

# SMOKE

PERCEPTIONS, MYTHS, AND MISUNDERSTANDINGS

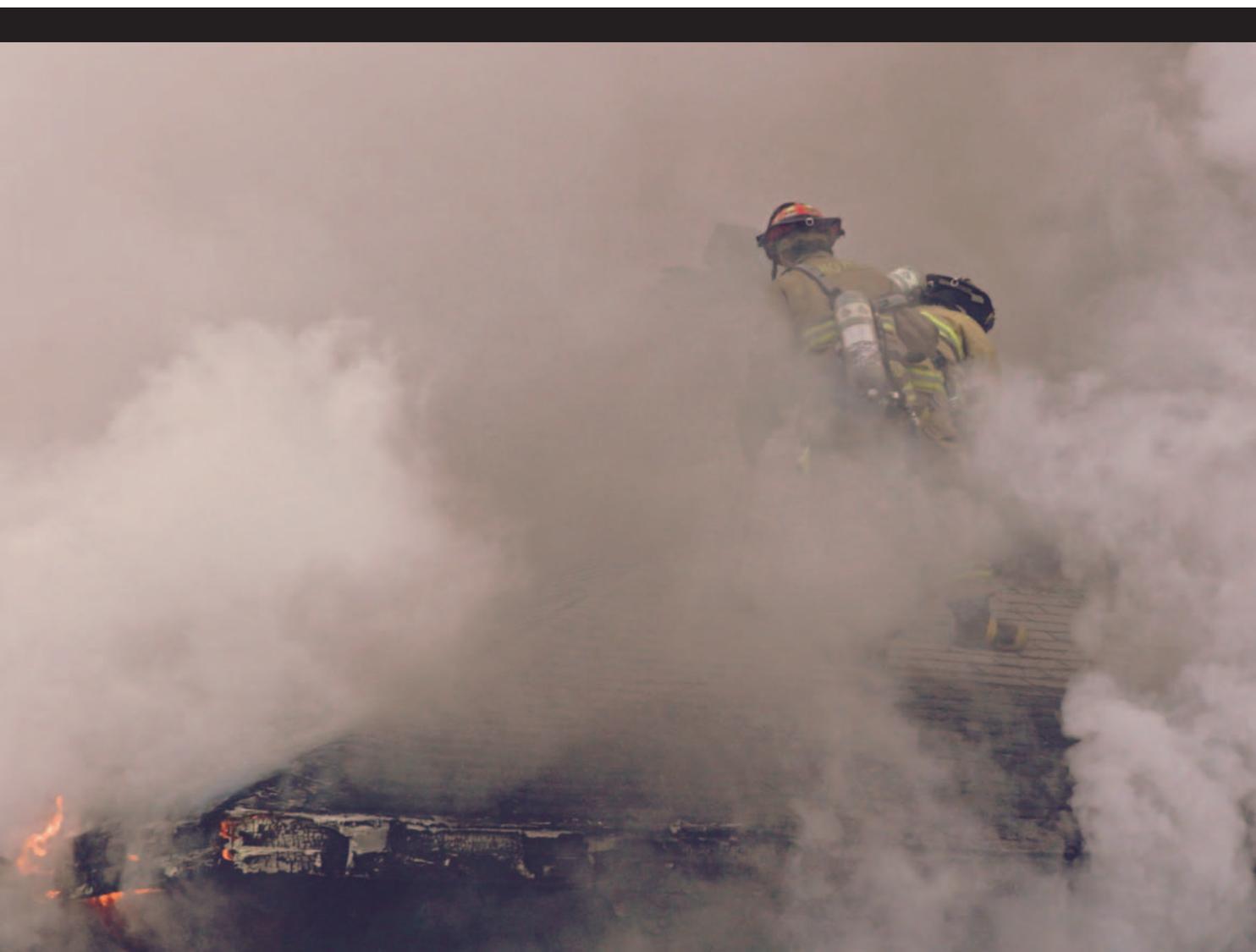


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# READING SMOKE IS ONE THING - BREATHING IT IS COMPLETELY DIFFERENT

BY ROB SCHNEPP, *Supplement Editor*

## **REVOLUTION: a drastic and far-reaching change in thinking and behavior.**

Americans are, by and large, assaulted with a steady stream of so-called “revolutions.” There’s been no shortage of fitness and dietary revolutions over the years, each one offering unbelievable results with a money back guarantee. The ongoing technology revolution has promised increased productivity and more free time, while the computerized banking industry has almost rendered cash obsolete. And while each of these examples has had an impact on daily life, they appear to be more evolutionary than revolutionary. It’s gotten to the point where “revolution” has become synonymous with benign terms like change, development, or progress. Unfortunately, such common usage of the term has watered down its meaning.

In reality, true revolutions are anything but benign.

Revolutions are fueled by a new way of thinking, risk taking, and the courage to do things completely differently. Something the American fire service is not entirely comfortable with. This is not to say that the fire service is backward or unable to embrace new ideas. It is however, accurately characterized as 200 years of tradition unimpeded by progress.

Why all the talk of revolution? Because the fire service is on the eve of one. A far-reaching and possibly tumultuous revolution that will challenge everything we thought we knew about smoke - the constant companion of the firefighter.

Research conducted over the years has proven that smoke is bad - we all know that. We all know that smoke kills more people than flames and that breathing smoke isn’t good. So why do we still go to fires and not wear our SCBA? And I’m not talking about wearing the tank with the mask dangling around your neck. After the fire is knocked down, why is it that firefighters drop their SCBA and perform overhaul

in the smoldering debris, breathing all those products of incomplete combustions? Why do we put so much effort into rapid intervention teams, when the current method of medically treating someone after the rescue is largely ineffective? We’ve figured out a better way to rescue our own, but have not completed the loop by providing an effective antidote to correct a potential cause of death in smoke inhalation victims - cyanide poisoning. Typically, when someone dies in a fire, it’s attributed to the nebulous cause of “smoke inhalation.” In truth, it’s more complicated than that - we just haven’t been looking at it the right way. We haven’t really digested the combustion chemistry to truly understand why the smoke is so nasty. Understanding the basics of combustion chemistry is the first step toward gaining a new respect for an old foe.

It’s fitting that this smoke revolution finds its roots in a busy fire department like Providence, Rhode Island - a key player in the American Revolution. In this supplement, Chief of Department David Costa provides a detailed description of a series of fire incidents that are emerging as a shot heard ‘round the world for the fire service. He describes an investigation that reached an unexpected conclusion: a large number of his firefighters were exposed to cyanide - from the smoke - after fighting a series of structure fires. These firefighters were operating at the same kind of fires occurring every day in each and every part of this country - the typical residential structure fire.

I encourage you to read about Chief Costa’s journey. A journey that every Fire Chief hopes to avoid - one that ends with a visit to a firefighter’s spouse, telling them that their loved one has been injured on the job.

I hope you’ll take the time to read the articles following Chief Costa’s foreword. You’ll learn about combustion chemistry, better ways to manage your air while fighting fire, the signs and symptoms of smoke inhalation, and why current methods of treating

smoke inhalation victims may be futile. The last piece, written by Dr. Jean-Luc Fortin, offers a look inside a successful resuscitation of a firefighter in Paris, France. The firefighter, overcome by smoke after getting lost inside a structure fire, is alive and well today because of aggressive pre-hospital care and an antidote for cyanide poisoning.

The bottom line is this - the fire service needs to become better educated about smoke. Hopefully, an increased level of knowledge will reinforce the importance of respiratory protection on the fireground, and the need to properly manage your air supply. It’s better to avoid getting into trouble than relying on a rapid intervention team to come in and find you! Unfortunately, a low air emergency does not come with a “money back” guarantee.

