CPTC
CYANIDE POISONING TREATMENT COALITION

Educational Supplement
Sposored by the
Cyanide Poisoning
Treatment Coalition

# SMOKE

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









Volume 2, March 2009

photo: Jim Duffy

**Cyanide Poisoning Treatment Coalition**
P.O. Box 301123
Indianapolis, IN  46230-1123
888-517-5554
For more information, please visit www.FireSmoke.org

Copyright® 2009
All supplement photos courtesy of FirefighterSafety.net or FireGroundImages.com

photo: John Rainey

# Table of Contents:

photo: Christine Ricci

# Foreword

by Jean Marie McMahon, MD

There is little question that the modern fire smoke environment presents hazards to today's firefighters not endured by their colleagues of just a few decades ago. Part of the reason for this change is the fact that over the last two decades, the construction and design industry has moved away from the use of wood and natural materials and toward lighter construction materials that include synthetics and petroleum-based products. These materials ignite and burn 2-3 times hotter and faster than conventional materials and when heated, emit a gas or smoke that will also ignite 2-3 times faster and burn 2-3 times hotter.

In this edition of the SMOKE supplement, Rob Schnepp discusses the chemical composition of smoke in his article, "Where There's Fire – There's Smoke."

Smoke is considered an aerosol – that is, it consists of solid or liquid particles dispersed in a gaseous medium. In most aerosols, the particles are suspended in air. In smoke, the particles are suspended in a gaseous medium consisting, in large part, of toxic gases.

Asphyxiation is one of the most dramatic and immediate effects of exposure to smoke and one of which most of us are aware. There are two types of asphyxiation: simple asphyxiation and chemical asphyxiation.

When exposed to a low oxygen environment, simple asphyxiation occurs. The concentration of oxygen in normal air is 20.95 percent. At oxygen concentrations less than 6 percent, rapid loss of consciousness and death are typical. In the modern closed-space fire environment, the concentration of oxygen can decline to these critical levels in a matter of seconds due to rapid consumption of oxygen by the fire and other gases replacing oxygen. Simulations of the Station Nightclub fire in Rhode Island, for instance, demonstrated that concentrations of oxygen declined to levels incompatible with life within 100 seconds of ignition.[1]

Add to oxygen deprivation the effects of carbon monoxide and hydrogen cyanide, and you have the "toxic twins" of fire smoke. These gases are chemical asphyxiants, so called because they chemically interfere with the delivery of oxygen and its use by the tissues. Carbon monoxide, for instance, adheres to oxygen binding sites in the blood with an affinity 220 times that of oxygen, thereby displacing oxygen from these sites.

Hydrogen cyanide cripples the ability of the cell to use oxygen. This means that even if oxygen can be delivered to the cells, they are unable to use the oxygen and die anyway.

Together, the chemical asphyxiant effects of carbon monoxide and hydrogen cyanide are deadly. They are even more deadly in the presence of a low oxygen environment.

Another immediate effect of exposure to smoke that is probably under-appreciated is consequences to the heart after exposure to particles. Short-term exposure to particles has been associated with triggering heart attacks, particularly among people with pre-existing heart disease[2,3]. Furthermore, long-term repeated exposure to elevated concentrations of particulate matter has been associated with heart disease and the initiation and progression of "hardening of the arteries."[4, 5, 6]

That brings us to another under-appreciated effect of exposure to smoke -- the death of individual cells. Even if the entire organism is not killed by a given exposure, such exposures can kill individual cells in an organism. Again, the cells most susceptible to this effect are those in the heart and brain. As time goes on, the cumulative effects of such cell death at repeated exposures can result in chronic heart and nervous system disease.

Finally, many of the components in fire smoke can cause cancer. Particles of soot contain substances called polycyclic aromatic hydrocarbons (PAHs). PAHs are known cancer causing substances. In 1775, Sir Percival Pott reported on the increased risk of scrotal cancer in chimney sweeps as a consequence of exposure to the PAHs in soot. A clear association between exposure to PAHs and the development of lung cancer has also been shown. In addition, many fire smoke environments contain benzene, a known cause of leukemia and some other very severe related blood disorders.

Cancers are usually not caused by one injury to the cell, but by repeated exposures, often acting at different sites in the same cell. This means that cancers do not usually develop soon after an exposure, but can take years of repeated exposure to develop. The lag time between exposure and the development of a cancer is called the latency period, and it can endure for many years and often decades. This means that the relationship of the cancer to the exposure is often not recognized and can be very hard to prove. The firefighter who suffers from a work-related cancer may never be able to prove the association.

It is very important to realize that even if a firefighter is not working in a low oxygen environment, he is still exposed to chemical asphyxiants and cancer-causing substances. This fact emphasizes the need for use of the SCBA during overhaul and the need for a comprehensive firefighter rehabilitation program as described in NFPA 1584. These issues are discussed in the article "Fire Overhaul, Rehab, and a Comprehensive Respiratory Protection Program" written by Phil Jose, Steve Bernocco, Mike Gagliano, and Casey Phillips.

In the article "SCBA Mayday!", Kevin Reilly and Frank Ricci address the importance of proper air management at the fire scene, including procedures for emergency breathing techniques. The safety of the firefighter in the modern smoke environment needs to be supported by appropriate SOPs, but ultimately rests in the hands of the individual firefighter.

In the last article in the supplement, Drs. Don Walsh, Daniel O'Brien and James Augustine discuss the signs and symptoms of cyanide exposure as it relates to smoke inhalation. The importance of a comprehensive smoke inhalation treatment protocol (including antidotal therapy) for BLS and ALS emergency medical providers is discussed.

Welcome to second edition of SMOKE! The practices of the fire service need to change as the fire environment changes. We hope that you find the information contained herein useful in understanding the current fire smoke environment, re-enforcing your present safe behaviors, and designing any necessary new behaviors. Ultimately, your safety in these important areas rests solely in your hands.


photo: Christine Ricci


## References:

1. Madrzykowski, D, Bryner NP, Grosshandler WL, et al. *Fire spread through a room with polyurethane foam-covered walls*. Interflam 2004. International Interflam Conference, 10th Proceedings; Volume 2; July 5-7, 2004.
2. Peters A, Dockery DW, Muller JE, Mittleman MA [2001]. *Increased particulate air pollution and triggering of myocardial infarction.* Circulation 103: 2810-2815.
3. Pope CA III, Muhlestein JB, Heidi TM, Renlund, DG, Anderson JL, Horne BD [2006]. *Ischemic heart disease events triggered by short-term exposure to fine particulate air pollution.* Circulation 114: 2443-2448.
4. Dockery DW, Pope DA, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG, Speizer FE [1993]. *An association between air pollution and mortality in six U.S. cities.* N Engl J Med 329: 1753-1759.
5. Pope CA III, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, Thurston GD [2002]. *Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution.* JAMA 287: 1132-1141.
6. Pope CA III, Burnett RT, Thurston GD, Thun MJ, Calle EE, Krewski D, Godleski JJ [2004]. *Cardiovascular mortality and long-term exposure to particulate air pollution: Epidemiological evidence of general pathophysiological pathways of disease.* Circulation 109: 71-77.


# Where There's Fire – There's Smoke!

by Rob Schnepp

Smoke is a universal constant on the third rock from the sun. In every nook and cranny of our planet, every second of every day, smoke is wisping, wafting or billowing from some point of origin. In many cases, the smoke is friendly. Other times, it's menacing and dangerous. All of it, to one degree or another, is harmful to breathe.

Think about smoke and its long-standing impact on the world. Millions of years ago, scientists theorize that a gigantic cloud of smoke and dust caused by a meteorite colliding with the Earth, contributed to the extinction of the dinosaurs. Fast-forward to the Industrial Revolution and the belching smokestacks of 19th century England. In one respect, smoke signified progress and innovation – factories provided jobs, consumer products and revenue. That same smoke, on the other hand, full of soot and toxic by-products of combustion, stained the landscape and sickened the surrounding population. Over time, the Industrial Revolution spread to the United States, resulting in similar complications and consequences, some of which are evident today. Most recently, images of thick black smoke pouring from the World Trade Center and Pentagon were burned into the heart and soul of mankind.

Smoke is everywhere, and the fire service knows it. But is there a thorough understanding of what's in the smoke or why people die from smoke inhalation? Nationwide, fire academies and fire science programs teach the basics of combustion chemistry, and it's well known that smoke kills more people than flames. But many firefighters would be hard-pressed to name five products of combustion from a typical residential structure fire. Carbon monoxide is frequently identified, but after that, the list gets hazy. Rarely acknowledged are compounds such as ammonia, hydrogen chloride, sulfur dioxide, hydrogen sulfide, carbon dioxide, the oxides of nitrogen and soot – a known human carcinogen. Even less frequently named are cyanide compounds, particularly hydrogen cyanide, recently identified as a major factor in smoke inhalation fatalities.

The good news is that we're learning more about smoke – the age-old companion of the fire service. The intent of this article is to provide basic information about the toxic components of smoke, especially cyanide, and to present compelling data from recent studies of smoke inhalation victims that show a new way to treat victims in the pre-hospital setting.

## Smoke Showing!

Smoke production is dependent on several factors, including the chemical make-up of the burning material, temperature of the combustion process, oxygen content supporting combustion, and presence or absence of ventilation. Simply put, fire is a complex process, and the smoke produced is an intricate collection of particulates, superheated air, and toxic chemical compounds (especially in closed compartment residential structure fires).

**According to a 2005 National Fire Protection Agency (NFPA) report, a civilian fire death occurs every 143 minutes in the United States.**

**Fire fatality rates in the United States roughly equate to three jumbo jets crashing every month for an entire year. Fire deaths due to toxic gases and/or oxygen deprivation from smoke inhalation outnumbered fire deaths resulting from burns .**

The extensive commercial and residential use of synthetic materials (plastics, nylons and polymers such as Styrofoam and polyurethane foam) has a significant impact on combustion and fire behavior, as well as the smoke produced during a structure fire. The majority of these materials are carbon based, bonded with various atoms like hydrogen, nitrogen, chlorine, and sulfur. Synthetic substances ignite and burn fast, causing rapidly developing fires and toxic smoke and making structural firefighting more dangerous than ever before.

A mattress fire in a small bedroom is an example of the toxicity firefighters routinely encounter at a structure fire. Polyurethane foam is the most predominate substance in a typical mattress and

## Smoke Dictionary

**Smoke is an aerosol of solid or liquid particles, usually resulting from incomplete combustion accompanied by various fire gases and dictated by burning or heated material.**

**Aerosol:** An assembly of liquid or solid particles suspended in a gaseous medium long enough to be observed and measured.

**Particle:** A small, discrete object with the same make-up and density as the parent substance.

photo: www.FireGroundImages.com

**Morbidity:** A disease or the incidence of disease within a population.

**Mortality:** The incidence of death in a population.

contains several chemicals – polyol (an organic alcohol molecule and the predominant ingredient in the polyurethane compound), toluene diisocyanate (or TDI), methylene chloride, and ammonia-based catalysts. When polyurethane foam is exposed to heat, the parent substances break down and bond with each other, creating other new compounds. Some of those compounds are irritants, such as hydrogen chloride and ammonia, causing eye irritation or airway problems during smoke exposure.

Other compounds, like carbon monoxide and cyanide, are toxic when inhaled. Carbon monoxide is created when carbon and hydrogen bond and is partly responsible for incapacitating a smoke inhalation victim. Cyanide, formed by carbon-hydrogen-nitrogen bonding during the combustion process, disrupts the body's ability to use oxygen and causes asphyxia at the cellular level. Recent studies conclude that cyanide, along with concurrent carbon monoxide poisoning, is responsible for many smoke related deaths and injuries.

The mattress example is demonstrative of countless items found in a typical residential fire that replicate the same toxic effects. Sofas, stereo cabinets, drapes, blankets, and carpeting all produce cyanide and other common toxins as by-products of combustion. Vehicle fires are also capable of generating cyanide, along with almost everything found in garage or dumpster fires. It would be safe to conclude that firefighters are assaulted with toxic gases, including cyanide, in virtually every fire scenario imaginable.

### From Texas to France . . . and Monkeys

Smoke is one of the first observable signs of a working structure fire. Firefighters note the volume, color and force of that smoke as it exits a burning building – all good indicators of what the fire is doing inside. They use that information to execute appropriate fire ground tactics.

Firefighters aggressively enter smoky buildings to search for victims, but rarely perform a conscious evaluation of the toxic substances lurking in the smoke. This could be a significant oversight in terms of treating victims, according to recent studies conducted in Paris, France and Dallas County, Texas.[1,2]

Both studies identified and evaluated the impact of cyanide on smoke inhalation patients. The Paris study was designed to prospectively assess the role of cyanide in fire related morbidity and mortality. Blood samples were drawn from survivors and victims (at the time of exposure), and cyanide levels were measured. In several deaths, cyanide levels measured in the lethal range while carbon monoxide levels were in non-toxic concentrations. This suggests cyanide toxicity as the primary cause of death.

