When a victim is removed from this 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 get exposed to the same contaminants, including HCN and a host of other chemicals.

After the victim is delivered to the hospital and the firefighters go back to their station, those rescuers may then start to experience headaches, nausea, vomiting, and things of that nature. While these symptoms may be a result of work stress, it's just as likely caused by exposure to contaminants such as HCN and CO. Moreover, firefighters may not realize the extent of damage to themselves. A firsthand experience by a Providence, RI firefighter attests to this.

Figure 2. Rescuers helping fire victims may unknowingly be exposed to HCN due to body tissue outgassing.

FIREFIGHTER BECOMES HCN VICTIM

The first well-documented case of HCN poisoning in a firefighter occurred only a few years ago in 2006 (Figure 3). It is related in a personal account of this firefighter's own experience. It could not have been scripted in a better way to point out the importance of using SCBAs. Here is the account by Lt. Anthony Toro of the Providence, RI Fire Department, who learned this lesson the hard way.

"On the night of March 23, 2006 at 10:31 hours, the Providence Fire Department dispatch center received a report of a restaurant fire. It was a converted McDonald's style restaurant. The first unit reported a smoke condition and a working fire upon arrival.

Figure 3. Providence, RI restaurant fire, March 23, 2006.

I was given the task, along with the operator of Ladder 1, of forcible entry. We used a K12 saw to cut the locks on the rollup doors and steel gates. Our K12 saw died several times due to the heavy smoke condition on the exterior of the restaurant. Although we were wearing our SCBAs, we did not have our face pieces on while we were exposed to the heavy smoke conditions outside.

The interior fire was knocked down. However, the fire that extended into the roof system was gaining significant headway and was self-venting. After several minutes of an aggressive interior attack, the conditions worsened and the incident commander ordered an evacuation of all members for exterior operations as a safety precaution.

The fire was knocked down and overhaul occurred. Returning to the station, I became increasingly ill, having a severe headache and difficulty breathing. My co-workers actually noticed that I was talking incoherently and wasn't making any sense to the questions that I was being asked. At that point, it was recommended by my officer that I be transported to a hospital for evaluation.

Upon arrival at the emergency room, a doctor who was familiar with firefighter symptoms and illnesses just happened to be passing by as I was brought in. He asked me what was wrong. I told him I was at a significant fire and now felt extremely ill and dizzy. Upon hearing this he ordered CO and HCN blood tests for me. I was treated for CO poisoning while I waited for the results of the HCN test to come back from the hospital lab. When these results came in, we learned I had an HCN level in my blood of 57 micrograms per deciliter, which is almost three times higher than the high safe limit of 20. I was administered sodium thiosulfate, an antidote for HCN effects. The side effects of this antidote were extremely severe – worse than the actual exposure itself.

When my exposure to HCN became known, the chief of the department was notified that as many as 50 firefighters may have been unknowingly exposed to HCN. An immediate recall of all the members that were at the restaurant fire was initiated, and they were ordered to go to the hospital for HCN blood tests.

While I was undergoing treatment, a second fire occurred in a six-unit apartment complex, but no significant incidents were reported. Then at 0200 hours a third fire was reported to the Providence Fire dispatch center – an occupied two-story residential structure. At this incident, a fellow firefighter who was the pump operator, collapsed on the side of his apparatus, apparently suffering from a heart attack. He received immediate advanced life support treatment at the scene and was transported pulse-less to the same hospital where I was receiving treatment. He was given advanced life support medications in addition to the HCN antidote, sodium thiosulfate. This apparently prevented a fatality. He has since recovered and is now retired, living with his wife and family.

For once, luck was on the side of the firefighters. Fortunately my department did not experience a line-of-duty death in fighting the three fires that occurred on March 23, 2006. In all, 91 firefighters were tested

after the three fires. More than 50% of those tested had elevated HCN levels in their blood."

"A department's existing standard operating procedures (SOPs) and rules may just not be enough for today's structure fires. If my documented exposure and treatment had not taken place, the outcome for our other firefighters that day may have been gravely different.

By my department conducting an extensive investigation, changing SOPs, rules, regulations, and enforcing behavioral change, we may be able to change the mindset of the fire service to use SCBAS consistently. Fortunately, when HCN exposure does occur, a newer antidote has been placed into service. It's called hydroxocobalamin and its side effects are significantly lower than what I had experienced with sodium thiosulfate.

If we can stop our members from being exposed, then we may stop needless line-of-duty deaths and injuries in the future. We should never enter a hot zone without the proper personal protective equipment. We should just consider all fires to be the source of hazardous materials and protect ourselves accordingly."