Smoke has become such a constant companion for us that we may have lost respect for it. According to Chief Costa, his department was shocked by the cyanide exposures. “We haven’t come up with a firm grasp of what will be different,” he says. “It’s too early to tell. There is, however, a lot of lively discussion going on around the firehouse coffee table.”

And that’s what we need to better appreciate the immediate and long terms effects of breathing smoke - a lively discussion. We also need a drastic modification of our attitude toward smoke. Most of all, it’s important to keep an open mind about the research and data presented here. You might discover some solutions on the following pages, but more than anything, I hope it raises some questions.

**Rob Schnepf** is the Chief of EMS and Special Operations for the Alameda County (CA) Fire Department. He is the primary author of a textbook entitled “Hazardous Materials: Regulations, Response & Site Operations,” by Delmar Publishing, and is on the editorial advisory board for *Fire Engineering* magazine. Rob is a member of the NFPA Technical Committee on Hazardous Materials Response.

# FOREWORD

DAVID D. COSTA

*Chief of Department*

*Providence Rhode Island Fire Department*

**March 23, 2006** began like most days in the City of Providence. I started the day by attending several meetings dealing with the administrative issues that every chief of a fire department encounters. I did not know that the next 24 hours would trigger a series of incidents that would thrust me into the forefront of a nationwide debate over the testing and treatment of smoke inhalation victims and air management at fireground operations.

The Providence Fire Department is a fully paid fire department with a uniformed strength of 469 personnel. We protect the capital city of Rhode Island, which has a population of 173,618 in a 20-square-mile area. The population swells to approximately 300,000 on business days.

At 10:31 AM on March 23, fire companies were dispatched to a structure fire in the south end of the city. They found a one-story restaurant with fire blazing from the cooking equipment into a concealed ceiling space and farther into a five-foot overhanging facade that lined the exterior of the building at the roofline. Most of the suppression effort focused on an exterior attack in which firefighters used their air packs intermittently while opening the soffits to get at the bulk of the fire. The operations appeared routine, and fire companies returned in service by 12:05 PM. At 2:15 PM, one firefighter that operated at the fire was transported to Rhode Island Hospital when he began talking incoherently and experienced a headache, dizziness, shortness of breath, and coughing.

At 5:35 PM the same day, fire companies responded to a fire in a six-unit apartment building. The fire started in a rear bedroom of an apartment on the first floor. The fire was brought under control at 6:07 PM, and no injuries were reported.

About 5:45 PM, I received a telephone call at home from a dispatcher saying that a member that operated at the restaurant fire earlier in the day was at Rhode Island Hospital and had been diagnosed with high levels of cyanide in his blood. The firefighter had received the standard cyanide antidote kit.

Having consulted with the firefighter and his doctor, I decided that every firefighter who responded to the restaurant fire should be instructed to seek medical treatment if they experienced symptoms possibly indicative of cyanide poisoning. Sixteen firefighters sought medical treatment; 4 of the 16 were confirmed to have high levels of cyanide in their blood.

As I discussed the situation further with doctors, my officers, and fellow firefighters, there did not seem to be a clear answer to what could have

symptoms of cyanide poisoning. Including the initial 16 firefighters who received medical attention, 28 sought evaluation and treatment. Cyanide exposure was confirmed in 27 firefighters, 8 of whom were identified as having high levels of cyanide in their blood.

Exposure to cyanide from the products of combustion is much more prevalent than many in the fire service are aware. A graduate of the Executive Fire Officer Program at the National Fire Academy with a Bachelors Degree in Fire Science, I was disturbed that I was not aware that cyanide is pervasive in fire smoke. While every firefighter is taught the basic information about the dangers related to hydrogen cyanide and other products of combustion, the depth of our understanding pales in comparison to the information available in medical journals.

“The cyanide exposure incidents have brought a harsh reality to our department about the real dangers of our profession.”

caused these poisonings, which were unexpected for us. The feeling was that this must be an isolated incident and that something unusual must have been present at the restaurant fire.

At approximately 2:30 AM on March 24, 2006, I received a telephone call from a dispatcher that one of our firefighters collapsed at the scene of a house fire and that cardiopulmonary resuscitation (CPR) was under way. The firefighter was transported to Rhode Island Hospital, where he was successfully resuscitated. While treatment continued in the emergency room, a test for cyanide exposure was conducted. The test confirmed that the firefighter had a high level of cyanide in his blood. The standard antidote was administered.

Having learned that we had positive tests for cyanide exposure at two separate incidents, we issued a directive that every firefighter who responded to any of the three structure fires in the past 16 hours should be contacted. They were instructed to seek medical treatment if they experienced any

Following the cyanide exposure incidents, I requested a Health Hazard Evaluation by the National Institute of Occupational Safety and Health (NIOSH), and I appointed a five-member team of fire department personnel to investigate fully the cause of our firefighters' exposure. The fire department report has been issued, and I expect NIOSH to issue their report some time in the fall. The recommendations from the fire department investigation team include awareness training for firefighters and the medical community; deployment of cyanide detection equipment; enhanced compliance with existing mandatory mask regulations; physical training with self contained breathing apparatus (SCBA); immediate deployment of an Air Supply Unit to aid in air management; additional command support for accountability and incident management; routine testing for cyanide in smoke inhalation victims; and additional research.

The fire service has seen dramatic technological advances and has gained



“ Firefighters need to understand and know that today’s fire smoke is more dangerous than ever.”

incredible experience since I joined the fire service 30 years ago. Examples include new and improved air packs, PASS devices, thermal imaging cameras, and the Fire Service Joint Labor Management Wellness/Fitness Initiative. But do we take full advantage of the knowledge we have gained throughout the years to protect ourselves? What are the real ramifications and true cost of our injuries?

Besides monetary costs such as medical bills, overtime costs due to lost time, and pension costs for disability, there are the pain and trauma to the injured firefighters. There is also a cost to the firefighter’s family. What are the emotional scars that a spouse, a child, or a parent is left with when they live through their loved one’s injury? I hope I never have to inform another firefighter’s spouse that a loved one is in grave condition because of smoke exposure or another job-related injury.

The cyanide-exposure incidents have awakened our department to the harsh reality of another of the real dangers of our profession. It is our responsibility to learn from our experiences, strive for improvements, and promote safety for every firefighter. This educational supplement was developed to educate the fire service on a deadly toxicant in fire smoke that has gone relatively undetected and certainly unreported. I encourage every firefighter to pass along the information in this supplement and read the full report of the Investigation Committee into the Cyanide Poisonings of Providence Firefighters, available online at <http://www.rifirechiefs.com/>.



Photo: Steve Redlick

# **HYDROGEN CYANIDE IN FIRE SMOKE:**

## **AN UNRECOGNIZED THREAT TO THE AMERICAN FIREFIGHTER**

BY DONALD W. WALSH, PhD, EMT-P

*President Cyanide Poisoning Treatment Coalition (CPTC)*

*Assistant Deputy Fire Commissioner, Chicago Fire Department, Chicago, Illinois*

Some parts of this manuscript were taken from the publication “Cyanide, a Ubiquitous Product of Combustion in Modern Fires” (DW Walsh), which appeared in *fireEMS* in May 2005.

### **INTRODUCTION**

**A**re American firefighters being poisoned unknowingly during the performance of their fire suppression and rescue duties? Recent findings suggest that firefighters may in fact frequently be exposed, sometimes unknowingly, to a dangerous toxicant: cyanide.

How many times have firefighters seen their colleagues on building roofs ventilating in heavy smoke or performing overhaul functions in smoldering fire debris without self-contained breathing apparatus (SCBA)? The fact is that firefighters perform unprotected fireground operations all the time. Many fire departmental standards

inadvertently allow for these practices. NFPA 1404, *Standard for Fire Service Respiratory Protection Training*,<sup>1</sup> and NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*,<sup>2</sup> establish standards for protecting firefighters when fire smoke and hazardous materials are present. However, the American fire service still allow firefighters to perform ventilation and overhaul activities without SCBA or appropriate protection.