The study also revealed other interesting information – death occurred in victims with cyanide and carbon monoxide levels in the nontoxic range, perhaps revealing a synergistic relationship between carbon monoxide and cyanide in smoke inhalation patients.[3,4,5] A summary of the Paris study finds that:

- Cyanide and carbon monoxide were both important determinants of smoke inhalation-associated morbidity and mortality.
- Cyanide concentrations were directly related to the probability of death.
- Cyanide poisoning may be more predominate than carbon monoxide poisoning as a cause of death in certain fire victims.
- Cyanide and carbon monoxide may increase the harmful effects of one another.

The Dallas County study[2] measured blood cyanide levels after exposure to fire smoke, and in many respects echoed the findings of the Paris study. In Dallas County, blood samples were collected from a total of 187 smoke inhalation patients within 8 hours of exposure and over a 2-year period; 144 viable patients arrived at the University of Texas Health Sciences Emergency Department; 43 victims were dead on arrival at the Dallas County medical examiner's office.

Of the 144 living patients that reached the emergency room, 12 had blood cyanide concentrations exceeding 1mg/L (see Figure 1). Of these 12 patients, 8 eventually died. None had blood carboxyhemoglobin (HbCO) concentra-

| Patient # | Age, Y | % Total Body Surface Area Burn | Blood Cyanide, mg/L | HbCO, % | Patient # |
|---|---|---|---|---|---|
| 1 | 47 | 98% | 1.20 | 18.6% | Died |
| 2 | 80 | 3% | 1.60 | 22.6% | Died |
| 3 | 29 | 4% | 1.40 | 6.0% | Died |
| 4 | 22 | 55% | 5.20 | 35.6% | Lived |
| 5 | 30 | 63% | 1.40 | 5.0% | Lived |
| 6 | 58 | 32% | 2.60 | 10.9% | Died |
| 7 | 32 | 5% | 6.00 | 32.0% | Lived |
| 8 | 50 | 25% | 2.20 | 17.2% | Lived |
| 9 | 4 | 0% | 11.50 | 22.4% | Died |
| 10 | 36 | 40% | 5.70 | 3.8% | Died |
| 11 | 19 | 90% | 1.20 | 40.0% | Died |
| 12 | 30 | 76% | 2.72 | 37.0% | Died |

**Figure 1: Source is Silverman, SH et al. J Trauma 1988; 28: 171-176.**

tions that suggested carbon monoxide as the cause of death (i.e., ≥50 percent). Although some patients had extensive burns that may have contributed to death, three (patients 2, 3 and 9) had ≤4 percent total body surface area burns.

According to the study, blood cyanide levels greater than 1mg/L had a significant impact on patient outcome. More importantly, the study revealed that elevated cyanide levels were pervasive in smoke inhalation victims and cyanide concentrations were directly related to the probability of death. Both studies shatter a long-held belief in the fire service that carbon monoxide is the predominant killer in fire smoke. In fact, it appears that cyanide plays a far greater role in smoke related death and injury than previously believed. Therefore, any victim(s) exposed to significant amounts of smoke or rescued from a closed space structure fire may suffer from cyanide toxicity.

Depending on the dose, cyanide has the ability to incapacitate a victim, preventing escape from the fire environment and increasing exposure to more cyanide, carbon monoxide and other toxic by-products of combustion. While this theory is currently unsupported with human data, there is ample information to substantiate the "knock down" potential of cyanide.[6]

In the mid 1980s, studies were conducted on monkeys exposed to the fumes of heated polyacrylonitrile (when this substance is broken down by pyrolysis, cyanide is emitted). Cyanide-exposed monkeys first hyperventilated then rapidly lost consciousness at a dose-dependent concentration. A concentration of 200 parts per million (ppm) was associated with rapid incapacitation, but not with elevated blood cyanide concentrations measured hours after exposure. The direct correlation to human data is unknown at this time, but the data could be interpreted in the following way: Cyanide could be responsible for rendering firefighters and civilians incapable of self-rescue when exposed to smoke.

## Cyanide: Mechanism of Action

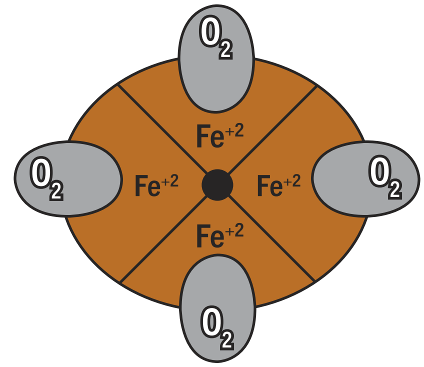
Cyanide disrupts the body's ability to perform aerobic (oxygen utilizing) metabolism, even in the presence of normal oxygen levels.

**Cyanide exposures can be fatal in the presence of normal oxygen levels.**

To appreciate cyanide's mechanism of action, it is first necessary to understand the way oxygen moves through and is used by the body and the basic idea of aerobic metabolism. To simplify the concept, imagine the circulatory system as a very efficient public transit system, full of hemoglobin buses (red blood cells) carrying passengers (oxygen) to and from a multitude of bus stops (the cells). The circulatory system, similar to a network of streets, is loaded with red blood cells (RBCs) – hemoglobin buses – each carrying four oxygen passengers.

During normal cellular respiration, the bus system transports oxygen passengers to the bus stops (cells). At the appropriate stop, four oxygen atoms get off and move through an electron chain, ultimately combining with the final electron acceptor – cytochrome oxidase (an enzyme) – before entering the mitochondria of each cell.

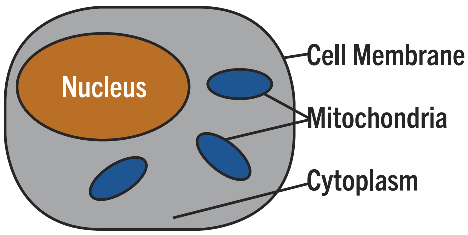
**Illustration: A hemoglobin bus carrying oxygen**




Mitochondria are responsible for converting nutrients into energy-yielding molecules of adenosine triphosphate (ATP) to fuel the cell's activities. ATP production is highly dependent on oxygen (and glucose) and without it, normal aerobic metabolism is impossible. If this process is seriously compromised, death is imminent.

Once absorbed in the body, cyanide compounds 'poison' the cytochrome oxidase, barring oxygen from entering the mitochondria and effectively shutting down the process of aerobic metabolism. Without oxygen, the cells switch to anaerobic metabolism, producing toxic by-products such as lactic acid, ultimately killing the cell. Therefore, cyanide toxicity is not about the amount

Illustration: Mitochondria in a cell




## Smoke Dictionary

**Aerobic metabolism:**
The creation of energy through the breakdown of nutrients in the presence of oxygen. The by-products are carbon dioxide and water, which the body disposes of by breathing and sweating.

**Anaerobic metabolism:**
The creation of energy through the breakdown of glucose. Without oxygen, the metabolic process results in the production of lactic acid.

of oxygen available to the body, it's about the inability of the body to use oxygen for aerobic (life sustaining) metabolism.

The signs and symptoms of acute cyanide toxicity, then, mimic the non-specific signs and symptoms of oxygen deprivation, including headache, dizziness, stupor, anxiety, rapid breathing, and increased heart rate. In extreme cases of cyanide poisoning, patients may present with seizures or a significant altered level of consciousness, including coma, severe respiratory depression or respiratory arrest, and complete cardiovascular collapse.

According to the studies conducted in Paris and Dallas County, there is a possible negative or harmful relationship between carbon monoxide and cyanide in smoke inhalation victims. This relationship could be attributed to the inability of the cells to use oxygen (due to cyanide), coupled with the adverse impact of carbon monoxide (CO) on the RBCs. Carbon monoxide binds in place of oxygen on the RBC, excluding oxygen from riding on the hemoglobin bus. The oxygen carrying capacity of the RBC becomes limited or non-existent, thereby reducing the amount of oxygen transported to the cells.

Practically speaking, carbon monoxide reduces the amount of oxygen carried to the cells; cyanide renders the cells incapable of using whatever oxygen is present.

### Treating Smoke Inhalation in the Pre-Hospital Setting: Is There a Better Way?

Smoke inhalation is one of the most complex and challenging patient presentations faced by all levels of medical care providers. Patient outcomes vary greatly, influenced by such factors as the extent and duration of the smoke exposure, amount and nature of toxicants in the smoke, degree of thermal burns to the skin and lungs, quantity/size of inhaled particulates (soot), and the patient's age and underlying medical condition. Nationwide, there are few established protocols for treating smoke inhalation, leaving paramedics and other pre-hospital care providers with limited tools or training to properly care for smoke inhalation victims.

In most cases, treating smoke inhalation outside the hospital boils down to supportive care – monitoring and appropriately responding to the vital signs, providing high-flow oxygen, establishing intravenous (IV) lines, performing advanced airway management techniques such as endotracheal intubation, monitoring cardiac rhythms, and ensuring rapid transport.

In reviewing the Paris and Dallas County studies, however, it is evident that supportive care alone will not correct the underlying cause of death in smoke inhalation patients – the adverse effect of cyanide and carbon monoxide on the body's oxygen transportation and utilization system, causing asphyxia at the cellular level.

The bottom line is this, until the underlying cause of asphyxia is reversed at the cellular level, normal oxygenation is not possible. This requires a chemical intervention – an antidote – to restore the body's ability to use oxygen.

**Cyanide toxicity should be suspected in smoke inhalation patients with significant hypotension, soot in the nose or mouth, and/or an altered level of consciousness.**

In the United States, there are two approved cyanide antidotes: the Cyanide Antidote Kit (CAK) – sometimes referred to as the Lilly Kit, Taylor Kit, or Pasadena Kit – and the Cyanokit™. Each has a distinctly different mechanism of action, which should be clearly understood.

The CAK contains amyl nitrite, sodium nitrite and sodium thiosulfate (amyl nitrite is administered as an inhalant; sodium nitrite and sodium thiosulfate are given intravenously). The nitrites are administered to convert hemoglobin in the RBC to methemoglobin. Methemoglobin pulls cyanide away from the cytochrome oxidase, restoring the cell's ability to take in oxygen and continue the process of aerobic metabolism. Thiosulfate is then administered to chemically bond with cyanide, rendering it less harmful to the body. When thiosulfate binds with cyanide, it becomes thiocyanate, which is then excreted by the kidneys.

The down side of this treatment method is that methemoglobin does not transport oxygen. Since smoke inhalation patients are commonly exposed to carbon monoxide, which also prohibits oxygen from binding in the RBC, the oxygen carrying capacity of the RBC is severely compromised, possibly to fatal levels. And while methemoglobin does draw cyanide away from the cytochrome oxidase, it also eliminates the oxygen carrying capacity of the RBC – a bad trade-off in smoke inhalation patients. Additionally, nitrites may cause a severe drop in blood pressure – exacerbating the


Figure 2: **The Cyanokit™**

hypotension commonly found in smoke inhalation exposures. Because of these adverse impacts, most experts agree that administering the current Cyanide Antidote Kit is a risky proposition for smoke inhalation patients.

The Cyanokit (shown in Figure 2) antidote may be more appropriate for smoke inhalation patients. Approved by the U.S. Food and Drug Administration (FDA) for use in the United States, Cyanokit has proven to be an effective and safe antidote for acute cyanide poisoning. Hydroxocobalamin (a precursor to vitamin B12) is the chemical compound in the Cyanokit. It is a relatively benign substance with minimal side effects, making it well suited for use in the pre-hospital setting. The Cyanokit, also approved in France and other parts of the world, is used as a pre-hospital antidote for smoke inhalation patients and other types of cyanide exposures, including those associated with potential acts of terrorism.

Hydroxocobalamin has no adverse effect on the oxygen carrying capacity of the red blood cells and no negative impact on the patient's blood pressure – significant benefits when treating victims of smoke inhalation. The mechanism of action is surprisingly simple: Hydroxocobalamin binds to cyanide forming vitamin B12 (cyanocobalamin), a non-toxic compound ultimately excreted in the urine.

The Cyanokit can be administered to a smoke inhalation patient without first verifying the presence of cyanide in the body and with little fear of making the patient's condition worse. The Paris Fire Brigade routinely administers the Cyanokit to smoke inhalation patients and has collected compelling data regarding its effectiveness. From 1998 through 2002, the Paris Fire Brigade retrospectively evaluated the pre-hospital use of Hydroxocobalamin.

