Toxic Twins (HCN & CO) in FIRE OVERHAUL

OVERVIEW

Today, with the proliferation of plastics and synthetic polymer building materials, the risk of a significant hydrogen cyanide (HCN)-poisoning component in victims of enclosed-space fire smoke inhalation has increased.[1]

Death by smoke inhalation has been known since antiquity. In some ancient conflicts, captured enemy soldiers were executed by placing them in cages over fires fueled with green wood. Although CO (carbon monoxide) poisoning as a cause of serious poisoning or death in smoke inhalation victims has long been recognized, it was only in the 1960s to 1980s when the potential for a significant HCN-poisoning component contributing to or, in some cases, being the major cause of serious poisoning or fatality in smoke inhalation victims began to be recognized.[2]

Barriers to change within the firefighting community include a "smoke eater" culture where many firefighters shun using safety equipment, such as gas-detection instruments, or keeping their breathing apparatus on for longer periods while on-scene or during fire-overhaul operations. Many firefighters consider smoke-filled uniforms or soot-covered faces a badge of honor, and not the telltale signs of exposure to dangerous gases and particulates that are known carcinogens.

One of the largest studies, conducted by the University of Cincinnati (UC), reveals that firefighters face increased risk for certain cancers. The study analyzed data on 110,000 mostly fulltime firefighters from information culled from 32 previously published scientific reports in order to correlate cancer and health risks for the profession.

"We believe there's a direct correlation between the chemical exposures firefighters experience on the job and their increased risk for cancer," says Grace LeMasters, PhD., a co-author of the study and professor of epidemiology and biostatistics at UC.[3]

The study found that firefighters are twice as likely to develop testicular cancer and have higher rates of non-Hodgkin's lymphoma and prostate cancer than non-firefighters, and confirmed that firefighters are at greater risk for multiple myeloma, a cancer that begins in the plasma cells in bone marrow.

These and other studies reveal new, blunt warnings regarding the health dangers of fire smoke, as well as the danger of breathing fire smoke toxins in the fire overhaul process.

[1] Alarie Y. Toxicity of fire smoke. Crit Rev Toxicol. 2002;32:259-289.
Stefanidou M, Athanaselis, S. Toxicological aspects of fire. Vet Human Toxicol. 2004;46:196-199.
[2] Wetherell JR. The occurrence of cyanide in the blood of fire victims. Journal of Forensic Science. 1966;11:167-173.
Birky MM, Clarke FB. Inhalation of toxic product products from fires. Bull NY Academic Med. 1981;57:997-1013.
Clark CJ, Campbell D, Reid WH. Blood carboxyhaemoglobin and cyanide levels in fire survivors. Lancet. 1981;1:1332-1335.
Jones J, McMullen MJ, Dougherty J. Toxic smoke inhalation: Cyanide poisoning in fire victims. Amer J Emerg Med. 1987;5:318-321.

[3] News Release from UC Health News, University of Cincinnati (10 Nov 2006) "Firefighters Face Increased Risk for Certain Cancers." Release on findings reported in the *Journal of Occupational and Environmental Medicine* about a study by Grace LeMasters, PhD, Ash Genaidy, PhD, and James Lockey, MD.

OVERHAUL AND HIGH HCN LEVELS

Overhauling is the late stage in a fire-suppression process during which the burned area is carefully examined for remaining sources of heat that may re-kindle the fire. This activity often coincides with salvage operations to prevent further loss to structures or their contents, as well as fire-cause determination and preservation of evidence.

During this stage of firefighting, there is no fire and little to no smoke in the environment, and firefighters are likely to work “barefaced” (remove their self-contained breathing apparatus, or SCBA).

In the overhaul process, the smoldering fumes of a recently doused fire can be filled with dangerous and toxic gases and vapors that threaten the life and health of firefighters involved in the fire overhaul operations. As firefighters sift through piles of materials of take down rafters and walls, poisonous gases such as CO, sulfur dioxide (SO2), hydrogen cyanide (HCN), nitrogen oxides (NO and NO2), formaldehyde, benzene and phosgene are released from the materials or are churned and become airborne particles that can be inhaled.

Direct exposure to these dangerous aerosols and particles during fire overhaul present a real risk for immediate harm or acute and chronic health problems, including heart failure and cancer.

HCN & CO, THE “TOXIC TWINS”

All firefighters are aware that where there’s smoke, there’s CO. But more recent studies have revealed that high HCN concentrations are be found in fire smoke. Even worse, firefighters are routinely exposed to dangerous levels of cyanide at fires without realizing it.[4]

A 2007 NIOSH publication, "Preventing Fire Fighter Fatalities Due to Heart Attacks and Other Sudden Cardiovascular Events," noted that HCN is formed by incomplete combustion of any substance that contains carbon and nitrogen (both naturally occurring and synthetic) and that airborne concentrations exceeding those of established occupational exposure limits occur in structural fires. It also acknowledges that HCN impairs cellular use of oxygen, which can result in cellular hypoxia and a variety of cardiac manifestations.[5]

HCN is created when materials such as laminates, synthetics, foams, plastics, and wood burn. Many of these materials are found in furniture and upholstery in homes and offices, and as a result, the smoke of a typical residential or office fire today is more toxic than ever.