Current scientific research is prompting the American fire service leaders to look much more closely at allowable practices. In addition, fire service experts are further asking for new, stronger fireground air-management standards to protect firefighters.

Research in Sweden has identified specific building materials that are very dangerous when burning and producing fire smoke.<sup>3-5</sup> In a study by the Swedish National Testing and

Research Institute (SNTRI), scientists identified fiberglass-based materials as producing some of the highest levels of cyanide in fire smoke. Use of fiberglass insulation in American building construction is much higher today than 30 years ago. Many fire departments’ tactical overhaul and extinguishing operations have not been updated to address these and other changes that make smoke increasingly dangerous. For their health and safety, firefighters need to understand that today’s fire smoke is more dangerous than ever. The days of the “smoke-eater” culture needs to end.

### **THE PROVIDENCE FIREFIGHTER’S POISONING**

A recent case of cyanide poisoning of a firefighter occurred in early 2006 during a structural house fire in Providence, Rhode Island.<sup>6,7</sup> During the fire, a firefighter collapsed into cardiac arrest while operating the engine pumps outside the fire building. The firefighter of Engine 6 was resuscitated at Rhode Island Hospital and was found to have hydrogen cyanide in his blood. The firefighter had no memory of the fire.

Following the fire, the fire chief had the poisoning investigated. Ninety-one of the department’s firefighters



Photo: Tim Olk

responded to three fires in March of 2006. Of those 91, 28 sought medical treatment, and 27 had their blood tested for cyanide. Eight of the firefighters, including the firefighter from Engine 6, had high levels of cyanide in their blood. The fire chief assembled a special task force to investigate the impact of cyanide in fire smoke. The task force concurred with experts who have concluded that hydrogen cyanide is a much more significant threat to firefighters than previously understood: "It would appear that the Providence Fire Department and Rhode Island Hospital may have run into the tip of a very large iceberg,"<sup>6</sup> the task force report indicates.

The task force made 16 recommendations to protect firefighters and civilians from fire smoke producing cyanide. The recommendations included educating firefighters about how fire smoke can produce high, deadly levels of hydrogen cyanide and how fast fire smoke can quickly incapacitate someone trying to escape a fire; educating the medical community to routinely test smoke inhalation victims for cyanide; establishing and supporting quick federal approval of safe cyanide antidotes (hydroxocobalamin) in the United States to treat firefighters and civilian smoke inhalation victims; educating firefighters on the dangers of cyanide poisoning and requiring the use of protective measures; and acquiring and deploying new technologies to detect cyanide at fire scenes.

### TRAGEDY IN WEST WARWICK: THE RHODE ISLAND NIGHTCLUB FIRE

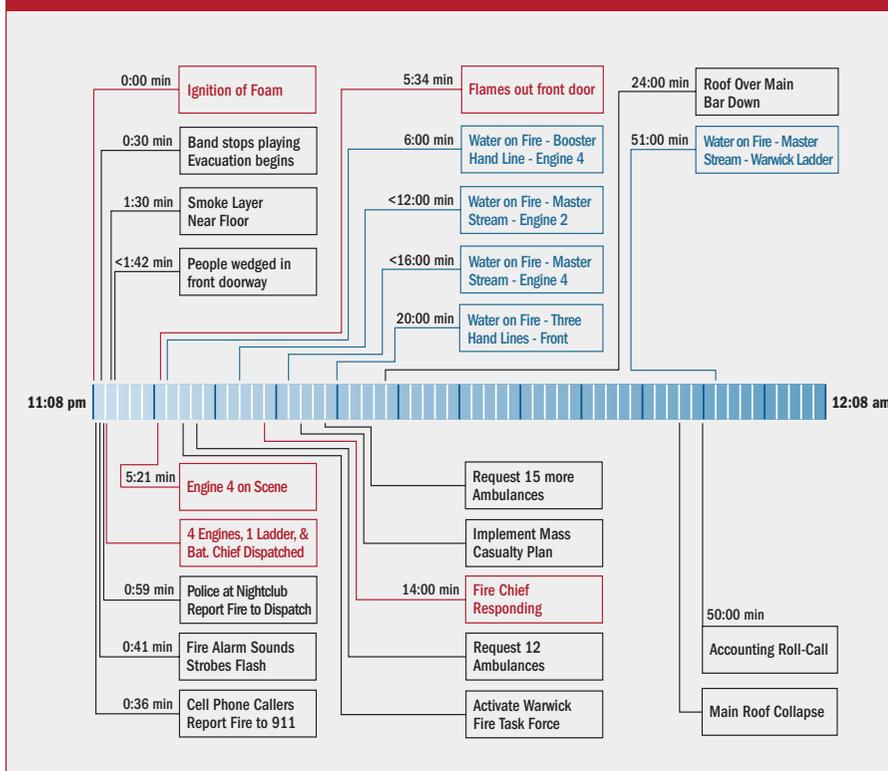
Approximately 440 people were in the Station nightclub in West Warwick, Rhode Island, that Friday night in February 2003 when a fire broke out in the single-story, wood-frame building.<sup>8</sup> The fire started just after 11 PM, when pyrotechnics used by Great White, the band performing that night, ignited polyurethane foam lining the walls of the stage area. The blaze quickly spread to the ceiling and then ignited the wood paneling on its way to becoming a full-blown structural fire.

Figure 1 shows the timeline of the Rhode Island Nightclub Fire and of the emergency response, which was rapid and well-executed.<sup>8</sup> In response to 911 calls made approximately 35 seconds and 1 minute after the fire ignited, four

engine companies, a tower-ladder truck, a rescue unit, and a battalion chief were dispatched to the scene. The first responding engine unit arrived at the scene in less than 5 minutes after receipt of the 911 call and began suppressing the fire with water. Ambulance units and additional fire companies were dispatched, and a mass casualty plan was implemented.<sup>9</sup>

The fire simulation experiments measured temperature as well as concentrations of various combustion gases in both sprinklered and un-sprinklered conditions. The un-sprinklered condition reproduced that of the Station nightclub, which did not have a sprinkler system. Building codes did not require the Station nightclub to have a sprinkler system given the size

**Figure 1.** Timeline of the Rhode Island Nightclub Fire and emergency response to it.<sup>8</sup>



Despite the rapid and capable emergency response, which is credited with saving many lives, 100 people perished in the fire, and scores of others were seriously injured. The US Department of Commerce's National Institute of Standards and Technology (NIST), which is responsible for investigating building-related failures leading to substantial loss of life, was deployed on a fact-finding mission to investigate the fire.

The NIST conducted experiments to simulate the spread of fire and smoke through the nightclub.<sup>8,10</sup> The experiments were conducted in a test room having dimensions and containing materials similar to those of the nightclub on the night of the fire.

of the nightclub (footprint of approximately 4500 square feet) and the date it was built. Given the similarity of the test conditions to conditions on the night of the fire, it is likely that the experimental observations closely reflect what happened on the night of the fire.