PROACTIVE MEASURES

As a whole, the firefighting community needs to be more proactive in the areas that will be most beneficial to fire victims and themselves. The most important areas are:

- Monitoring the environment around a fire for HCN, CO, and possibly other chemicals
- Monitoring firefighters for possible exposure to these chemicals
- Monitoring firefighters' use of SCBAs
- Taking personal responsibility for SCBA usage
- Decontamination of personal protective gear after returning to the station
- Educating the medical community on the probability of HCN exposure by victims and firefighters

With regard to that last point, always make sure to convey information on the possibility of HCN exposure to doctors and nurses when a victim or firefighter is presented at the hospital. While symptoms may point to a heart attack, the underlying cause may be more than overexertion.

During the first half of 2010, the US Fire Administration reported that 34 firefighters lost their lives in the line of duty in various applications of firefighting. The cause of death in a little more than half of those firefighters was attributed to heart attacks brought on by stress and overexertion. Knowing what we do now about HCN, we need the medical community to investigate further before reaching that conclusion. Fortunately, there's ongoing research to find out whether or not HCN and CO are contributing factors in the deaths of firefighters we see each year.

Watch for Signs of HCN Exposure – At the fire scene, and afterward at the station, everyone needs to be on the alert for HCN poisoning in fellow firefighters. HCN is a cellular asphyxiant that interferes with aerobic respirations. During normal respiration, we are providing nutrients to key enzymes that allow our bodies to function properly. However, when we inhale HCN, 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.

Unfortunately, there is no quick test that be administered to individuals at the site of a fire to check for HCN toxicity. The outward signs and symptoms are lethargy, weakness, shortness of breath, chest tightening, headache, drowsiness, disorientation, possibly bizarre behavior, and cardiac issues. In addition, look for bright red discoloration on the skin of those who have experienced prolonged exposure inside a contaminated environment. The individuals we should pay particularly close attention to are those with soot around the mouth and nose, burns in those areas, and coughing up carbonaceous sputum.

If you are among the 60% of the population who has a nose for it, another classic symptom is a smell of almond extract on the breath. Even then, this particular odor may not be detected due to other chemicals outgassing from the person's body. Of course, all these things apply to both firefighters and victims who have been removed from the fire. If there is sufficient indication of HCN toxicity in any of these individuals, then administration of HCN antidotes can be utilized to help speed up the person's recovery.

Make Monitoring a Standard Procedure – We have good reason to believe that HCN and CO are the primary cause of death in those overcome by smoke. In addition

CONCENTRATIONS (LC50)		EFFECTS
mg/m3	mg/m3	
300 mg/m3	270 ppm	IMMEDIATELY LETHAL
200 mg/m3	180 ppm	Lethal after 10 minutes
150 mg/m3	135 ppm	Lethal after 30 minutes
120-150 mg/m3	108-135 ppm	Highly dangerous Fatal after 30-60 minutes
20-40 mg/m3	18-36 ppm	Light symptoms after several hours

Table 2. Bodily effects of breathing in HCN

to the results of blood tests, this conclusion has come to us by way of atmospheric monitoring, by using a four-gas combustible indicator and looking through the smoke. We need to convey this information as an integral part of fire and rescue training, and show the mounting evidence that HCN is directly responsible for many more deaths than previously assumed. Furthermore, the combined effects of HCN and CO can be worse than either of them are individually.

Table 2 shows how toxic various levels of HCN can be. Rochford's studies reveal that HCN levels above 200ppm are common in a normal structure fire. However, current guidelines call for respiratory protection for time weighted average (TWA) HCN levels above 4.7ppm, and above 35ppm for CO. In addition, firefighters must consider the lower explosive limit (LEL) of these gases. The LEL for HCN is 5.6%, and for CO it is 12.5%. While these may seem high, in the fires we are fighting today, with quantitative decomposition of synthetics, firefighters are stepping into a highly combustible atmosphere.

In Rochford's atmospheric studies, he uses a Draeger PAC7000 single cell chemical sensor, which is suitable for a wide variety of fire applications. Even after a fire is out, he has gone back into structures with that sensor and has found elevated readings of HCN, which clean-up crews should be aware of. Not surprisingly, he has also found elevated HCN readings associated with vehicle fires, which can be attributed to all the synthetics used in today's cars. More surprising are the fairly high readings associated with wild land fires, but these do consume organic materials that can break down into HCN.

For atmospheric monitoring to be effective in protecting the lives of firefighters, the instrumentation must be on the first unit to arrive at a fire. And it must be used consistently to let the firefighters know exactly what they are facing in terms of toxic environments. Put simply, the fire service needs to deploy HCN detection equipment in the field and use it at all fires.