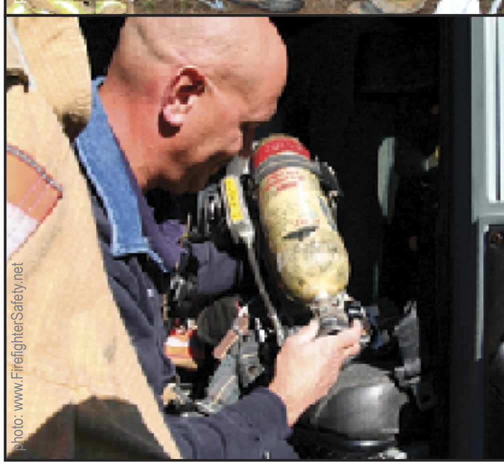
According to the study[7], 81 total victims (41 males and 40 females) were treated for smoke inhalation. The focus, however, was on two subsets of victims – 29 patients found in cardiac arrest and 15 hemodynamically unstable patients. The patient population ranged in age from 21 to 38 years. Of the 29 patients in cardiac arrest before supportive care, cardiac resuscitation and Hydroxocobalamin administration (typically a 5 gram infusion), 18 recovered – a survival rate of 62.1 percent. The average time between administration of antidote and recovery of spontaneous cardiac activity was 19.3 minutes. Four patients recovered without after-effect of the incident.

In the subgroup of 15 patients who were hemodynamically unstable before the Cyanokit was administered, 12 patients (80 percent) showed hemodynamic improvement – defined as systemic arterial blood pressure exceeding 90mmHg. The average time to attaining hemodynamic improvement was 49.2 minutes from the beginning of antidote infusion and 28.8 minutes from the end of infusion.

Patients tolerate the drug at high doses. Some quickly passing side effects such as a reddish color to the skin, urine and mucous membranes, may interfere with some colorimetric laboratory values (blood glucose, iron levels, creatinine, etc.). To date, however, no allergic reactions have been documented.[8]

In France, the Cyanokit comes with two vials of Hydroxocobalamin (each with 2.5 grams of red powder). The powder is reconstituted with 100 cc's of normal saline per vial, infused into the patient at a rate of 5 grams over 15 minutes.






## Final Thoughts

In 1736, Benjamin Franklin formed the Union Hose Company, creating the nation's first organized fire brigade. Franklin and his group of hearty Pennsylvanians, "whose business is to attend all fires whenever they happen", were dedicated men striving to improve their skills through training, prevention and innovative ideas. Franklin prided himself on being a firefighter and throughout his life continued to refine the art of fighting fire.

Conceptually, the modern fire service is much like it was in Franklin's era. Fires happen every day and continue to destroy property – firefighters respond and put them out. Civilians get trapped in burning buildings and firefighters go inside to save them. Frequently, rescuer and/or victim breathe toxic smoke and require some level of medical attention. With this in mind, firefighters and emergency medical personnel must dedicate themselves to understanding the injuries caused by structure fires and smoke inhalation.

The studies conducted in Paris and Dallas County illustrate a growing need to better address the pre-hospital treatment of smoke inhalation victims. Those studies indicate that supportive care alone may not successfully resuscitate a smoke inhalation victim, and that cyanide may play a greater role than carbon monoxide in fatal smoke exposures. The data collected by the Paris Fire Brigade on the effectiveness of Hydroxocobalamin as a cyanide antidote underscores the need to re-evaluate how smoke inhalation patients are treated.

Understanding the complicated pathophysiology of smoke inhalation is well beyond the scope of this article, and it's impossible to address all facets of patient care. But the studies referenced here suggest an undeniable need to look at an old problem with new perspective. Perhaps that new look will equip firefighters, paramedics and other health care providers with a better understanding of smoke toxicity and potential antidotes for successfully treating smoke inhalation patients.

## References:


1. Baud FJ, Barriot P, Toffis V, et al. *Elevated blood cyanide concentrations in victims of smoke inhalation*. New England Journal of Medicine 325: 1761-1776, 1991.
2. Silverman SH, Purdue GF, Hunt JL, et al. *Cyanide toxicity in burned patients*. Journal of Trauma 28 (2): 171-176, 1988.
3. Birky MM, Clarke FB. *Inhalation of toxic products form fires*. Bulletin of the New York Academy of Medicine 57 (10): 997-1013, 1981.
4. Teige B, et al. *Carboxyhemoglobin concentrations in fire victims and in cases of fatal carbon monoxide poisonings*. Zeitschrift fur Rechtsmedizin 80 (1): 17-21, 1977.
5. Norris JC, et al. *Synergistic lethality induced by the combination of carbon monoxide and cyanide*. Toxicology 40: 121-129, 1986.
6. Purser DA, Grimshaw P, Berril KR. *Intoxication by cyanide in fires: A study in monkeys using polyacrylonitrile*. Archive of Environmental Health 39: 394-400, 1984.
7. Fortin J-L. *Use of Hydroxocobalamin in Fire Victims by The Brigade De Sapeurs Pompiers De Paris* from 1998-2003. Presentation at the Second World Congress on Chemical, Biological and Radiological Terrorism, September 2003.
8. Mégarbane B, et al. J Chin Med Assoc 2003; 66: 193-203.
   Baskin SI, Brewer TH. In: *Medical aspects of chemical and biological warfare*. Office of the Surgeon General, Department of Army, U.S., 1997, 271-286.
   Curry SC, et al. Ann Emerg Med 1994; 24: 65-67.
   Yacoub M, et al. J Eur Toxicol 1974; 7: 22-29.
9. Karter, Jr., Michael J. *Fire Loss in the United States During 2005 – Full Report*. National Fire Protection Agency (NFPA), September 2006.
10. Hall, John R., Jr. *Characteristics of Home Fire Victims.* Fire Analysis and Research Division, National Fire Protection Agency (NFPA), July 2005.



**Photo:** Firefighter monitoring for CO level at a fire scene

photo: Kevin Reilly

# Air Management on the Fireground: the Need, the Mandate, the Solution

by Captain Mike Gagliano, Battalion Chief Phil Jose, Captain Casey Phillips, and Lieutenant Steve Bernocco

The modern fireground is one of the deadliest environments in the world. It is a combination of forces and factors that can kill, cripple, or maim in a matter of seconds. A "routine" house fire can produce any of the following within seconds of ignition: extreme temperatures/thermal insult, poisonous/asphyxiating atmospheres, structural collapse, explosions, entrapment and electrical shock.

Firefighters around the world fight fires in this deadly arena on a daily basis, armed with only the basic tools of water, protective clothing, and air. These tools are extremely important and the job of fighting fires could not be done without them. It is air, however, carried on the back of a firefighter in a Self-Contained Breathing Apparatus (SCBA) that makes it possible to safely enter a burning building and get the job done. It is also air, or the lack thereof, that is the primary cause of non-cardiac related death on the fireground.

## Air Management

The principle of air management involves the discipline of knowing how much air a firefighter has in their SCBA, monitoring the air level, and ensuring it is being utilized to safely and effectively accomplish the task at hand.

Unfortunately, the fire service developed some bad habits when the SCBA was first introduced. These bad habits have carried over to poor air management practices. The fire service is paying a steep price for these behaviors. Numerous fireground deaths are attributed to firefighters running out of air and dying of asphyxiation.

Initially, SCBA were not worn by the majority of firefighters because they were deemed too bulky and time consuming. This was combined with tremendous peer pressure that insinuated you were a "weak" firefighter if you wasted the time it took to put on your breathing apparatus. These attitudes were demonstrated to be incorrect and unsafe, yet it is still common practice in some departments to routinely disregard wearing a self-contained breathing apparatus.

Most progressive and professional fire departments around the world are now mandating the use of SCBA. New technology continues to improve SCBA by decreasing its weight, improving reliability, and enhancing the overall effectiveness of the equipment. With the availability of better protective equipment, tactical training, and improvements in leadership, firefighter deaths rates on the fireground should be decreasing. But this is not the case. Fireground deaths hover around the same numbers despite a decrease in actual fires.

One factor stands out that needs to be addressed – firefighters that die in structures are dying in increasingly higher numbers due to asphyxiation.

**Or, to put it in street terms... When firefighters run out of air, they breathe smoke; and when firefighters breathe smoke, they die.**

## The Need

The need for a progressive, comprehensive air management program is obvious for one simple reason: Firefighters are running out of air on the fireground. The consequence of firefighters running out of air vary dramatically – increased firefighter line-of-duty deaths, close calls, injuries, and increased cancer/respiratory disease rates with direct correlations to the smoke firefighters breathe when their air is depleted.

The fire service has seen dramatic changes since Benjamin Franklin began building the American fire service. But despite all the changes, deaths on the fireground not related to heart attack or vehicle accidents still occur in the same ways they have for 200 years: smoke, thermal insult, structural collapse, getting lost or separated, and running out of air. "No Air" affects all of the other categories on the list.

photo: Pete Santos

**"No Air"** in the toxic smoke environment of today leads to rapid asphyxiation.

**"No Air"** during a thermal insult event will result in immediate and fatal burns to the throat and lungs.

**"No Air"** during a structural collapse means a lack of time for rescue and eventual asphyxiation.

**"No Air"** when lost or separated leads to panic and asphyxiation.

**"No Air"** requires the firefighter to breathe the products of combustion or toxic smoke that is proven to be both poisonous and carcinogenic.

**"No Air"** means that even if the firefighter survives the initial assault on their respiratory system, the toll on their wellness will be immeasurable.

According to NFPA firefighter fatality reports, there were 103 deaths directly attributed to asphyxiation between 1996 and 2003. These numbers did not take into account the direct contribution "running out of air" played in deaths that were attributed to other factors, such as thermal insult, cardiac arrest or collapse.

The need for air management is etched on fallen firefighter monuments across the country and in the tragic consequences line-of-duty deaths bring to the families and fire departments of these fallen firefighters.

## The Mandate

To address the disturbing firefighter death statistics, more mandated changes have come/are coming to the American fire service that focus directly on air management. The most significant change is language in the National Fire Protection Association (NFPA) 1404 respiratory standard that took effect in 2007 and includes the following provisions:

**NFPA 1404 Chapter 1: Administration**

**1.1* Scope.** This standard shall contain minimum requirements for the training component of the Respiratory Protection Program found in NFPA 1500, Standard on Fire Department Occupational Safety and Health Program.

**1.2* Purpose.** The purpose of this standard shall be to specify the minimum requirements for respiratory protection training for the emergency response organization, including safety procedures for those involved in fire suppression, rescue, and related activities in a toxic, contaminated or oxygen-deficient atmosphere or environment.

**NFPA 1404 5.1.4*** The authority having jurisdiction shall establish and enforce written Standard Operating Procedures for training in the use of respiratory protection equipment, and that training shall include the following:

**NFPA 1404 A5.1.4(2) Individual Air Management Program.** This program will develop the ability of an individual to manage his or her air consumption as part of a team during a work period.... The individual air management program should include the following directives:

- Exit from an IDLH atmosphere should be before consumption of reserve air supply begins.
- Low air alarm is notification that the individual is consuming their reserve air.
- Activation of the reserve air alarm is an immediate action item for the individual and the team.

The NFPA 1404 standard outlines that fire departments must train their members to operate in accordance with the Rule of Air Management (ROAM), which states: "Know how much air is in your SCBA and manage that air so that you leave the IDLH environment BEFORE your low air warning alarm activates."

This will be a significant change for many fire departments in how fireground operations are performed. The current practice is for firefighters to operate until activation of the low-air warning alarm and then begin to exit the structure. This practice allows a firefighter to use 75 percent of the air in their SCBA for entry and work in the IDLH environment, leaving only 25 percent for exit and no margin for error.

The new language in the NFPA 1404 standard will be the measure used by the professional and legal community to determine if a fire department has taken the minimum required action necessary to protect firefighters from exposure to IDLH environments. To that end, fire departments must train firefighters to manage their air.

## Will the Law be on Your Side?

This moves the discussion to the legal arena where departmental and personal liabilities are factors that will have far-reaching impact on the fire service. Many firefighters are already dealing with the fallout from the realization that "giving your all" to the citizens as a member of the fire service does not necessarily correlate into being take care of in return.

The article included in this supplement on the harmful effects of smoke and its components highlight the toxic and carcinogenic nature of the modern fire environment. Every firefighter is subjected to products of combustion as a normal course of doing their job. Exposure to products of combustion is causing cancer in firefighters at levels far above those found in the general population. It might be assumed that the willingness to take on these risks would be met with an equal responsibility of the employer to care for the individual who gets sick because of them. That assumption is proving nightmarishly wrong for many firefighters.

Many states are adopting "Presumptive Legislation" that attempts to address the right of firefighters to get medical care for cancer and other diseases that are a direct result of the job. As always, the devil is in the details of just what is and is not deemed "job related". In the state of Washington, for example, the first presumptive legislation considered the following as valid "job related" conditions that would be covered: primary brain cancer, malignant melanoma, leukemia, non-hodgkin's lymphoma, bladder cancer, ureter cancer, and kidney cancer.