The results of the simulations under un-sprinklered conditions dramatically demonstrate how quickly conditions in the nightclub may have become deadly. Within seconds of ignition of the fire, concentrations of the toxic combustion products carbon monoxide and hydrogen cyanide soared and oxygen levels plummeted to create conditions incompatible with sustaining life (Figure 2).<sup>10</sup>

The striking differences in temperature and in concentrations of oxygen, carbon monoxide, and hydrogen cyanide between the sprinklered condition and the un-sprinklered condition support the judgment of on-the-scene firefighters who contended that the lack of a sprinkler system cost many lives (Figure 2).<sup>10</sup> Whereas temperature and oxygen levels were maintained at nearly ambient levels from the floor to approximately 1.4 meters above floor level in the sprinklered condition, flashover conditions occurred approximately 60 seconds after ignition in the un-sprinklered condition. These findings contributed to the NIST's primary recommendations that model codes require sprinkler systems for all new and existing nightclubs regardless of size and that state and local authorities adopt this provision.<sup>8</sup>

### CYANIDE IN FIRE SMOKE INHALATION: A DEADLY TOXIC MIX

Results of the NIST experiments are consistent with the possibility that an elevated level of hydrogen cyanide was among the causes of incapacitation and death in the Rhode Island Nightclub Fire. Hydrogen cyanide is a

highly toxic combustion product that is formed during combustion of any material containing nitrogen<sup>3</sup>-that is to say, during combustion of almost any material found or used in the construction of human dwellings. The possibility that cyanide contributed to morbidity and mortality in the Rhode Island Nightclub Fire was not considered by at least some of the health care providers administering to fire victims as illustrated by a case report published in the *New England Journal of Medicine* in 2004.<sup>11</sup> The authors assessed and treated a woman severely burned in the Rhode Island Nightclub Fire for carbon monoxide poisoning but did not report evaluating her for toxicity arising from other combustion products including hydrogen cyanide. Furthermore, although the authors discussed several aspects of managing burn injury and smoke inhalation, they did not discuss cyanide toxicity despite the presence of several signs and symptoms suggesting cyanide poisoning. The failure to consider cyanide as a potential cause of fire-related morbidity and mortality characterizes much of the medical literature on the management of smoke inhalation.

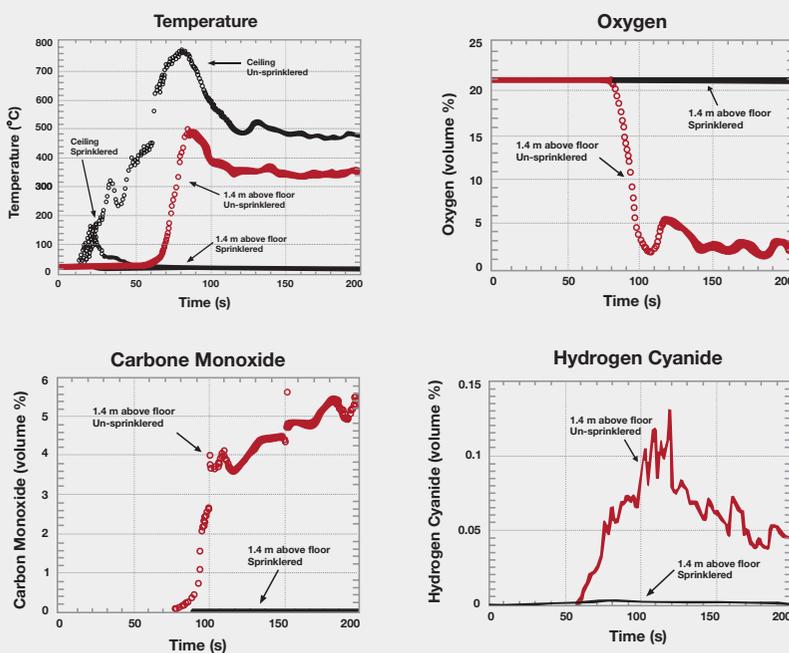
Why this lack of awareness of the importance of cyanide as a toxic combustion product? Researchers at the Swedish National Testing and Research Institute (SNTRI), which has conducted pioneering work identifying toxicants in fire smoke, suggest that the pervasive and relatively well recognized hazard of carbon monoxide can blind researchers and clinicians to the possibility that other toxicants, too, can be important in causing smoke inhalation injury.<sup>5</sup> *In effect, cyanide has not been found because it has not been sought.*

### FIRE SMOKE RESEARCH FROM THE SWEDISH NATIONAL TESTING AND RESEARCH INSTITUTE

As discussed in the introduction, data from studies conducted by the SNTRI are consistent with NIST data in showing that cyanide is a major combustion product generated during burning of materials commonly found in domestic structures. In one series of experiments, the SNTRI assessed the emission of hydrogen cyanide and carbon monoxide under both non-flaming (i.e., pyrolyzing) and flaming (i.e., fire) conditions during burning of wool, nylon, synthetic rubber, melamine, and polyurethane foam.<sup>5</sup> The results show that all of these substances liberated high quantities of cyanide when burned-particularly under pyrolyzing conditions characterized by low oxygen. Carbon monoxide was also emitted during the burning of these substances. Noting that hydrogen cyanide is approximately 35 times more toxic than carbon monoxide during acute exposure, the authors emphasized the need for increased recognition of the contribution of cyanide to smoke toxicity.<sup>5</sup>

The SNTRI conducted other experiments to identify factors that affect the amount of cyanide generated in a fire.<sup>3</sup> They developed combustion models that take into account the observations that oxygen content in the air near a fire is lower than that of fresh air; that air in the fire contains combustion products that reduce the efficiency of burning and result in incomplete combustion; and that growth of a fire increases the contents of combustion products in the air. Using these models, they identified two conditions that increased the probability of cyanide formation in a fire. First, recycling of combustion

**Figure 2.** Temperature and oxygen, carbon monoxide, and hydrogen cyanide concentrations in an experiment simulating the Rhode Island Nightclub Fire.<sup>10</sup> Temperature and gas concentrations were measured 1.4 meters above the floor and 1.6 meters away from the stage where the fire started.



products within a confined space increased the formation of hydrogen cyanide. Second, lowered ventilation rate to the fire increased the formation of hydrogen cyanide by 6 to 10 times relative to conditions of higher ventilation rate. Carbon monoxide formation was also increased under these two conditions, which are particularly likely to apply to closed-structure fires.

## HYDROGEN CYANIDE AS AN ESCAPE INHIBITOR

Cyanide poisoning from fire smoke can be directly lethal or, as the SNTRI and other researchers emphasize, can indirectly cause death by incapacitating a fire victim.<sup>5,12</sup> Hydrogen cyanide and other toxicants in sublethal concentrations appear to act as escape inhibitors in modern fires.<sup>5,12</sup> Exposure to low cyanide concentrations in a fire can cause unconsciousness that make self-directed escape from the fire very difficult.<sup>5</sup> The victim of cyanide-associated incapacitation may continue to inhale increasing amounts of carbon monoxide and other noxious gases. Carbon monoxide poisoning may eventually be the direct cause of death. However, as the carbon monoxide poisoning might not have occurred without cyanide-induced incapacitation, hydrogen cyanide arguably is the cause of death in this example.

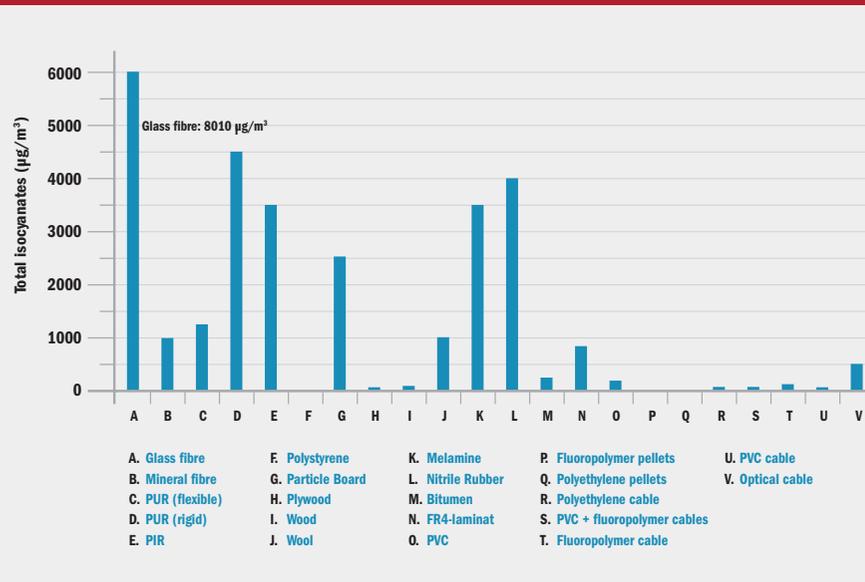
## SISTERS OF CYANIDE: ISOCYANATES GENERATED DURING COMBUSTION

Other findings from the SNTRI suggest that the impact of cyanide as isocyanates should be considered in estimating the cyanide-associated hazards of fire smoke.<sup>4</sup> Derived from cyanide and hydrocarbons, isocyanates are commonly found in plastics and adhesives. They are generated during the thermal decomposition of urethanes and, it is hypothesized, during the incomplete combustion of nitrogen-containing compounds.<sup>4</sup> The SNTRI assessed the formation of isocyanates in small-scale combustion experiments involving 18 standard materials used in building (Table 1) and in large-scale experiments involving two domestic products (i.e., a sofa and a mattress). Other combustion products including carbon monoxide, sulfur dioxide, hydrogen fluoride, hydrogen chloride, and hydrogen cyanide were also measured.