Cyanide is an invisible gas that cannot be detected by the color or the amount of smoke emitted by a fire. It can only be detected through metering and monitoring. Exposure to large amounts of cyanide can cause convulsions, unconsciousness or rapid death. CO, also only detectable using a sensor device, can cause tissue hypoxia when inhaled, which prevents the blood from carrying sufficient oxygen, and can cause dizziness, nausea, headache and, at higher concentrations, convulsions, tachycardia and death. When inhaled together, the so-called “toxic twins” can have a synergistic effect, experts say, causing even more harm.[i]

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[4] http://inletemergencyservices.files.wordpress.com/2010/07/hydrogencyanide1.pdf

[5] Jankovic J, Jones W, Burkhart J, et al. Environmental study of firefighters. Ann Occup Hyg. 1991;35:581-602.
Brandt-Rauf PW, Fallon LF, Tarantini T, et al. The health hazards of fire fighters: exposure assessment. Br J Ind Med. 1988;45:606-612.
Gold A, Burgess WA, Clougherty EV. Exposure of firefighters to toxic air contaminants. Am Ind Hyg Assoc J. 1978;39:534-539.
Purser DA, Rimshaw P, Berrill KR. Intoxication by cyanide in fires: A study in monkeys using polyacrylonitrile. Arch Environ Health. 1984;39:394-400.
Breen PH, Isserles S, Westley J, et al. Combined carbon monoxide and cyanide poisoning: A place for treatment? Anesth Analg. 1995;80:671-677.

As part of a composition of materials, HCN is relatively safe. But when the material is heated, it becomes a concern:

- 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 often incapacitates the victim within a short period of time.
- HCN is again produced after the flame is out and the materials continue to off-gas. In other words, HCN may be present even if smoke is not visible.

HEALTH EFFECTS OF TOXIC TWINS (CO AND HCN):

HCN and CO in fire smoke are at least additive toxicants and may indeed be synergistic (having greater toxicity than predicted from the concentrations of either toxicant alone). Clinically, this was observed in smoke inhalation victims in the classic Paris, France, study, where some fatalities were associated with blood CO and HCN concentrations, neither of which were predicted to cause death.[6]

CO attaches to the oxygen molecules in the body, preventing oxygen from reaching vital organs, which causes suffocation after a short period of time.

HCN, on the other hand, targets the central nervous system, cardiovascular system, thyroid and the blood, causing firefighters to become disoriented and agitated, and to lose focus on the task at hand. Some have even fought against colleagues attempting to rescue them. Others have run away from their rescuers, and at times, run deeper toward the seat of the fire until they become physically exhausted and overcome by smoke or thermal injuries. This is why you hear of so many firefighters who become lost and disoriented, and/or take off their masks once they're out of air.

Acute exposure to HCN can result in symptoms such as weakness, headache, confusion, vertigo, dyspnea and, occasionally, nausea and vomiting. Respiratory rate and depth usually increase at the onset, and eventually cause the victim to gasp for breath. Coma and convulsions occur in some cases. If a firefighter gets to the point where they lose color and become ashen, or cyanosis is present, it usually means that respiration has ceased or has been inadequate for an extended amount of time.

SCBA is a firefighter's best friend when it comes to protecting against HCN. For years, wearing an SCBA was optional or considered taboo. Nowadays, in most departments, it is mandatory, but a question still remains: When is it appropriate to remove the SCBA?

After the flames are out, HCN might still be present, but we can't see it or test for it. Should SCBA be worn until the atmosphere is completely free of HCN? The answer is yes, but how do firefighters know if or when the air is clean, since the four most commonly used gas detectors generally do not have an HCN sensor in them?

SOLUTION: TREAT A FIREGROUND LIKE HAZMAT

Because a growing number of firefighting experts consider structural fires HazMat hot spots, calls for greater teamwork between HazMat and firefighters during common structural fires are increasing. Many departments now have a standard operating procedure (SOP) for using gas-detection equipment during structural fires, including using standalone instruments or wireless systems that allow on-scene agencies with compatible systems to share data.[7]

While fire, HazMat and special operations teams utilize a variety of detection instruments today, wireless gas detectors offer key benefits to fire-service agencies. These include fast deployments, centralized command monitoring and data sharing with other on-scene units or off-site experts

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[6] Levin BC, Paabo M, Gurman JL, et al. Effects of exposure to single or multiple combination of the predominant toxic gases and low oxygen atmospheres produced in fires. Fundam Appl Toxicol. 1987;9:236-250.

Pitt BR, Radford EP, Gurtner GH, et al. Interaction of carbon monoxide and cyanide on cerebral metabolism and circulation. Arch Environ Health. 1979;34:345-349.