The Washington State Senate Ways and Means Committee specifically amended the original list of diseases that provided more appropriate coverage for firefighters. The original list was dramatically slashed and eliminated the following cancers from the list of presumptive cancers: breast cancer, reproductive system cancer, central nervous system cancer, skin cancer, lymphatic system cancer, digestive system cancer, hematological system cancer, urinary system cancer, skeletal system cancer, and oral system cancer.

The Washington State Ways and Means Committee also included additional language that imposed limits on how long coverage would be in place. The current system allows for three months of coverage for every year of employment up to 60 months. In other words, a firefighter who has been subjected to the hazardous smoke for a career of 30 years had better test positive for cancer within five years of retirement or they are not covered – they will get zero coverage, despite the obvious links to years of service and high rates of cancer probability. There are additional variables included in the language that allow further questioning of whether the cancer is job related, such as smoking history, fitness, etc.

As a result of intensive lobbying by the Washington State Council of Firefighters and pressure from citizens, additional changes were incorporated in 2007. The following illnesses were added back into the existing presumptive legislation: prostate cancer diagnosed prior to age 50, colorectal cancer, multiple myeloma, and testicular cancer.

The gaps that remain, however, are extensive. A recent study conducted in Cincinnati highlights the extreme risks firefighters face in their efforts to protect our citizens. Those risks are not truly being acknowledged by the legislators and the current presumptive legislations. Many states, such as Florida, have no such protections for their firefighters.

**There is a growing recognition that proper use of equipment and adherence to operating guidelines/policies will be more closely monitored because of personal liability. An injury or exposure will be judged based on how the firefighter operated during the emergency and if they used provided safety equipment.**

Much like discussions centered around the use of seatbelts to save lives in car accidents, proper use of SCBAs and following respiratory guidelines will be expected norm and standard in personal liability. Deviation from these guidelines exposes the firefighter to accountability for their own personal liability.

Finally, all of the above will certainly result in court cases in which firefighters, fire officers, and fire departments may be required to justify their actions. A case in Memphis, Tenn., is currently examining why a "30-Minute Bottle" did not last 30 minutes and resulted in a firefighter death. This is a question all who have donned a mask can answer easily. Everyone in the fire service understands that the label "30 minute cylinder" is a misnomer. These cylinders have only enough air for firefighters to work 15-20 minutes at best. Imagine explaining to the judge – or the widow – that "everyone knows" of the deficiency, yet no action to make a change was taken prior to the fatality.

photo: Chris Saraceno

### In a court of law, those in charge must answer:

- Why do they allow their firefighters to enter a structure fire without breathing from an SCBA?
- Why they routinely allow firefighters to operate until their low-air warning alarm activates?
- Why aren't they training, and operating, according to recognized minimum national standards?

The mandate for air management answers these concerns.

### The Solution

The solution for the air management problem is a simple one. It does not require the purchase of expensive equipment, the addition of more personnel, or the cessation of aggressive fireground attack to implement. The Rule Of Air Management (ROAM) is the simple means by which the fireground can be made safer, exposure to toxic/carcinogenic smoke can be greatly minimized, and exposure to legal/liability issues can be significantly decreased.

The ROAM suggests you know how much air you have in your SCBA, and manage that air so you leave the hazardous environment before your low-air warning alarm activates.[1]

### In simple firefighter language:

- Know what you've got
- Manage it as you go
- Leave before your bell hits

While this seems a simple solution, it is a radical change in behavior for the fire service. Most firefighters have never checked there air before entry or during operations at structure fires. Up until now, the standard indication for "time to exit" is when the low air warning alarm activates. The problem with this approach is that it allows for no margin of error. The ROAM changes all that.

By checking your air before entry, there is verification that nothing has gone wrong with the breathing apparatus pack prior to interior smoke exposure. A full bottle gives a baseline from which the firefighter can build a good approach to managing the air they have. A READY-Check[2] (*Fire Engineering* magazine) is recommended prior to entry and was developed to eliminate some of the key problems that are killing and/or injuring firefighters.

A routine check of the air status by the individual and team leader during the operation is the second critical component of the ROAM. While this seems like an obvious thing to do, most firefighters have never done it. This check serves two purposes. The first is an obvious reminder of where the crew stands as far as air level is concerned and gives a good indicator of when to make the "time to exit" decision. The second is an increase in situational awareness that keeps the team from getting tunnel vision while performing their task. The air gauge check provides a brief break in the action that allows the team leader not only to monitor air, but also check condition changes and status of crew members.

Finally, the ROAM requires the team to exit the structure before the low air warning alarm activates. The final 25 percent of the bottle is the emergency reserve air and should only be used when something has gone wrong for the firefighter or the crew. Unfortunately, firefighters routinely use this "emergency reserve" for the incident itself. This has caused numerous firefighters to run out of air and suffer exposures to products of combustion. By exiting the structure with the emergency reserve intact, firefighters allow themselves a margin of error for an unexpected collapse, disorientation, or other problem. It also gives the Rapid Intervention Team time to make entry and affect rescue if necessary. This is the model used by SCUBA divers who regard their emergency air as sacred. Just as our lungs were not designed to breathe water, neither were they meant to inhale smoke.

Firefighters who stay in the hazardous environment until their low air warning alarm activates are betting their life that nothing will go wrong on the way out. This is a gamble that firefighters can no longer afford to take.

The ROAM is the future of the fire service. It can be combined with any technological or personnel advance, but it does not rely on them. Technology can be relied on only so far, as it is always subject to failure. Shrinking staffing levels and human error make air management at the strategic level a secondary option at best.

The simple reality of the fireground is that an individual firefighter's air is their responsibility to manage. The ROAM ensures that this happens and will save the lives of firefighters who use it.

### References:


1. Gagliano, M. et al. *Air Management for the Fire Service,* Fire Engineering, 2007.
2. Gagliano, M. et al. *READY-Checks and the Rule Of Air Management*, Fire Engineering, June 2005.

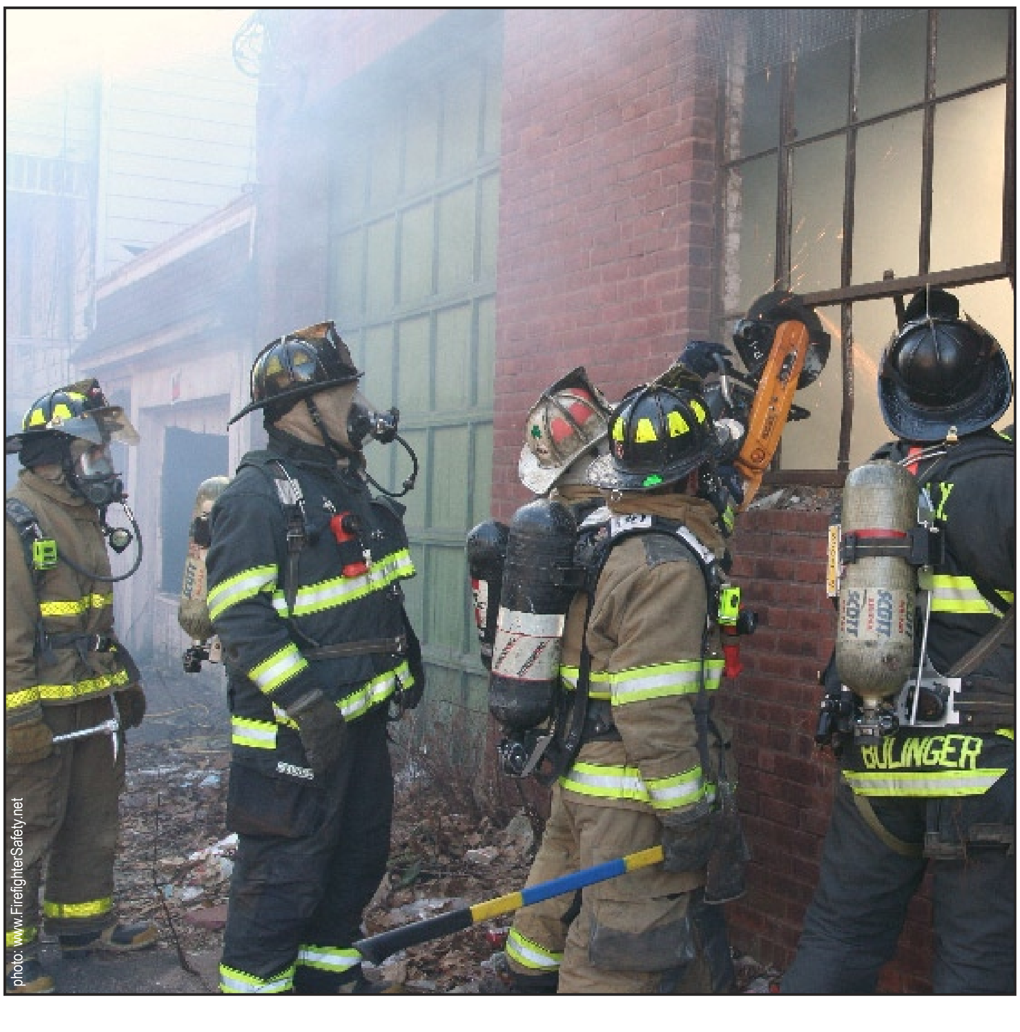




photo: www.FirefighterSafety.net


photo: FirefighterSafety.net

# Firefighter Rehab

by Battalion Chief Phil Jose, Captain Mike Gagliano, Captain Casey Phillips, and Lieutenant Steve Bernocco

Firefighters love making a difference at the emergency scene. This is especially true when they respond to a structure fire. Firefighters recognize there are significant dangers associated with the job and accept extreme risks as part of the profession.

While risks are inherent to the job of the firefighter, diligent training and effective supervision is needed to identify and reduce those risks wherever possible. One risk that firefighters can identify and manage revolves around the physiological effects of maximum effort applied under extreme conditions. In other words, firefighters work hard while fighting fire. Several factors can add to the impact of these physiological effects, including Personal Protective Equipment (PPE), Self Contained Breathing Apparatus (SCBA), high or low temperatures, humidity, and pre-response hydration. Preventing firefighters from becoming casualties of the event includes recognizing and dealing with the physiological effects of their hard work in extreme environments. This process is defined in NFPA 1584, Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises, 2008 Edition.

Firefighting combines high intensity workloads with high metabolic heat production, limited ability to dissipate body heat, and increased external heat stress from the environment. This combination of factors means that firefighters are producing an incredible degree of heat stress and a high potential for heat related illness. Heat stress produces effects ranging from minor dehydration to heat stroke. In addition, the primary risk of fatality for all firefighters – heart attack – is significantly increased when heat stress is added to high work and stress loads. This occurs because higher body core temperatures place additional strain on the heart. The body then increases the blood volume sent to the skin for cooling.

## Smoke Dictionary

**Rehabilitation:** An intervention designed to mitigate against the physical, physiological, and emotional stress of fire fighting in order to sustain a member's energy, improve performance, and decrease the likelihood of on-scene injury or death.

### Pre-Incident

There is no substitute for pre-incident planning as it applies to all areas of the fireground. From the layout of the fire building to the preparedness of the firefighters who respond, actions taken before the event occurs are crucial.

Fire departments should implement a wellness and fitness program to increase and monitor the physical ability of their firefighters. Guidelines for implementing such a program are outlined in NFPA 1583, Standard on Health-Related Fitness Programs for Fire Department Members. Departments need a thorough understanding of the effects of specific thermal, stress, and workloads on their firefighters. These factors directly impact the firefighters and should be monitored to determine their ability to perform at an acceptable level for the next work cycle. Information is readily available to support the positive impact of wellness-fitness programs on the overall health of firefighters.

Another step fire departments can take is to reduce the pre-incident heat stress that firefighters endure. Previous studies and common sense demonstrate that people have an improved ability to perform in high heat conditions if they are cool before they start.[1] Fire departments can take proactive measures to ensure that firefighters have appropriate cooling and ventilation in fire stations prior to responding to an incident and on the apparatus while responding. Fire departments should also have Standard Operating Procedures (SOPs) identifying when reductions in training or other outside activities should be reduced in order to prevent environmental injury to firefighters.

### Hydration

Proper hydration is critical to the body's ability to self-regulate and maintain safe core temperatures. The impact of proper hydration is two-fold in that it supports the body's ability to produce enough sweat for effective cooling while maintaining blood volume in order to support skin surface cooling and blood pressure. Studies conducted as early as 1947[2] demonstrate the need for proper hydration in order to maintain body core temperatures.