**Table 1.** Materials and products investigated in the test program.<sup>4</sup>

Material	Comment	Usage
Glass fibre	insulation wool	building insulation
Mineral fibre	insulation wool	building insulation
Wood	deal board	building construction
Bitumen	waterproofing membrane	building construction
Polystyrene	expanded polystyrene(EPS)	packaging, insulation, etc
Nitrile rubber	insulating material	tubing insulation
PVC	flooring material	surface lining
Fluoropolymer	pure pellet material	cable base material
Polyethylene	halogen free, fire retarded pellets	cable base material
FR4 laminate	brominated laminate	printed circuit board base material
Melamine	laminite	building construction
Wool	92% wool, 8% polyamide	lining, clothes
Particle Board	laminite	building base material
PUR	flexible foam	furniture upholstery
PUR	rigid foam	building insulation
PIR	rigid foam-polyisocyanurate (modified PUR)	building insulation
Plywood	laminite	room surface lining
Carbon fibre laminate	composite material, small and intermediate scale experiments	high performance vehicles, airplanes, etc
<b>Cable products:</b>		
Polyethylene cable	halogen free, fire retarded cable	data cable
PVC cable	fire retarded cable	data cable
Fluoropolymer cable	high performance cable	data cable
PVC + fluoropolymer cables	50% of each material	data cable
Optical cable	uses urethane acrylate based polymer	optical signal transport
<b>Real-scale products:</b>		
Sofa	PUR upholstery; full scale experiment	furniture
Mattress	PUR; large scale experiment	furniture

**Figure 3.** Total isocyanate concentrations in Cone calorimeter tests.<sup>4</sup>



The small-scale experiments involved highly ventilated conditions under which generation of large quantities of dangerous combustion products such as carbon monoxide and hydrogen cyanide was neither expected nor observed. In these small-scale experiments, isocyanates were found to be present at a concentration

that made them potentially more dangerous to humans than the other combustion products that were tested (Figure 3).<sup>4</sup> The results suggest that elevated isocyanate levels in a fire can result in life-threatening conditions even when hydrogen cyanide and carbon monoxide remain at nondangerous levels.

The large-scale experiments differed from the small-scale experiments in that combustion generated high concentrations of dangerous combustion products such as hydrogen cyanide and carbon monoxide. Isocyanates were also present at high levels in these large-scale experiments. For example, in a large-scale test in which a sofa in an enclosed room was ignited, isocyanates reached approximately 17% of the concentration that is immediately dangerous to life and health (IDLH) and carbon monoxide reached 30% of the IDLH value during the test period. The authors concluded based on these results that the contribution of isocyanates should be included in estimating the toxic effect of a gas mixture.<sup>4</sup>

## CONCLUSIONS

Medical lab results of the Providence Rhode Island firefighters identified high levels of hydrogen cyanide in their blood. The results cause significant changes in the operational fire fighting practices and procedures. The investigations cause the recommendations for new cyanide detecting systems, new cyanide medical testing protocols, new cyanide antidote treatments, and educational programs on the dangers of fire smoke.

Results of fire modeling experiments including simulations of the February 2003 Rhode Island Nightclub Fire suggest that cyanide is a ubiquitous toxicant in modern fires. Depending on the fire conditions, hydrogen cyanide is formed as an intermediate combustion product and/or an end product. Isocyanates, too, are formed during combustion and should be considered in estimating cyanide-related hazards from fire smoke. The amount of cyanide produced can vary from fire to fire and from one location to another in a given fire depending on factors such as the composition of the burning material, the rate of burning, the absolute temperature, and ambient oxygen level.

Experience with the Rhode Island Nightclub Fire, in which cyanide is likely to have contributed to morbidity and mortality, and data from studies reviewed elsewhere in this supplement show that cyanide can be rapidly lethal—a daunting challenge for first responders working to save lives. While daunting, the challenge is not

insurmountable. Effective management of cyanide poisoning in a fire emergency is possible. The first responder's awareness that cyanide poisoning is highly probable in smoke inhalation victims of closed space structure fires constitutes a first step in effective management of smoke inhalation-associated cyanide poisoning. Specific measures to help victims of smoke inhalation-associated cyanide poisoning in the prehospital setting are discussed elsewhere in this supplement.

## RECOMMENDATIONS TO THE AMERICAN FIRE SERVICE

1. Increase education of firefighters and civilians about the risk of cyanide poisoning from fire smoke.
2. Support blood testing for cyanide of firefighters and fire victims.
3. Support the use of safe cyanide treatment antidotes (hydroxocobalamin) in the United States to treat firefighters and civilian smoke-inhalation victims.
4. Submit to the NFPA scientific research to identify health and safety issues related to mandatory air management standards especially during overhaul operations.

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Photo: Tim Oik

# AIR MANAGEMENT ON THE FIREGROUND:

## THE NEED - THE MANDATE - THE SOLUTION

BY CAPTAIN MIKE GAGLIANO  
CAPTAIN CASEY PHILLIPS  
CAPTAIN PHIL JOSE  
LIEUTENANT STEVE BERNOCCO

*All contributors to this article are from the Seattle Fire Department*



**T**he 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.

On a daily basis, firefighters around the world fight fires in this deadly arena armed with only some basic tools - 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), which makes it possible to safely enter a fire 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 fireground.

### AIR MANAGEMENT

The concept of Air Management revolves around the discipline of knowing how much air a firefighter has in their SCBA, monitoring that air, 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 into 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 to bother with. 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 assertions were demonstrated to be incorrect and unsafe; however, it is still a 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 the SCBA. The SCBA continues to improve as newer technology seeks to decrease the

weight, improve reliability, and enhance overall effectiveness. Combined with better protective equipment, along with training and improvements in leadership, it should be expected that firefighter deaths rates on the fireground should be decreasing. Unfortunately, that is not the case as fireground deaths are staying about the same in spite of 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.**

**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 results of firefighters running out of air vary dramatically — increasing firefighter line-of-duty deaths, close calls, injuries and increased cancer/respiratory disease rates that are directly linked to the smoke firefighters breathe when their air is depleted.

According to NFPA firefighter fatality reports, between 1996 and 2003 there were 103 deaths directly attributed to asphyxiation. 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

**A “ROUTINE” HOUSE FIRE CAN PRODUCE ANY OF THE FOLLOWING WITHIN SECONDS OF IGNITION:**

- 1 Extreme Temperatures/ Thermal Insult**
- 2 Poisonous/Asphyxiating Atmospheres**
- 3 Structural Collapse**
- 4 Explosions**
- 5 Entrapment**
- 6 Electrical Shock**

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

Besides the disturbing firefighter death statistics, there are other mandated changes coming to the American fire service that focus directly on air management.