Enhance Compliance – With effective monitoring, the issue then becomes one of compliance in the use of SCBAs. Enhanced compliance comes about largely as a result of a cultural change on the part of firefighters. That includes adherence to the NFPA 1404 Respiratory Standards for 2007. Since this is fairly new, some departments may not be aware of its Rule of Air Management, commonly known as ROAM.

The gist of ROAM is for firefighters to know how much air they have in their bottle. When firefighters report for duty at the station each day, the first thing they should do is make sure they have a full bottle of air. This should be checked again before going into the contaminated atmosphere of a working fire. The firefighter then needs to manage this while in the structure, as supply pressure decreases from the full 4500psi level down to the 1100psi mark where the low-level alarm goes off. Rochford's analogy is that the air supply from 4500 to 1100psi belongs to the department. From 1100psi down to zero belongs to the firefighter and his family. Considering the time it can take to get out of a structure, it's best to get out before the bell goes off.

On average, 100 firefighters lose their lives each year. Therefore, the last life saved should be that of the firefighter. An essential step is proactive use and management of SCBA air.

Since a department's incident commander cannot see exactly what's going on, the company officer needs to lead by a consistent positive example. When he's inside the structure, he needs to be wearing his respiratory protection, because his subordinates are looking to him for what they should do. If the company officer is not wearing his mask, his subordinates are not likely

to do so either. Then when a subordinate becomes a company officer later on, this destructive cycle may be repeated.

Positive behavior needs to be reinforced through other forms of training. That training should include explanations as to why HCN is more of a threat today, where it is coming from, and the medical complications from exposure to this toxicant. Firefighters need to understand why they no longer can rely on past experience to determine whether or not a particular atmosphere is safe.

Decontaminate After the Fire – Departments also need to be concerned about post-fire decontamination. They need to make sure that firefighters shower and change their clothes soon after they finish a response. Since HCN can stay in the body for up to eight days, even simple things like sneezing, coughing, and blowing the nose can still expose individuals to residual contaminants.

It is also essential for turnout gear to be washed on a frequent basis, including Nomex hoods. Those hoods are the closest to the material that firefighters go through in a structure, and are next to their skin where dermal absorption brings contaminants into the body.

Some departments have scheduled times when they have all their gear washed. Still, firefighters should wash it on their own when returning from a fire between those scheduled times, because contaminant molecules can build up on personal protection materials. If not washed off, this can lead to complications down the road. It's even better when a department issues a second set of gear, which allows rotation of the two sets.

CHRONIC EFFECTS OF CONTAMINANT EXPOSURE

Repeated and prolonged exposure to HCN and other contaminants can have long-lasting effects on the body. These effects can include breathing problems, respiratory arrest, chest pains, cardiac arrhythmias, cardiovascular collapse, vision dimming, headaches, depression, loss of appetite, extreme weakness in the extremities, and paralysis. Another fairly common problem is an enlarged thyroid gland. Rochford has noted that within the Jacksonville fire department, several firefighters are being treated for hyperthyroidism or have had their thyroid glands removed.

Some departments like Jacksonville have rigorous physicals, and may even use ultrasound to check the thyroid gland and other internal organs for discrepancies. It's important to have thyroid problems taken care of early to reduce the chance of complications later on in life. In the absence of a rigorous department physical, a firefighter should regularly get a thorough physical exam by a personal doctor.

CONCLUSIONS

The main points of this e-book are:

1. HCN is present in the combustion byproducts of virtually every fire today. It comes from the thermal breakdown of plastics and other synthetic polymers. These materials burn two to three times hotter than natural materials, causing quicker flashovers and creating more toxic vapors.

2. Firefighters need to watch for the effects of HCN exposure, such as disorientation, weakness, shortness of breath, headache, drowsiness, and cardiac issues. Repeated and prolonged exposure can lead to chronic and debilitating health problems, and early death.

3. The most important form of protection from HCN, CO, and other contaminants is diligent use of SCBAs, and monitoring the air supply in those devices until the firefighter is well away from a burning structure.

4. Atmospheric monitoring is by far the most reliable way of determining if the environment around a fire scene is contaminated or not.

5. Post-fire decontamination should be followed rigorously to prevent exposure afterward.

6. Department-wide education and training are key elements in improving safety and the use of SCBAs, but company officers must also lead by example.

7. Still, it comes down to individual firefighters to perform their duties in a safe manner that protects their lives as well as the victims of a fire. Ultimately, this is in the best interests of the firefighters and their families, who want to see long and healthy retirement years.

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