**Firefighters must practice self-hydration at all times as they must always be ready to respond on emergency incidents. Rates of fluid loss are documented within NFPA 1584 as follows: "Humans can easily exceed a sweat rate of 64 oz. (2L) per hour in hot and humid conditions. Firefighters can easily lose 32 oz. (1L) of water in less than 20 minutes of strenuous fire-fighting activity."**

Studies have shown it is unlikely that firefighters will be able to comfortably consume enough fluid on the emergency scene to adequately replace the large amounts of fluid lost through sweat in firefighting efforts.[3] Given this, officers must ensure that firefighters drink some fluids at every opportunity, with particular attention paid to ensure firefighters consume appropriate volumes of liquid while in formal rehab.

## Protective Clothing

Changes to firefighter protective clothing have improved the ability of firefighters to withstand temporary exposures in extreme heat environments that are created during pre-flashover conditions. Firefighter protective clothing is severely limited, however, in its ability to protect firefighters from death if exposed to flashover. Any firefighter caught in the flashover compartment, even briefly, will experience significant pain and a probability of extensive thermal insult.[4] The improvements to the protective clothing have come at the cost of increasing the thermal stress on firefighters.

The protective clothing ensemble severely limits the effects of the body's two primary means of temperature control, surface cooling through increased blood flow to the periphery and evaporative cooling through increased sweat production. Firefighters should consider themselves industrial athletes. Just as a parka on a hot summer day would negatively affect a professional athlete, structural firefighting PPE negatively affects the firefighter's ability to dissipate heat. Understanding the impact of the PPE ensemble will improve the ability of the Company Officer to identify and provide relief for the firefighters under their command.

## Self-Contained Breathing Apparatus (SCBA)

The SCBA is widely recognized in the fire service as the single biggest improvement for firefighter safety and health. By providing a reliable supply of uncontaminated air for the firefighter operating in an IDLH environment, the SCBA allows firefighters to work for extended periods while protecting their respiratory system. SCBA have improved over the years and now represents a relatively lightweight and reliable piece of equipment that firefighters should use at all times. Exposure to products of combustion is an unnecessary and unacceptable risk for firefighters in the modern era. In addition, improved air management techniques, including the Rule Of Air Management[5] (ROAM), help to maintain an effective work/rest interval while operating in SCBA and maintaining an appropriate margin for safety.

While SCBA provide a significant increase in overall safety, there is a cost to the wearer. SCBA can easily add in excess of 25 pounds to the firefighter. In addition, the backpack carrying system compresses the thoracic cavity and restricts the ability of the respiratory muscles to function normally.[6] Each 1kg increase in the weight of the SCBA ensemble has related impacts on the respiratory rate, heart rate, and energy expended. This increases the workload of the firefighter, thereby increasing the rate of metabolic heat that is produced simply through the effort of breathing.

## Work Rate

Fire grows at an exponential rate, doubling in size every minute. An excellent average response time for a fully staffed paid department is approximately four minutes. When firefighters arrive at the scene of a fire, it is necessary to provide a maximum level of work immediately. The critical need and type of workload are combined to produce large amounts of metabolic heat that the body must dissipate. High work levels may be necessary for a significant time if the fire is difficult to fight or is present in a large occupied structure. Early recognition of increased staffing needs is important to ensure effective crew rotations on these incidents.

## Environmental Factors

Environmental factors include the ambient temperature, humidity, wind, and exposure to direct sunlight. On the hot side, temperature and humidity will have the most impact on how much heat is produced, as well as determining how quickly heat can be shed by firefighters during a rest cycle. High heat and humidity have an immediate impact on the firefighter responding to, operating at, or resting during the firefighting effort. Low temperatures will have most of their impact during the rest and rehabilitation cycle.

High heat and humidity temperatures are recognized by NFPA standards[7] as having a significant impact on structural firefighters operating at incident scenes. The 2008 edition of the standard provides heat stress index charts, sample SOGs, and other resources outlining identification and prevention methods for heat stress and other environmental factors.

## Company Level Rehab

Company officers and incident commanders must take all of the above into consideration when determining when crews must rotate through an assignment at rehab. Current recommended[7] practice identifies work-to-rest intervals in terms of "30-minute" cylinder rotations for interior operations and time-based 20-minute work cycles for non-SCBA operations. Company officers or crew leaders should perform self-rehab after one "30-minute" cylinder use or 20-minutes of intense work.[7] This rehabilitation process is informal and is most often conducted and supervised by the company officer during the SCBA cylinder exchange at the apparatus. NFPA 1584 recommends that fire departments "store fluids on the apparatus where spare SCBA cylinders are located so that members can replace fluids while changing SCBA cylinders."[7] The recommended work-to-rest interval includes 10 minutes of rest for each "30-minute" cylinder work cycle. Incident commanders must be able to forecast incidents where rehab will be needed beyond the company level and establish a formal rehab area early.

When firefighters must report to the rehabilitation area is outlined in NFPA 1584 and is defined by the two primary methods of cylinder use and time. Cylinder use is predicated on the knowledge that "Air = Time" and that the requirements of the standard are a recognition that the amount of time working (with or without SCBA) must be balanced with appropriate rest and fluid intake resulting in a safe work-to-rest ratio. NFPA 1584 explanatory material outlines this for the Company Officer in A.6.3.2.1:

- There should be at least 10 minutes of self-rehabilitation after using one "30-minute" cylinder or after performing 20 minutes of intense work without SCBA.
- There should be at least 20 minutes of rest (with hydration) in a rehabilitation area after using two "30-minute" SCBA cylinders, one "45-minute" cylinder, or performing 40 minutes of intense work without SCBA.


photo: Robert Yates

While acknowledging the standard requires assignment to the rehabilitation area after one "45-minute" cylinder, it is important to understand that even the 2008 edition of NFPA 1584 does not address the use of air management techniques or the ROAM on the fireground. Because "Air = Time", we recommend that the industry accepted standards for the "30-minute" cylinder work interval can also be extended to the "45-minute" cylinder if air management is practiced in accordance with the Rule Of Air Management (ROAM). NFPA 1584 permits this adjustment in 6.2.2.2.1 stating, "A supervisor shall be permitted to adjust the time frames depending upon the work or environmental conditions."

By expanding on the premise that "Air = Time", we can make the case effectively. A "30-minute" cylinder contains 1200L of air. The standard allows a company to use 1200L of air followed by company level rehab (10 minutes) and a return to the firefight for a second 1200L of air use. Since "Air = Time", a firefighter following the ROAM and using a "45-minute" cylinder that holds 1800L of air uses a maximum of 1350L of air, leaving 450L of air in the emergency reserve. The maximum difference between the two work intervals is about 150L of air. Firefighters working hard can easily use air at a rate exceeding 100L/min. Since "Air = Time", the increase in the work cycle for a firefighter using a "45-minute" cylinder and the ROAM over the "30-minute" cylinder is approximately 1-2 minutes. This means that the "work conditions" of the "45-minute" cylinder and ROAM are consistent with that of a "30-minute cylinder", permitting the use of the 2-cylinder rotation in both cases.

Without adhering to the ROAM, company officers should follow the recommended practice of using only one "45-minute" cylinder before rotating to a designated rehabilitation area. Any use of a "60-minute" cylinder should be followed by an assignment to the rehab area.

## Tactical Level Rehab

Formal incident scene rehabilitation is a tactical level function normally assigned as a division, group, or sector. The rehab supervisor should be trained in all the functions and responsibilities inherent to the position and should understand how rehab operates within the Incident

Management System (IMS) and the SOPs of the department. Rehabilitation areas should be far enough from a working incident to provide protection from the products of combustion and from apparatus exhaust. They should also be close enough so ready access can be made between the incident scene and the rehab area. Rehab should also provide appropriate protection from the environment, whether this includes hot or cold weather. Companies should be able to resupply and stage firefighting equipment before entering the rehab area.

When and how unit's are assigned to rehab should be dictated by formal department SOPs or implemented based on trained observation of the above listed factors that impact firefighters physiological status. Minimum standards should include the following:

**■ Identified work-to-rest intervals before company level rehab are listed below and should require a 10 minute company rehab, including rest, hydration and an evaluation of the company's readiness for reassignment at the completion of the 10 minute rehab:**

- One "30-minute" cylinder without air management.
- One "45-minute" cylinder following the ROAM.
- 20 minutes of intense work.

**■ Identified work-to-rest intervals before assignment to the rehabilitation area:**

- Two "30-minute" cylinders without following the ROAM, including a 10 minute rest and hydration period between cylinders.
- Two "45-minute" cylinders following the ROAM, including a 10 minute rest and hydration period between cylinders.
- One "45-minute" cylinder or "60-minute" cylinder work cycle without following the ROAM.
- One "30-minute" cylinder without following the ROAM or one "45-minute" cylinder following the ROAM after having rotated through rehab previously or when extreme conditions are present. This requirement recognizes the cumulative impact of repeated work-rest intervals over the course of an incident and promotes coordinated company rotations and incident accountability.

**■ In addition to the work-rest interval considerations, any SOP should include the following for assignment to rehab:**

- When adequate resources are available, every company should be assigned to the rehab area after each cylinder used or 20 minutes of intense work.
- Whenever the company officer recognizes that any member of the company requires rehabilitation.
- The incident commander assigns the company to rehab.

## What Happens At Rehab?

Once units are assigned to report to rehab, they should report to the rehab supervisor for check in and recording of their arrival time. According to NFPA 1584, each department Standard Operating Guideline (SOG) for a systematic approach for the rehabilitation of members "shall include, but not be limited to, the following: Relief from climatic conditions, rest and recover, active and/or passive cooling or warming as needed for incident type and climate conditions, rehydration (fluid replacement), calorie and electrolyte replacement, medical monitoring, emergency medical services treatment in accordance with local protocol, member accountability, and release."

## New Equipment for Medical Evaluation

More recent improvements in medical evaluation equipment provide the ability to screen all firefighters entering rehab for exposure to carbon monoxide (CO). CO exposure can be indicative of exposure to products of combustion, including hydrogen cyanide. While no exposure to CO or other products of combustion is safe, department SOPs should clearly identify screening protocols and when exposure indicates firefighter treatment and transport is necessary. Recommendations for CO screening and exposure protocols are outlined in the article written by Drs. James Augustine, Daniel J. O'Brien, and Donald W. Walsh found in this supplement. Serious consideration should be given to screening firefighters exposed to products of combustion for cyanide poisoning. Recent events have demonstrated the potential for cyanide exposure both during fire and post-fire operations, and significant risk of harm is present when firefighters are exposed to cyanide in the form of hydrogen cyanide gas.[8]

Following initial medical monitoring, companies should spend a minimum of 15 minutes in an appropriate climate environment before being re-evaluated for their ability to return to incident operations. Department SOPs should clearly identify minimum standards that personnel must meet before returning to work from rehab. Such standards should meet the intent of NFPA 1584 and provide an adequate level of protection for the firefighters operating at the incident.

Given the choice between rehab and fire ops, most firefighters will choose the fire operation. Written standards provide clear guidance to personnel responsible for operating the rehab area and ensure that firefighters do not return to the incident until they have been properly rested and medically evaluated.