The most significant change is the new language in the National Fire Protection Association (NFPA) 1404 respiratory standard that will take effect in 2007. Beginning in January, NFPA 1404 will include 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's 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:

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

The NFPA 1404 Standard outlines that fire department 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.”

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

The new language in the NFPA 1404 standard is going to 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 their firefighters from the 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 into 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 taken care of in return.

The preceding article on the deleterious effects of smoke and its components highlights 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 could 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. The devil, as always, is in the

The fire service has seen dramatic changes since Benjamin Franklin began building the American fire service. Despite all the changes, deaths on the fireground that are not related to heart attack or vehicle accidents still occur in the same ways they have for 200 years. These are:

- Smoke
- Thermal Insult
- Structural Collapse
- Getting Lost or Separated
- Running out of Air

### “Running out of Air” affects all other categories on the list:

- “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 asphyxiation.
- “No Air” when lost or separated leads to panic and asphyxiation.
- “No Air” requires the firefighter to breathe the products of combustion - 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.

details of just what is, and is not, deemed “job-related.” In the state of Washington, for example, the following are considered valid “job-related” conditions under current presumptive legislation:

- **Primary Brain Cancer**
- **Malignant Melanoma**
- **Leukemia**
- **Non-Hodgkin’s Lymphoma**
- **Bladder Cancer**
- **Ureter Cancer**
- **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**
- **Oral System Cancer**

The Washington State Ways and Means Committee also included additional language that put limits on how long coverage would be in place. The current system allows for 3 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 5 years of retirement or they are not covered. They will get zero coverage despite the obvious links to the years of service and high rates of cancer probability. There are additional variables written in that allow further questioning of whether the cancer is job related including smoking history, fitness, etc.

There is a growing recognition that proper usage of equipment and following of operating guidelines/policies will be scrutinized in the light of personal liability. An injury or exposure will be judged based on how the firefighter operated during the emergency

and if they used the safety equipment provided them. Much like the current discussions that are ongoing in regard to vehicle accidents in which seatbelts are not worn, the proper use of SCBAs and respiratory guidelines will be expected. Deviation from these guidelines opens the firefighter up to questions of personal liability.

Finally, all of the above will certainly result in court cases in which firefighters, fire officers, and fire departments as a whole may be required to justify their actions. A case in Memphis, Tennessee, is currently questioning why a “30-Minute Bottle” did not last a deceased firefighter 30 minutes. This is something all who’ve 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 was taken prior to the fatality. Those in charge must answer:

- 1) Why do they allow their firefighters to enter a structure fire without breathing from an SCBA?
- 2) Why they routinely allow firefighters to operate until their low-air warning alarm activates?
- 3) 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 limited, and exposure to legal/liability issues can be decreased.

### The Rule of Air Management says:

Know how much air you have in your SCBA, and manage that air so that you leave the hazardous environment before your low-air warning alarm activates.

While this looks like a simple solution, it is a radical change in behavior for the fire service. Most firefighters have never checked their 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 a 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 Radio—Equipment—Air—Duties—Yes! (R.E.A.D.Y.) Check (See *Fire Engineering* magazine June 2005 for more details) is recommended prior to entry, to eliminate some of the key problem areas that are killing and/or injuring firefighters.

A routine check of the air status by the individual and team leader during

“Know how much air you have in your SCBA, and manage that air so that you leave the hazardous environment before your low-air warning alarm activates.” 

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 to not only 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% of the bottle is the emergency reserve air, and should only be utilized 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 allows 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 endure 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 Rule of Air Management 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 always is 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.

## FIRE OVERHAUL, REHAB, AND A COMPREHENSIVE RESPIRATORY PROTECTION PROGRAM

BY CAPTAIN PHIL JOSE  
LIEUTENANT STEVE BERNOCCO  
CAPTAIN MIKE GAGLIANO  
CAPTAIN CASEY PHILLIPS

*All contributors to this article are from the Seattle Fire Department*



**A**fter firefighters extinguish a structure fire, they typically re-enter the building to conduct overhaul activities.

During overhaul, firefighters often open up and look in the walls, ceilings, attics, and any other void space where these still-burning embers might be located. To accomplish the strenuous task of overhaul, firefighters use thermal imaging cameras (TICs), and other tools such as axes, chainsaws, and pike poles to search for hidden fire after the main body of the fire has been extinguished.

During overhaul, there may be little or no smoke, so most firefighters remove the face piece of their SCBA (self contained breathing apparatus) and work in the environment without any respiratory protection. Firefighters falsely believe that due to the reduced

amount of smoke and fire during overhaul, they are not being significantly exposed to the products of combustion. Science has proved this notion to be false. Firefighters are, in fact, routinely breathing toxic gases and being exposed to dangerous carcinogens in the post-fire environment. These products may include hydrogen cyanide (HCN), aldehydes, benzene, nitrogen dioxide (NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), polynuclear aromatic hydrocarbons (PNA), and other substances.

Recent scientific studies show that the post-fire environment may be more dangerous than firefighters realize. Based on that concept, all fire departments should have an overhaul policy that requires firefighters to wear respiratory protection throughout the overhaul phase of the fire.

## OVERHAUL AND RESPIRATORY PROTECTION

In their excellent study of firefighter exposure during fire overhaul, authors Bolstad-Johnson, et al, found that contaminants in the “overhaul atmosphere exceeded occupational exposure limits and could therefore result in adverse health effects in firefighters without respiratory protection.” In this important study, the authors found that in many fires, concentrations of acrolein, CO, formaldehyde, and gluteraldehyde exceeded exposure limits set by the Occupational Safety and Health Administration (OSHA). They also found that concentrations of coal tar pitch volatiles (PNAs) exceeded the OSHA and NIOSH limits. In other words, the post-fire environment, though there is little or no smoke present, is extremely toxic and dangerous to firefighters. The authors conclude that respiratory protection should be worn by firefighters during overhaul activities, and that the SCBA is a far better choice of respiratory protection than full-face air purifying respirators, which provide only limited protection to the firefighters as compared to the positive pressure SCBA.

Many fire departments allow firefighters to take off their SCBA during overhaul if carbon monoxide (CO) readings are below acceptable levels. However, CO levels have no correlation to irritants, other toxic gases, or carcinogens that are present in the post-fire environment. The current air monitors/gas detectors used by most fire departments do not monitor these carcinogens and toxic gases - gases like hydrogen cyanide, which is proving to be one of the most deadly compounds in the fire and post-fire environment.

To that end, the practice of allowing firefighters to take off their SCBA during overhaul should stop. Because of this uneducated and dangerous practice, too many firefighters are being injured, contracting various kinds of cancers, and suffering from respiratory illnesses.

Having firefighters wear their SCBA during fire overhaul, however, is just one piece of a comprehensive respiratory protection program.

## RESPIRATORY PROTECTION PROGRAM AND AIR MANAGEMENT

First and foremost, firefighters must



become educated about their SCBA. They must understand the limitations of the SCBA and how it functions. They must be fitted with the proper face-piece. They must be properly trained on how to use it under normal operating conditions, and how to handle a low air emergency. All of this is mandated by NFPA 1404, *Standard for Fire Service Respiratory Protection Training*.

The SCBA is widely recognized in the fire service as the biggest single improvement for firefighter safety and health. By providing a reliable supply of uncontaminated air for the firefighter operating in a highly dangerous and contaminated environment, the SCBA allows firefighters to work for extended periods while protecting their respiratory system. SCBA have improved over the years and now represent a relatively lightweight and reliable piece of equipment that firefighters should use at all times. Exposure to products of combustion is an unnecessary and therefore unacceptable risk for firefighters in the modern era. In addition, improved air management techniques and an effective work/rest interval while operating in SCBA and maintaining an appropriate margin for safety. And while a SCBA will provide a significant increase

in overall safety, there is a cost to the wearer. A complete self contained breathing apparatus 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. Each 1 kg 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.