[7] http://www.firesmoke.org/wp-content/uploads/2012/07/SacramentoOverhaulSOG.pdf

RAE Systems book "Wirelessly Networked Chemical & Radiation Detection Systems: Essential Technologies and Applications for Increased Safety in Continuous Gas and Radiation Monitoring." 2012 http://www.amazon.com

QRAE 3: VERSATILE 4-GAS OVERHAUL MONITOR

The RAE Systems QRAE 3 is an affordable, personal protection gas monitor developed by RAE Systems with a dedicated configuration for fire overhaul applications, with CO and HCN sensors (model PGM2530).

This model is available either with an integrated pump (as shown in the picture) or as a natural diffusion model. QRAE 3 also provides the following features: Datalogging capability, policy enforcement features and man down alarm capability with real-time remote wireless notification.

QRAE 3 (model PGM-2530) allows firefighters to be aware of risks in their environment by measuring the presence of CO and HCN. Its unique wireless option provides extra safety when working in extremely dangerous environments, as real-time data are available on EchoView Host or on a computer running ProRAE Guardian™ software. This means that firefighters in the safe area can monitor their peers and work in concert with them to provide enhanced situational awareness and support.

CROSS-SENSITIVITY

Due to the chemical make-up of many manufactured materials, today's fires reach hotter temperatures faster, flashovers occur more rapidly and the resulting smoke is much more toxic. Other chemicals that can also be found in fire smokes include carbon monoxide, nitrogen dioxide, polynuclear aromatic hydrocarbons, formaldehyde, acid gases, phosgene, benzene and dioxins.
In short, the smoke is a highly complex mixture of solids, fumes and gases that are produced due to thermal decomposition of materials, or in other words, are produced when these materials burn.

It is really important to understand potential cross-sensitivity phenomena that can occur while using electrochemical sensor technology. RAE Systems has characterized the cross-sensitivity by performing tests on its sensors. The following table shows cross-sensitivity due to chemicals found in this particular application (fire overhaul). For other cross-sensitivity values on CO and HCN sensors, refer to RAE Systems Technical Note TN-114.

CO Sensor Cross-Sensitivity From Potential Chemicals in Fire Overhaul Applications

Compound	Concentration (ppm)	Output (ppm equivalent)
Benzene	5	0
Hydrogen chloride	10	0
Ammonia	35	0
Naphthalene	125	0
Sulfur dioxide	5	0
Nitrogen monoxide	35	-4 ~ 0
Nitrogen dioxide	5	0
Vinyl chloride	10	0
Hydrogen sulfide	15	0
Acrylonitrile	10	0
Formic acid	100	0
Acetaldehyde	50	0
Toluene	20	0
n-Heptane	100	0
Glutaraldehyde	20	0
Formaldehyde	5	0
Hydrogen cyanide	10	0
Hydrogen fluoride	15	0*
Hydrogen bromide	15	0*
Isocynates	0.13	0*
Acrolein	20	0*

*Notes: Estimated from hydrogen chloride, acrylonitrile and glutaraldehyde, respectively.
CO sensors were tested under the following conditions: ambient temperature 25˚ C with a relative humidity of 63%.

HCN Sensor Cross-Sensitivity From Potential Chemicals in Fire Overhaul Applications

Compound	Concentration (ppm)	Output (ppm equivalent)	Cross-Sensitivity
Benzene	5	0	0%
Gasoline	100	0	0%
Formaldehyde (HCHO)	5	-0.7	-14%
Hydrochloric Acid (HCl)	15	0	0%
Ammonia (NH_3)	35	0.5	1%
Carbon Monoxide (CO)	300	0	0%
Sulfur Dioxide (SO_2)	5	1.5	30%
Nitrogen Dioxide (NO_2)	5	-3	-60%
Nitric Oxide (NO)	35	-1	3%
Ethylene	100	0	0%
Hydrogen Sulfide (H_2S)	15	30	200%
Vinyl Chloride	10	0	0%
Acetaldehyde	100	0	0%
Toluene	10	0	0%
Acrylonitrile	20	0	0%
Phosphine	5	9	181%
Phosphine	100	181	181%
Formic acid	100	0	0%
Glutaraldehyde	20	0	0%
Naphthalene	125[1]	0	0%
Hydrogen Bromide[2]	15	0	0%
Hydrogen Fluoride[3]	15	0	0%
Acrolein[4]	20	0	0%
Isocyanates[5]	0.13	~0	~0%

*Notes: Unless otherwise specified, the ambient temperature is 20 ˚ C ±5˚ with a relative humidity of 50% to 85%.

[1] Naphthalene is a white powder and volatile. Vapor pressure increases with temperature.
Based on theoretical estimation, at 25˚ C, about 125 ppm naphthalene can be emitted.
[2] Estimated from HCl result.
[3] Estimated from HCl result.
[4] Estimated from glutaraldehyde and acrylonitrile result.
[5] Estimated only. Based on theoretical estimation, methylene bisphenyl isocyanate is 0.13 ppm vapor saturation at 25˚ C.