## References:


1. Veghte JH, Webb P. *Body cooling and response to heat*. J Appl Physiol., 1961; 16: 233-238.
2. Adolf EF, et al, eds. *Physiology of Man in the Desert*. New York, NY. Interscience Publishers Inc., 1947.
3. McLellan, T. and Selkirk, G. *The Management of Heat Stress for the Firefighter*. Defence R&D Canada-Toronto. 2004.
4. Burnette, Scott. *Flashover Risk Management*. Fire Engineering, June 2004.
5. Jose, P et al. *Air Management for the Fire Service*. Fire Engineering, 2007.
6. *Operational Physiological Capabilities of Firefighters: Literature Review and Research Recommendations*. Office of the Deputy Prime Minister Publications: Weatherby, West Yorkshire, 2004.
7. *NFPA 1584: Recommended Practice on Rehabilitation for Members Operating at Incident Scene Operations and Training Exercises – 2008 ed.*, National Fire Protection Association, Stillwater, Okla.
8. Gagliano, M. et al. *The Breath From Hell*, Fire Engineering, March 2006.


photo: www.FirefighterSafety.net

# SCBA MAYDAY!

by Kevin J. Reilly and Frank Ricci

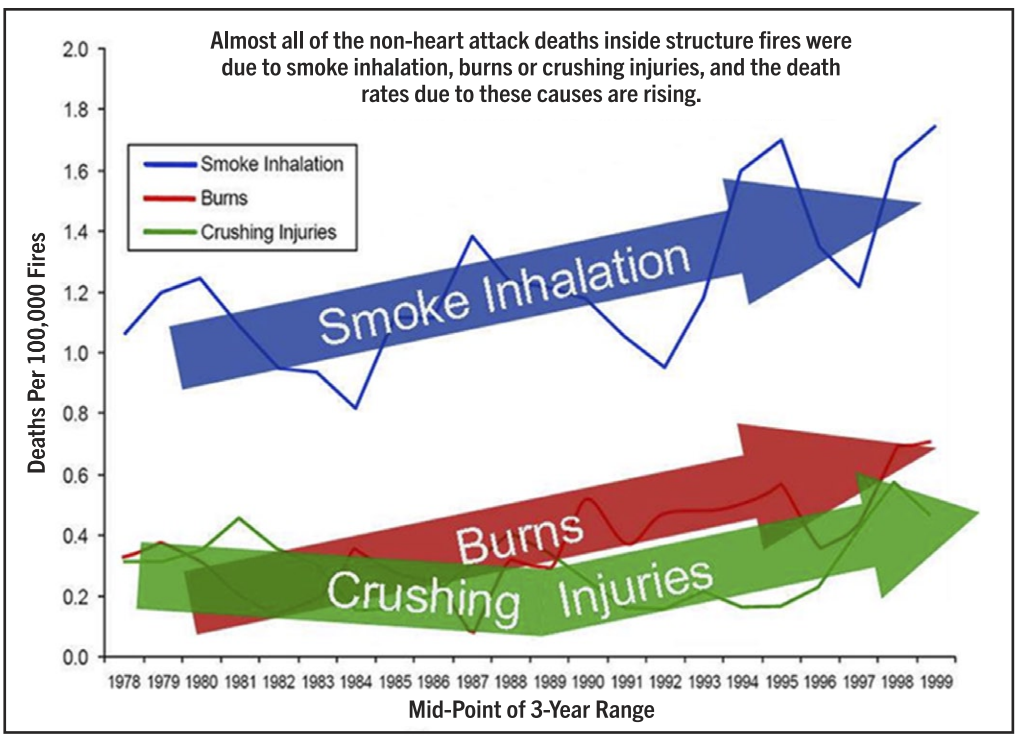
The advancement of SCBA, as well as other technologies, has made firefighting more efficient and effective. But these advances have also taken firefighters deeper into Immediately Dangerous to Life and Health (IDLH) environments. Exposure to lethal concentrations of toxic gases is a major concern, with smoke inhalation as one of the leading causes of line-of duty-deaths (LODD).

Situations are varied, and even the most experienced firefighters can find themselves in a mayday scenario. Regrettably, maydays happen, and firefighters need to be prepared for the worst with proper training. Fortunately, the stigma associated with calling a mayday is becoming a thing of the past, as firefighters are recognizing how essential it is to call a mayday as soon as trouble is realized.

During a mayday incident, there are multiple operations that happen simultaneously. These include commanding the fire, commanding the rescue, and tactical operations for the Rapid Intervention Team (RIT). Adequate staffing, proper size-up, and knowledge of building construction will serve to minimize the number of maydays.

The focus of this article is what the individual firefighter can do with self-rescue techniques during a mayday incident. Good instruction, combined with practical training, can dramatically increase the chances of surviving a mayday.

In most situations, the single most critical factor for those in need of rescue is AIR. There is no question that preparation and training with air management will increase the chances for survival.




Source: Adapted from Rita F. Fahy, Ph.D., "U.S. Fire Service Fatalities in Structure Fires, 1977-2000." National Fire Protection Association, July 2002. Used with permission.

## Preparation

Preparation starts in the fire house. SCBA bottle pressure is the key to air-time longevity. During the SCBA check at the beginning of each day, bottle pressure should read full. Full means...full. Keep in mind that every 100 psi in a half-hour bottle equals approximately 8-12 breaths of air.

SCBA training typically involves everything except how to breathe efficiently. It is common to think that proper breathing technique comes naturally, but that's not usually the case. It's important to be familiar with individual limitations. There are various breathing methods that have been developed for controlled breathing. Examples of two methods that are proven to extend air time in an emergency are the Counting Method and the Reilly Emergency Breathing Technique.

**The Counting Method, typically used in yoga, is accomplished by following these simple steps:**

- Inhale for 5 seconds – slowly and fully
- Hold for 5 seconds
- Exhale for 5 seconds
- Hold for 5 seconds
- Repeat cycle

**The Reilly Emergency Breathing Technique (REBT), also referred to as "the humming method", has performed well in medical studies and is achieved by following two simple steps:**

- Inhale as you normally would in your breathing.
- "Hum" your breath out in a prolonged, consistent manner while exhaling.

In situations when a firefighter needs to disentangle his/her SCBA or rapidly move around obstacles, it may be difficult to continuously hum after each breath. In these circumstances, resume breathing as you normally would and intermittently utilize REBT. The more you use REBT, the more your survival time will increase. It is important to be familiar with individual limitations, and this is realized through practice.

There are various breathing methods that are effective to extend air supply. With appropriate research and comparisons, you can see what works best for you. Besides the obvious physiological advantages that are associated with breathing efficiently, there are psychological benefits as well. Focusing on these breathing techniques will enhance your ability to be as calm as possible.

## Training

Development of a practical mayday training course is also important to ensure known protocols and processes are in place if a problem occurs. The key word here is "practical". Classroom review, although important, is not sufficient for proper or meaningful mayday training. For example, when you teach a beginner to swim, you explain how to swim and you go through the motions out of the water. But there is nothing that can replace getting in the water.

Proper mayday training must include hands-on evolutions with five basic mayday scenarios:

1. Trapped
2. Entangled
3. Lost
4. Collapse (something falls on you)
5. Fall (through floor/ roof)

The next step is to develop training props that can simulate each mayday scenario without putting the student at risk. The goal is to create a real-life experience that will trigger the mayday calling response. Props may consist of the student crawling (complete PPE, SCBA, blacked-out face piece) into a closet or small bathroom where the door is blocked and unable to be opened, simulating being in a <u>trapped or disoriented/lost situation</u>. A secondary prop can be a hose line coupling, which would assist in finding the way out.

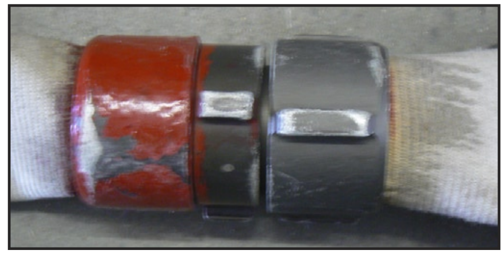


Photo: Bumps to the Pump
Source: www.FirefighterSafety.net

To simulate an <u>entanglement</u>, loop a wire over the student's SCBA bottle while he/she is <u>crawling</u>. To simulate <u>collapse</u>, drop a piece of chain link fence over the firefighter while he/she is crawling. Drop the crawling student into a ball pit or onto a mattress to simulate a <u>fall</u>.

photo: FirefighterSafety.net

## Mayday, Mayday, Mayday!

Mayday must be communicated as soon as trouble is realized. There will be times when the firefighter or crew in trouble will have to take protective measures first, such as finding an area of refuge before transmitting the mayday.

While the circumstances will dictate your actions, there are basic guidelines for when to call the mayday:

- Medical emergency
- Trapped by fire
- Fall through floor or roof
- Building collapse
- Lost and can't find crew or lost crew member
- Trapped and can't free yourself on the first attempt
- Low on air and not near an exit
- SCBA malfunction

While this list is not all-inclusive, it all comes down to a simple catch-all rule of thumb: If you think you are in trouble, you are! Call for help! Help can always be turned back. We must keep in mind the zero impact factor (the amount of time it will take for a company to make an impact on your situation). Survival is predicated on your ability to remain calm by relying on your training. Don't wait to sound the mayday. Every second delayed is two seconds (at least) that someone is not coming to help you. Activate your Personal Alert Safety System (PASS) device intermittently, but not when you are transmitting your call for help. Even if in contact with command, periodically activate your PASS device. This will give the RIT an audible target to locate you.

We recommend establishing a protocol for what information should be delivered during transmission for help – the acronym is LUNAR, which represents:

- **L**ocation
- **U**nit
- **N**ame and Nature of problem
- **A**ir Supply and Assignment
- **R**esources needed

It all boils down to WHO is in trouble (Engine 25, Firefighter Johnson), WHERE he/she is (lost on second floor, fell through floor into basement), and WHAT is the situation (out of air in closet, trapped under debris with injuries). The message must be acknowledged. An unacknowledged mayday is no different from a transmission never sent.

All firefighters should have a radio, but not everybody should talk on the radio. Radio discipline is imperative because it leaves channels available for necessary and critical communication transmissions. Members must listen to the radio so mayday calls are not missed. Fire companies not given an assignment on the fire scene should monitor the radio and track crews on their own. This will allow them to know the location of personnel and the ability to provide assistance in the rescue response if needed.

From the moment the crew enters a structure, a transition in size-up takes place. It now becomes the crew's responsibility to provide information about interior conditions and to monitor exterior operations. Periodic updates on the interior location of trapped victims and conditions are essential, especially in a mayday situation. Besides search or fire attack, communication among the crew should also be taking place to assess points of refuge in case the situation deteriorates. Moving to a place that provides refuge from heat smoke or additional collapse will increase chances for survival.

**NFPA 1584. Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises: Smoke inhalation symptoms could be indicative of hydrogen cyanide (HCN) and carbon monoxide (CO) intoxication, and immediate medical assessment should be initiated. HCN and CO gases are present in every fire. Symptoms of exposure poisoning are non-specific and easy to miss. Any firefighter exposed to HCN/CO or who presents with headache, nausea, shortness of breath, or gastrointestinal symptoms should be assessed for smoke inhalation poisoning. At an incident scene, HCN and CO exposure can be measured with a portable exhaled breath analyzer.**

NFPA 1584 and screening firefighters at the scene are important for a number of reasons:

- 1584 is now an official standard.
- HCN and CO leave the blood stream quickly and usually go undetected.
- It can ease peer pressure to get checked out.
- It covers some liability issues.
- Most importantly, it save lives.

## Conclusion

There are many preventive measures that can be taken to avoid a mayday situation. This starts with proper training and being familiar with the similarities that indicate a mayday scenario. Unfortunately, malfunctioning equipment or encountering the unexpected is occasionally going to happen. Academic, hands-on, and real-life training scenarios are essential for a firefighter to remain calm and focused in a mayday situation. This training will allow for instinctive reactions that save lives.

**For more in-depth analysis on the mayday topic, visit: www.FireFighterSafety.net**


**Photo:** Firefighter having his CO level checked at Yale's "Last Chance Survivability Study"

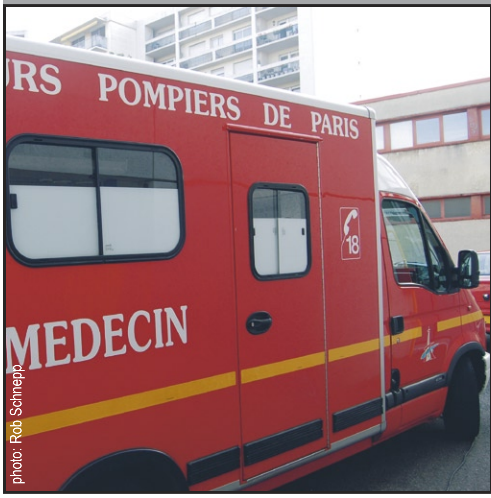



photo: Rob Schnepp

# Cyanide Exposure, Smoke Inhalation, and Pre-Hospital Treatment: Recognizing the Signs and Symptoms and Available Treatment Options

by Daniel J. O'Brien, MD, FACEP, James Augustine, MD, FACEP, and Donald W. Walsh, PhD, EMT-P

The preceding articles cover the toxic composition of smoke, means of improving firefighting operations to reduce smoke toxicity, and the need for effective interventions to reduce smoke-related toxicity. This article describes the signs and symptoms of cyanide exposure and discusses the importance of a comprehensive smoke inhalation assessment and treatment protocol for improving outcomes in smoke-associated cyanide poisoning.

## Context

Both civilians and firefighters die as a result of inhalation of products of combustion from fire. Cyanide is one of the products of combustion that will contribute significantly to inhalation injury and death. Hydrogen cyanide, a toxic product of combustion of common nitrogen and carbon-containing substances, is likely to be generated under the conditions of high temperature and low oxygen that characterize closed-space structure fires.

Research on victims of smoke inhalation indicates that cyanide poisoning may be an important agent of death, particularly for victims in closed-space fires. For example, studies that simulated the nightclub fire in Rhode Island found rapid buildup of heat, carbon monoxide and cyanide to levels incompatible with survival. Cyanide poisoning can be treated effectively if it is recognized promptly and if intervention is initiated immediately. In this context, it is important that pre-hospital providers recognize the signs and symptoms of cyanide poisoning and have smoke inhalation evaluation and treatment protocols in place.