Additionally, a comprehensive respiratory protection program must ensure that firefighters wear and use their SCBA while fighting fire. Unfortunately, there are many fire departments around the US that either do not mandate or do not enforce the policy that every firefighter must wear and use their SCBA during fires.

Another component of a comprehensive respiratory protection program should require firefighters to manage their air supply, ensuring they maintain a supply of emergency reserve air in case they run into trouble. Ideally, this reserve air must only be used in case the firefighter encounters an unforeseen emergency - it should not be

used as part of the working air for fighting the fire.

The commercial and recreational SCUBA diving industry has used the concept of air management for decades. Every SCUBA diver knows that they never breathe into their emergency reserve air unless they run into trouble underwater. In fact, dive masters expect every diver to return to the dive boat with their reserve air in tact. If they do not, and they had no emergency, those divers are deemed unsafe, and are not allowed to dive again for that day or that company. Currently, the American fire service does not enforce such stringent penalties for utilizing emergency supplies of air. It is commonplace to see firefighters working past the low-air warning whistle or bell, failing to have any air in reserve.

The last step of a comprehensive respiratory protection program is a comprehensive fire overhaul policy; a policy requiring firefighters to wear and use their SCBA during fire overhaul.

multiple units working together should do overhaul. This provides firefighters with regular rest breaks - a concept consistent with following safe work-rest intervals.

Company Officers and Incident Commanders must take all of the above into account when determining when crews must rotate through an assignment and move toward rehabilitation (rehab). Current recommended practice identifies work-to-rest intervals in terms of "30-minute" cylinder rotations for interior operations and time-based 20-minute work cycles for outside operations. Company officers or crew leaders should perform self-rehab after one "30-minute" cylinder use or 20-minutes of intense work. This rehabilitation process is informal and is most often conducted and supervised by the company officer during the SCBA cylinder exchange at the apparatus. The recommended work-to-rest interval includes 10 minutes of rest for each "30-minute" cylinder work cycle. Incident Commanders

before beginning to exit. Firefighters who use the ROAM recognize that the time to exit is before the low air alarm activates. 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 formal rehab area.

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 standard operating procedures (SOP's) 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 re-supply and stage firefighting equipment before entering the rehab area.

Departmental SOP's or trained observations of company officers may dictate when and how units are assigned to rehabilitation. Minimum standards for rehabilitation programs should include:

- **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 re-assignment 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**

#### An overhaul policy must have a few important pieces to make it work.

- **First, there should be an air support unit on scene.** Fire crews will be breathing through many SCBA cylinders during overhaul, so the air unit must be there to refill or replace empty cylinders in a timely fashion.
- **Next, firefighters should follow the ROAM** (see the preceding article entitled "Air Management on the Fireground: The Need - The Mandate - The Solution" for more details on the ROAM) concept during fire overhaul.
- **Finally, firefighters should ensure they are out of the hazardous environment before their low-air warning alarm activates.** Again, this gives firefighters a safety margin should they become trapped or lost in the structure.

Since overhaul is can be more physically demanding than extinguishing the initial fire, there should be more firefighters on scene to share in the overhaul workload. Overhaul operations should also include mandatory rest breaks for firefighters, providing personnel time to cool off and hydrate. Safe work-rest intervals should be observed, since overheating, dehydration, and fatigue will all be working against the firefighters performing overhaul. The practice of leaving one unit on scene to perform fire overhaul should be discontinued -

must be able to forecast incidents where rehab will be needed beyond the company level and establish a formal rehab area early.

Industry accepted standards for the "30-minute" cylinder work interval may also be extended to the "45-minute" cylinder if air management is practiced in accordance with the Rule Of Air Management (ROAM). Firefighters who follow the ROAM will have work cycles that closely match those of firefighters operating in "30-minute" cylinders while working in the hazard area until the low-air alarm activates

- 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. 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
- The company officer recognizes the company needs to move to the rehab area at any time
- The incident commander assigns the company to 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. Personal Protective Equipment (PPE) should be removed and SCBA should be re-supplied with full cylinders. The company should then be given an initial medical screening by assigned EMS personnel in accordance with department SOP’s. This initial evaluation should include:

- Symptoms of dehydration
- Heat/Cold stress
- Physical exhaustion
- Cardiopulmonary abnormalities
- Emotional/mental stress or exhaustion

## FINAL THOUGHTS

Fire overhaul is necessary to assure that the fire is out and will not rekindle. However, the post-fire environment is dangerous due to irritants, toxic gases, and carcinogens in the atmosphere. Firefighters must wear their SCBA during this overhaul phase of firefighting to protect them from breathing in these harmful compounds. Fire departments must adopt a comprehensive respiratory protection program that mandates the wearing and use of SCBA during all phases of the fire and adheres to safe and effective air management practices.

# SMOKE ASSOCIATED CYANIDE EXPOSURE:

## THE IMPORTANCE OF PROMPT RECOGNITION AND PROTOCOLS FOR PREHOSPITAL TREATMENT

BY JAMES AUGUSTINE, MD AND DONALD W. WALSH, PhD, EMT-P

*James Augustine, MD, is an emergency physician from Atlanta and the Director of Clinical Operations for EMP Management. He serves as Medical Director for the Atlanta Fire Department, which includes operations at Atlanta Hartsfield Jackson International Airport, and is on the Clinical Faculty in the Department of Emergency Medicine at Emory University. He has served 25 years as a firefighter and EMT-A.*

*Donald W. Walsh, PhD, EMT-P is the Assistant Deputy Fire Commissioner for the Chicago Fire Department’s Emergency Medical Services Division. Dr. Walsh is also President of the Cyanide Poisoning Treatment Coalition. Dr. Walsh is a Fellow of the Chicago Institute of Medicine, and Adjunct Faculty at the US Department of Homeland Security’s National Fire Academy.*



## INTRODUCTION

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 citizens and firefighters die as a result of inhalation of products of combustion from fire. Cyanide may contribute significantly to these deaths. 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. Studies in Paris have also been illuminating regarding the role of cyanide in fire death. The blood cyanide levels from 66 fire victims who survived and 43 fire victims who died in fires in the environs of Paris were compared with those from 114 control individuals who had not been exposed to cyanide. Mean blood cyanide concentrations in both groups of fire victims substantially exceeded those in the control individuals. Cyanide concentrations in fatalities were more than three times higher than concentrations in smoke inhalation victims who survived. Blood cyanide exceeded levels that are potentially lethal (i.e., 1 mg/L) in the group of victims with fatal outcomes but not in the group that survived. Co-exposure to carbon monoxide and cyanide was frequent. Elevated levels of both compounds were found in many victims.

Cyanide poisoning can be treated effectively if it is recognized promptly and if intervention is initiated immediately. In this context, it is important that prehospital providers recognize 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 allowing cells to utilize oxygen. Because cyanide-poisoned cells are unable to use oxygen, they transition from aerobic metabolism to anaerobic metabolism and generate toxic byproducts such as lactic acid. The buildup of toxic byproducts of anaerobic metabolism ultimately breaks down the cell. 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 hyperpnea 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. Later manifestations of exposure are cardiac arrhythmias, 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 short time available 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 prehospital 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 concurrent 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 lack the ability to smell this odor, so the prehospital provider's failure to detect an almond odor does not reflect the absence of cyanide poisoning.