## Mechanisms and Manifestations of Cyanide Toxicity

Cyanide causes human toxicity by deactivating the mechanisms that allow cells to utilize oxygen. Because cyanide-poisoned cells are unable to use oxygen, they transition from aerobic metabolism to anaerobic metabolism and generate toxic by-products, such as lactic acid. Organs such as the heart and brain, which rely on a substantial, continuous supply of oxygen, are quickly affected by cyanide poisoning. Exposure to smaller concentrations can initially cause respiratory activation (manifested by rapid breathing and tachycardia) in an attempt to compensate for lack of oxygen. Early manifestations include headache, anxiety, blurry vision, and loss of judgment. As cyanide accumulates further, signs and symptoms of poisoning reflect the effects of oxygen deprivation on the heart and brain. These include cardiac dysrhythmias, seizure, coma, and death. The time between exposure and incapacitation or death is typically minutes, but varies depending on the concentration of cyanide and other toxicants. Many toxicants affect oxygen utilization. The presence of multiple toxicants in fire smoke can be particularly hazardous.

## Recognizing Acute Cyanide Poisoning

Currently, there is no diagnostic test to confirm cyanide poisoning within the limited window for initiating potentially lifesaving intervention. Transcutaneous monitors, such as those used to detect carbon monoxide poisoning, might some day be available to quantify the level of cyanide attached to hemoglobin; however, such an assessment tool is not currently available. Therefore, in the pre-hospital setting, acute cyanide poisoning must be diagnosed presumptively.

Cyanide poisoning should be suspected in any person exposed to smoke in a closed-space fire. The simultaneous presence of hypotension increases confidence in the diagnosis of cyanide poisoning. A few cyanide-poisoned victims have a pinkish to cherry-red complexion caused by the (abnormal) high oxygenation of venous blood. The victim's breath may have an almond-like odor attributed to excretion of small amounts of cyanide in the breath. However, many people cannot smell this odor, sometimes resulting in the failure of the pre-hospital provider to accurately diagnose cyanide poisoning.

At most hospitals, rapid measurements of cyanide are not available. Assessment and treatment rely primarily on clinical judgment. Hospital laboratory findings that may indicate a strong possibility of cyanide poisoning include:

- Metabolic acidosis
- Elevated plasma lactate concentrations caused by the accumulation of lactic

acid, a by-product of anaerobic metabolism
- Elevated oxygen content of venous blood, caused by failure of cyanide-poisoned cells to extract oxygen from arterial blood
- Carbon monoxide by blood tests or use of the transcutaneous monitor that is inconsistent with clinical symptoms.

It can be difficult to differentiate the effects of cyanide and carbon monoxide poisoning. The classic symptoms of poisoning with each agent are outlined in Tables 1 and 2. They are very similar. Detection of carbon monoxide poisoning can be achieved with the transcutaneous carbon monoxide oximeter (CO-oximeter). The assessment for cyanide poisoning in the smoke inhalation victim remains a matter of clinical assessment by the astute emergency provider.

**Table 1: MANIFESTATIONS OF CYANIDE POISONING**

**Early Indications of Exposure to Low Inhaled Concentrations:**

- Anxiety
- Drowsiness
- Dyspnea
- Headache
- Impaired judgement
- Tachycardia
- Tachypnea
- Vertigo

**Inhalation of Moderate to High Concentrations:**

- Cardiovascular collapse
- Cardiac dysrhythmia
- Hypotension
- Markedly altered level of consciousness
- Respiratory depression or arrest
- Seizure
- Smell of almonds on the breath (sometimes undetectable)

**Table 2: MANIFESTATIONS OF CARBON MONOXIDE POISONING**

**Early Indications of Exposure to Low Inhaled Concentrations:**

- Difficulty with balance
- Fatigue
- Headache
- Palpitations

**Inhalation of Moderate to High Concentrations:**

- Altered level of consciousness
- Cardiac dysrhythmia
- Nausea and vomiting
- Respiratory arrest
- Seizure
- Severe headache
- Shock and death
- Syncope

## Support for the Smoke Inhalation Victim

Basic life support care for the smoke inhalation victim includes removing the victim from the source of exposure; providing cardiopulmonary support, warmth and fluids; administering 100 percent oxygen; and assuring appropriate ventilation. Nebulizer treatment with a bronchodilator may be given for wheezing.

The suspicion of acute cyanide poisoning should prompt the pre-hospital provider to consider antidote therapy. Advanced life support care includes anticonvulsants for seizures. The motor activity associated with seizures can aggravate acidosis. Victims, especially those with heart disease, may develop significant dysrhythmias. Correction of underlying metabolic abnormalities and antiarrhythmics, as warranted, should be administered to stabilize cardiovascular function. Initial management of shock should include fluids resuscitation. Prevention of hypothermia is a critical consideration. Severe acidosis may be a treatment consideration, and sodium bicarbonate may need to be administered to reverse this state and improve the effectiveness of other therapies.

## Transportation Considerations

Some communities have hospitals equipped to manage burn patients and/or provide hyperbaric oxygen treatment. In those communities, local medical control protocols typically prescribe the transportation of victims with burns and those with suspected carbon monoxide poisoning. The American Burn Association recommends, in part, that partial-thickness and full-thickness burns greater than 10 percent of the total body surface area in patients under 10 years old or over 50 should be transported to a burn center. Partial-thickness burns greater than 20 percent of the total body surface area in other age groups, and full-thickness burns greater than 5 percent of the total body surface area in any age group, or an inhalation injury, ideally should be transported to an adult or pediatric burn center. In communities that have multiple hospitals with different capabilities, EMS providers should preferentially transport smoke inhalation patients to those emergency departments that are prepared and equipped to manage burns, carbon monoxide inhalation, and cyanide poisoning. When in doubt, on-line medical control should be contacted and assistance requested in determining the correct destination hospital.

## Protocols for Pre-Hospital Assessment and Treatment of the Smoke Inhalation Victim

Smoke-associated poisoning with cyanide and other toxicants can rapidly culminate in death. To ensure that smoke inhalation victims are appropriately evaluated and intervention is promptly provided, it is essential to have protocols in place for pre-hospital assessment and treatment of victims of smoke inhalation. The following sample protocol can be adapted to department- or facility-specific needs and capabilities:

### Indications

The protocol applies to the patient who has been trapped or rescued from a closed-space structure fire. The presence of soot in the nose and/or mouth in the unconscious patient may be a strong indicator of cyanide poisoning. The protocol applies regardless of whether a concurrent injury or burn is present. Smoke inhalation can be a dangerous medical condition requiring prompt evaluation and treatment!


photo: www.FirefighterSafety.net

## Patient Evaluation

The patient should be moved to an area safe for assessment and clinical management. Key elements of the evaluation include:

- Mental status
- Any concurrent burn
- Any concurrent severe or critical injury
- Degree of respiratory distress
- Ability to oxygenate

The patient's airway, breathing and mental status are evaluated as part of the primary assessment. Compromise of any of these elements makes the patient a "red category" triage victim and makes rapid treatment a priority. The patient requires support of airway, breathing and supplemental oxygen. The patient that has a sustained burn injury or other severe or critical traumatic injury should be given treatment specific to those medical presentations. In addition, a smoke inhalation treatment protocol should be initiated.

A pulse oximeter reading can assist in the evaluation of the patient's overall ability to perfuse the body with oxygen. In the presence of carbon monoxide exposure, the pulse oximeter alone may produce an incorrect reading as the device does not assess the percent of hemoglobin affected by carbon monoxide. A reading below 90 percent reflects ineffective breathing, direct injury to the airway or lungs, or severe underlying lung disease (or some combination of these elements). When available, the carbon monoxide oximeter detects the level of carbon monoxide attached to the victim's hemoglobin. A detector reading exceeding 12 percent reflects moderate carbon monoxide inhalation, and one exceeding 25 percent reflects severe inhalation. Smoke and other toxic products cause direct irritation of the airway and lungs, and treatment should reduce this irritation. Any injury to the airway or lungs causes impaired ability to oxygenate and ventilate, and treatment should supplement oxygen delivery, protect the airway, and facilitate exhalation of toxins.

## Emergency Treatment and Transportation

1. Perform a primary survey to evaluate airway, breathing, mental status, and the presence of burns or other injuries. If possible, obtain a patient history of any underlying heart or lung problems.
2. Evaluate the patient's oxygenation by pulse oximeter and listen to the lungs for any abnormal sounds, particularly wheezing. When available, obtain a CO-oximetry reading. Victims with carbon monoxide levels exceeding 25 percent should be preferentially transported to the appropriate receiving hospital.
3. Evaluate for potential cyanide toxicity. The patient should be evaluated for the presence of soot in the nose or mouth and/or an altered mental status, hypotension or shock, flushed skin, and seizures. These patients may be candidates for treatment with a cyanide antidote. Contact on-line medical control, if needed.
4. Treat any burn or traumatic injury. The spine should be immobilized if indicated. If there is no indication for immobilization, allow the victim to find his/her position of comfort. Significant inhalation will cause violent coughing and at times vomiting, so the victim should be placed in a protective position or in a position of comfort.
5. If the airway is compromised, the patient should undergo endotracheal intubation. If unsuccessful, a rescue device can be utilized.
6. Provide supplemental oxygen. Most victims with an inhalation injury do not tolerate dry oxygen; therefore, the oxygen line should have a nebulizer attached with a full container of saline as soon as possible. If mental status permits, allow the patient to self-administer the oxygen by holding the mask and sitting in a position of comfort.
7. If any wheezing is present on the lung evaluation or if the patient has a history of asthma or wheezing, administer nebulized Albuterol. The nebulizer should contain 2.5mg in

3ml of Albuterol premix and filled with normal saline. The patient should continue use of the nebulized Albuterol and saline until it is dry.

8. If there are a large number of victims and an oxygen distributor manifold is available, place the victims in the same area, set up the manifold with an appropriate number of oxygen masks, and obtain the large nebulizer cup. Place 6ml or two premix ampules of Albuterol in the cup, fill the cup with saline, and allow patients to self-administer the mixture by mask.
9. Victims with mild smoke inhalation may be treated and released. To allow the victim to self-release from care, the following conditions must be met: mental status unimpaired or back to baseline for that individual (with verification by a friend or family member); no signs of respiratory distress and a pulse oximeter reading above 92 percent; lungs clear on auscultation; and no other significant burn or traumatic injury. Victims should be advised to seek medical attention if systems recur as some aftereffect of smoke inhalation injury may not be evident at the time of injury and only develop after several hours .

photo: Chris Saraceno

10. Victims with more severe smoke inhalation should be transported to the hospital.
    - For patients requiring transport to a hospital, appropriate treatment should occur in conjunction with the transport agency, and the patient should be turned-over for further assessment and interven tions.
    - Symptoms of carbon monoxide poisoning require possible removal of the patient to a hospital with hyperbaric oxygen treatment capabilities. Evidence of carbon monoxide poisoning includes impaired mental status, neurologic compromise to include seizures, and a carbon monoxide reading over 25 percent.
    - Major burn injuries get precedence in the determination of a receiving facility. A significant burn injury (generally, any burn over 10 percent full-thickness, a respiratory burn, or a burn over 20 percent partial-thickness) requires transport to the appropriate adult or pediatric burn center.

## When to Consider Empiric Management of Acute Cyanide Poisoning in Smoke Inhalation

Prior to the availability of Hydroxocobalamin, the empiric management of the cyanide toxicity associated with smoke inhalation was not a viable treatment option as the methemoglobin-induing antidotes were contraindicated in carbon monoxide poisoning. All victims of smoke inhalation should be treated as previously outlined. Published experience with pre-hospital Hydroxocobalamin administration for presumed cyanide toxicity associated with smoke inhalation suggests that it may be an important supplemental tool in the management of smoke inhalation.

Clearly, not everyone exposed to fire smoke is at risk or warrants treatment. There are costs and complications associated with all medications, and prudence dictates that only those patients likely to benefit should be exposed to the risks. Based on current clinical experience, there are historical and physical cues that suggest which victims may benefit from treatment.

### Mild Smoke Inhalation

Victims with normal levels of consciousness, without hypotension and experiencing only headache, dyspnea, chest tightness, nausea, vomiting, and transient confusion do not require empiric management for cyanide intoxication. They should be managed as previously described.

### Moderate Smoke Inhalation

Victims with altered levels of consciousness (GCS>8) without hypotension – even though they may be experiencing confusion and disorientation in addition to headache, dyspnea chest tightness or nausea – also do not appear to warrant empiric management for cyanide intoxication. These patients should be transported to the closest appropriate facility and monitored for any deterioration. Emergency department management may include the collection of 5ml or 7ml blood in an iced EDTA vacutainer for subsequent analysis for cyanide. The patients COHB level and serum lactate should be determined. Serum lactate levels >10mmol/l has a high correlation with cyanide toxicity and will likely be the only lab available to the clinician in determining the likelihood of cyanide exposure.

### Severe Smoke Inhalation

Victims presenting with seizures or who are in a coma (GCS <8) with hypotension or impending cardiovascular collapse, mydriasis, dyspnea, nausea or vomiting should be considered candidates for empiric administration of Hydroxocobalamin 5gm IV over 15 minutes. In addition to managing the airway appropriately and providing adequate oxygentation and ventilation, two IV or IO lines should be established. Consideration should be given to obtaining 5ml to 7ml of blood in an iced EDTA vacutainer for subsequent analysis for cyanide.

Hydroxocobalamin may interfere with the accuracy of some laboratory values. Depending on local protocol, blood may be drawn for cardiac enzymes, serum lactate, and basic chemistries prior to the administration of the medication. Blood collection should not delay medication administration in any circumstance. The patient should be monitored enroute, with any hemodynamic or cardiac instability managed as appropriate. A second 5gm infusion may be considered based on clinical response.

## Cardiac Arrest in Smoke Inhalation

There is very little experience in the clinical literature describing the management of victims of smoke inhalation in cardiac arrest with Hydroxocobalamin. All routine patient care, airway management and oxygenation should be accomplished according to currently accepted AHA guidelines. Likewise, all trauma protocols should be observed. Conceptually, carbon monoxide and cyanide toxicity associated with cardiac arrest secondary to smoke inhalation may be considered a potentially treatable oxygenation issue and should be treated with Hydroxocobalamin 5gm IV as early as possible in the cardiac arrest to combat tissue hypoxia that can not otherwise be addressed with CPR, cardioversion, defibrillation, or cardiac medications. Two IV or IO lines should be established. All AHA guidelines regarding CPR and rhythm management should otherwise be observed. Depending on clinical response, a second infusion of Hydroxocobalamin 5gm IV may be warranted.

## Conclusions

Both prompt recognition of acute cyanide poisoning and immediate initiation of care are necessary for effective treatment. The fire professional often provides the first line of medical care for victims of smoke associated cyanide poisoning in the pre-hospital setting. By recognizing cyanide poisoning and efficiently initiating corrective measures according to protocol, the fire professional can save lives.

## References:


1. Hall A, Rumack BH. *Clinical toxicology of cyanide*. Ann Emerg Med., 1986; 15: 1067-1074.
2. Jones J, McMullen MJ, Dougherty J. *Toxic smoke inhalation: Cyanide poisoning in fire victims*. Am J Emerg Med., 1987; 5: 317-321.
3. Silverman SH, Purdue GF, Hunt JL, et al. *Cyanide toxicity in burned patients*. J Trauma, 1988; 28: 171-176.
4. Kulig K. *Cyanide antidotes and fire toxicology.* N Engl J Med., 1991; 325: 1801-1802.
5. Baud F, Barriot P, Toffis V, et al. *Elevated blood cyanide concentrations in victims of smoke inhalation*. N Engl J Med., 1991; 325: 1761-1766.
6. Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services, Public Health Service. *Cyanide toxicity.* Am Fam Phys., 1993; 48: 107-114.
7. Houeto P, Hoffman JR, Imbert M, et al. *Relation of blood cyanide to plasma 18 cyanocobalamin concentration after a fixed dose of hydroxocobalamin in cyanide poisoning.* Lancet, 1995; 346: 605-608.
8. Borron SW, Vicaut E, Ruttimann M, et al. *Biological tolerance of Hydroxocobalamin in fire victims intoxicated by cyanide.* Intensive Care Medicine, 1997; 23: S181.
9. Lee-Chiong TL. *Smoke inhalation injury.* Postgrad Med., 1999; 105: 55-62.
10. Ferrari LA, Arado MG, Giannuzzi L, et al. *Hydrogen cyanide and carbon monoxide in blood of convicted dead in a polyurethane combustion: A proposition for the data analysis.* Forensic Sci Int., 2001; 121: 140-143.
11. Sauer SW, Keim ME. *Hydroxocobalamin: Improved public health readiness for cyanide disasters.* Ann Emerg Med., 2001; 37: 635-641.
12. Moriya F, Hashimoto Y. *Potential for error when assessing blood cyanide concentrations in fire victims.* J Forensic Sci., 2001; 46: 1421-1425.
13. Calafat AM, Stanfill SB. *Rapid quantitation of cyanide in whole blood by automated headspace gas chromatography.* J Chromatogr B Analyt Technol Biomed Life Sci., 2002; 772: 131-137.
14. Alarie Y. *Toxicity of fire smoke.* Crit Rev Toxicol., 2002; 32: 259-289.
15. Koschel MJ. *Where there's smoke, there may be cyanide.* Am J Nurs., 2002; 102: 39-42.
16. Borron SW, Baud FJ. *Toxicity, cyanide.* February 2003. Available at: www.emedicine.com/emerg/topic11 .htm. Accessed May 2006.
17. Mégarbane B, Delahaye A, Goldgran-Tolédano D, et al. *Antidotal treatment of cyanide poisoning.* J Chin Med Assoc., 2003; 66: 193-203.
18. Gill JR, Goldfeder LB, Stajic M. *The happy land homicides: 87 deaths due to smoke inhalation.* J Forensic Sci. 2003; 48: 161-163.
19. Madrzykowski D. T*he Station Nightclub Fire: Simulation of fire and smoke movement in laboratory reconstruction.* NIST, U.S. Department of Commerce. National Construction Safety Team Investigation. June 2004.
20. Eckstein M, Maniscalco P. *Focus on smoke inhalation – the most common cause of acute cyanide poisoning.* Prehosp Disaster Med., 2006: 21: 49-55.
21. Alarie Y. *Toxicity of fire smoke.* Crit Rev Toxicol., 2002; 32: 259-289.
22. http://www.burnsurgery.org/Betaweb/Modules/initial/bsinitialsec11.htm accessed January 2009.
23. Rosen and Barkin's *5-Minute Emergency Medicine Consult.* Lippincott Williams & Wilkins (LWW) Author(s): Peter Rosen, MD; Roger M. Barkin, MD; Stephen R. Hayden, MD; Jeffrey J. Schaider, MD; and Richard Wolfe, MD; ISBN-10: 0781771722, ISBN-13: 9780781771726.


# SMOKE Author Biographies:

**Rob Schnepp** has more than 20 years of fire service experience and currently serves as the Assistant Chief of Special Operations for the Alameda County (Calif.) Fire Department. He is a member of the NFPA Technical Committee on Hazardous Materials Response Personnel and 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, Rob's works include "Hazardous Materials Awareness and Operations" from Jones and Bartlett Publishers and numerous magazine articles for *Fire Engineering* magazine. He 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. He is also an instructor for the U.S. Defense Threat Reduction Agency, providing hazmat/WMD training to an international audience.

**Mike Gagliano** has more than 20 years of fire/crash/rescue experience with the Seattle Fire Department and the United States Air Force. He currently serves as the Captain of Training and is a member of the Seattle Fire Department Operational Skills Enhancement Development Team. Captain Gagliano teaches across the country on Air Management, Firefighter Safety, and Fireground Strategy and Tactics. He is a member of the FDIC Advisory Board and, along with the other "Seattle guys", is co-author of the textbook *Air Management for the Fire Service*.

**Casey Phillips** is a 20-year veteran of the fire service, the last 13 years serving with the Seattle Fire Department. He currently holds the position of Captain on Engine 28 and is a member of the Seattle Fire Department Operational Skills Enhancement Development Team. Captain Phillips teaches across the country on Air Management and Firefighter Safety and, along with the other "Seattle guys", is co-author of the textbook *Air Management for the Fire Service*.

**Phillip Jose** is a 20-year veteran of the Seattle Fire Department, where he serves as a Battalion Chief. He has served as a Lieutenant and Captain in the Training Division and is a member of the Seattle Fire Department Operational Skills Enhancement Development Team. Captain Jose teaches across the country on Air Management and Firefighter Safety with the "Seattle guys". He is a co-author of the book *Air Management for the Fire Service* and numerous articles in fire service publications.

**Steve Bernocco** is a 17-year veteran of the Seattle Fire Department, where he is a Lieutenant on Ladder 10. He has served as a Training Officer and is currently a member of the SFD's Operational Skills Enhancement Development Team. Lt. Bernocco has written numerous articles and teaches across the country on the topics of Air Management, Firefighter Safety and Survival, and Fireground Strategy and Tactics with the "Seattle guys". He is a co-author of the book *Air Management for the Fire Service* and numerous articles in fire service publications.

**Kevin J. Reilly** is a member of the Ridgewood NJFD; FDIC H.O.T. instructor; member, Board of Directors, Fire Safety Directors Association of New York City (FSDNY); member, Board of Directors, Cyanide Poisoning Treatment Coalition (CPTC); consulting committee member for the People's Burn Foundation, "To Hell and Back IV" series (2009); Emergency Action Plan (EAP) writer and High-Rise / Life Safety consultant in New York; contributing author to *Carbon Monoxide Poisoning*, edited by Dr. David Penney (October 2007); creator of Reilly - Emergency Breathing Technique; founder of FSP Instruments, Inc.; co-founder of www.FirefighterSafety.net. Kevin has also been previously published in *Fire Engineering*, "Chronic CO Poisoning in Firefighters" (June 2006) and "Rethinking Air Management" (April 2008).

**Frank Ricci** is a member of the New Haven Fire Department. He currently serves as the Director of Fire Services for ConnectiCOSH and is an adjunct instructor for the New Haven, Emergency Training Solutions, Middlesex County Fire School, and an FDIC H.O.T. instructor and lecturer. Ricci is a contributing author to *Carbon Monoxide Poisoning* (CRC Press, 2008) and the *Firefighters Handbook I and II* (PennWell, 2008). He has worked on a heavy rescue unit covering Bethesda and Chevy Chase, Md. Ricci was a "student live-in" at Station 31 in Rockville, Md. He developed the *Fire Engineering* film "Smoke Showing" and is a member of the IAFC Safety and Survival Section. His DVD, "Firefighter Survival Techniques / Prevention to Intervention" and "Live Fire Training in Acquired Structures" are available at *Fire Engineering* books and video.

**James Augustine, MD, FACEP,** is an emergency physician from Washington, D.C. and the Medical Director and Assistant Fire Chief for the District of Columbia Fire and EMS. Dr. Augustine serves on the clinical faculty in the Department of Emergency Medicine at Wright State University in Dayton, Ohio. He serves as Director of Clinical Operations for EMP Management and has served 28 years as a firefighter and EMT-A. Dr. Augustine may be contacted at james.augustine@dc.gov.

**Daniel J. O'Brien, MD, FACEP,** is an Associate Professor of Emergency Medicine at the University of Louisville School of Medicine. Dr. O'Brien is the fire surgeon for the Louisville Division of Fire and tactical physician for the Louisville Division of Police SWAT team. Dr. O'Brien may be contacted at obrien@pol.net.

**Donald W. Walsh, PhD, EMT-P,** is President and CEO of International Emergency Medicine Disaster Specialists and Retired Deputy Chief of the Chicago Fire Department. Dr. Walsh is a Fellow of the Institute of Medicine of Chicago and adjunct faculty at the U.S. Department of Homeland Security's National Fire Academy and National Emergency Training Center. Dr. Walsh may be contacted at drdonwalsh@aol.com.

**Jean Marie McMahon, MD,** is the Medical Director of the Occupational and Environmental Health Center of Eastern New York (OEHC). OEHC is one of several clinics operated statewide as part of the New York State Occupational Health Clinic Network. Dr. McMahon is board certified in Internal Medicine and in Occupational and Environmental Medicine. She has a special interest in firefighter health and safety.

# NOTES:

## NOTES:

CPTC

CYANIDE POISONING TREATMENT COALITION

photo: David Traiforod

photo: Steve Redick

The Cyanide Poisoning Treatment Coalition (CPTC) is a 501(c)(3) non-profit comprised of fire service organizations, firefighters and physicians. Through joint strategic initiatives to focus the required attention and resources on the issues, the CPTC aims to increase awareness about the risk of fire smoke cyanide exposure to improve early recognition and appropriate treatment for firefighters and EMS personnel. The CPTC has been on the cutting edge of fire smoke cyanide exposure and treatment protocols since 2005.

Appropriate recognition of the signs and symptoms of cyanide toxicity, as well as a comprehensive understanding of treatment and antidotes, is the educational objective of the CPTC.

Cyanide Poisoning Treatment Coalition
P.O. Box 301123
Indianapolis, IN  46230-1123
888-517-5554

For more information, please visit www.FireSmoke.org