Even at the hospital, rapid measurements of cyanide are not available. Therefore, 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 byproduct of anaerobic metabolism**
- **Elevated oxygen content of venous blood caused by failure of cyanide-poisoned cells to extract oxygen from arterial blood**
- **Minimal elevation of carbon monoxide by blood tests or use of the transcutaneous monitor**

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. Detection of carbon monoxide poisoning can be accomplished with the transcutaneous carbon monoxide meter. 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

- |                     |               |
|---------------------|---------------|
| • Drowsiness        | • Headache    |
| • Impaired judgment | • Dyspnea     |
| • Anxiety           | • Tachypnea   |
| • Vertigo           | • Tachycardia |

### Inhalation of Moderate to High Concentrations

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

**Table 2. Manifestations of Carbon Monoxide Poisoning**

**Low Inhaled Concentrations**

- Fatigue
- Difficulty with balance
- Headache
- Palpitations

**Manifestations of Exposure to Moderate to High Concentrations**

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

**BASIC AND ADVANCED LIFE 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% oxygen; and assuring appropriate ventilation. Nebulizer treatment with a bronchodilator may be given for wheezing. The suspicion of acute cyanide poisoning should prompt the prehospital provider to initiate antidote therapy. The use of antidotes is discussed in the next article written by J.L.Fortin.

Advanced life support care includes anticonvulsants for seizures. The motor activity associated with seizures can aggravate acidosis. Victims with heart disease may develop significant dysrhythmias, so antiarrhythmics should be administered to stabilize cardiovascular function. Shock is treated with fluids and prevention of hypothermia. If the victim has indications of severe acidosis, sodium bicarbonate may 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 to 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. Most local protocols consider significant burns as the priority treatment con-

sideration, so a patient with more than 10% full-thickness burns, respiratory burns, or more than 27% partial-thickness burns are preferentially taken to the adult or pediatric burn treatment hospital. Not all hospitals are prepared and equipped to manage minor burns, moderate inhalation, and cyanide poisoning. When in doubt, on-line medical control should be contacted and their assistance requested in determining the correct destination hospital.

**PROTOCOLS FOR PREHOSPITAL 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 efficiently evaluated and intervention is promptly provided, it is essential to have protocols in place for prehospital 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 expedient evaluation and treatment!

**Patient Evaluation**

The patient should be removed to an area safe for their evaluation and

management. The key elements of 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 sustained burn injury or other severe or critical traumatic injury should be given treatment specific for those elements. In addition, the 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 inhalation, the pulse oximeter alone can produce an incorrect reading as the machine does not assess the percent of hemoglobin affected by carbon monoxide or cyanide. A reading below 90% 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% reflects moderate carbon monoxide inhalation, and one exceeding 25% 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 and carbon dioxide removal.

**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 history regarding the patient's 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 carbon monoxide oximeter reading. Victims with carbon monoxide levels exceeding 25% 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.
- 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 the position of comfort.
- 5) If the airway is compromised or injured, the patient should undergo endotracheal intubation. If unsuccessful, a secondary device can be inserted.
- 6) Provide supplemental oxygen. Most victims with an inhalation injury do not tolerate dry oxygen; therefore, the oxygen line should have a nebulizer placed in-line 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 lung evaluation or if the patient has a history of asthma or wheezing, administer nebulized albuterol. The nebulizer should have 2.5 mL of Albuterol placed in it and then be 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 2 ampules of albuterol in the cup, fill the rest of the cup with saline, and allow the patients to self-administer the mixture by mask.
- 9) Victims with mild to moderate smoke inhalation may be treated and released. To allow the victim to release himself or herself from care, the following conditions must be met:
  - a. Mental status unimpaired or back to baseline for that individual (with verification by a friend or family member)
  - b. No signs of respiratory distress with a pulse oximeter reading above 92%
  - c. Lungs clear on auscultation
  - d. No other significant burn or traumatic injury
- 10) Victims with more severe smoke inhalation are transported to the hospital.
  - a. For patients requiring hospital removal, appropriate treatment should occur in conjunction with the transport agency, and the patient should be turned over for further assessment and interventions.
  - b. Symptoms of carbon monoxide poisoning require the crews to consider removal of the patient to a hospital that has a hyperbaric oxygen treatment capability. Evidence of carbon monoxide poisoning includes impaired mental status, neurologic compromise including seizures, and a carbon monoxide reading over 25%.
  - c. Major burn injuries get precedent in the determination of a receiving facility. A significant burn injury (generally, any burn over 10% full thickness, a respiratory burn, or a burn over 25% partial thickness) requires transport to the appropriate adult or pediatric burn center.

### 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 prehospital setting. By recognizing cyanide poisoning and efficiently initiating corrective measures according to protocol, the fire professional can save lives.

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Photo: Steve Redick

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## ACUTE CYANIDE POISONING:

### A PARIS FIREFIGHTER RECOVERS FROM SEVERE SMOKE INHALATION

BY J.L. FORTIN, *Emergency and Intensive Care, Military Hospital Legouest, Metz, France*  
S. WAROUX, *Emergency Medical Service, Fire Brigade, Paris, France*  
A-M ARVIS, *Emergency Medical Service, Fire Brigade, Paris, France*  
JP GIOCANTI, *SAMU 25, J. Minjoz Hospital, Besançon, France*  
C. FUILLA, *Emergency Medical Service, Fire Brigade, Paris, France*  
D. WALSH, *Medical Service, Chicago Fire Department, Chicago, USA*  
M. RUTTIMANN, *Emergency and Intensive Care, Military Hospital Legouest, Metz, France*  
M. ECKSTEIN, *Medical Service, Los Angeles Fire Department, USA*



Photo: Rob Schnepf

### EDITORS FOREWORD

**T**he following case study chronicles the exposure and subsequent treatment of a Paris firefighter suffering from smoke inhalation. It underscores a common exposure scenario for firefighters the world over: getting lost or trapped inside a structure fire and running out of air. The outcome in this case was favorable. However, the case illustrates the need in the US prehospital arena for a safe and effective antidote to counteract the effects of hydrogen cyanide, one of the most deadly fire gases.

During the last several years, firefighters in the United States have spent countless hours on rapid-intervention training. Today, almost every fire department in this country has incorporated the concept of “backing up” interior firefighters with a group of rescuers outside the structure, tasked solely with the mission of locating and rescuing firefighters who become trapped, disoriented, or lost inside the fire building. While the training and equipment used for rapid intervention and/or firefighter rescue helps in

removing the downed firefighter from the toxic environment, they do not counteract the toxic and potentially lethal effects of smoke inhalation. To that end, the medical management of



Photo: Rob Schaepp

smoke inhalation victims must be more fully addressed by the American fire service. This case study sheds light on possible means of improving care for smoke inhalation victims.

The US Food and Drug Administration is evaluating hydroxocobalamin as an antidote for acute cyanide poisoning. Hydroxocobalamin, a precursor to vitamin B12, is a relatively benign substance with minimal side effects, properties that make it well suited for use in the prehospital setting. Its mechanism of action is simple: hydroxocobalamin binds to cyanide to form vitamin B12 (cyanocobalamin), a non-toxic compound excreted in the urine.

Hydroxocobalamin (Cyanokit®) is used by the Paris (France) Fire Brigade as a prehospital antidote to treat suspected cyanide poisoning from smoke inhalation and other sources of cyanide exposure. 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 worse. The Paris Fire Brigade routinely administers Cyanokit® to smoke inhalation patients and has collected compelling data regarding its effectiveness. From 1998 through 2002, the Paris Fire Brigade retrospectively evaluated the prehospital use of hydroxocobalamin.\* During this time, 81 victims (41 males and 40 females) were treated for suspected cyanide poisoning from smoke inhalation. The

study focused 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 patient sfound in cardiac arrest, 18 recovered for a survival rate of 62.1%. The average time between administration of antidote and recovery of spontaneous cardiac activity was 19.3 minutes. Four patients recovered without sequelae. In the subgroup of 15 patients hemodynamically unstable before the Cyanokit® was administered, 12 patients (80%) showed hemodynamic improvement, defined as systemic arterial blood pressure exceeding 90 mmHg. The average time to hemodynamic improvement was 49.2 minutes from the beginning of antidote infusion and 28.8 minutes from the end of infusion.

In France, Cyanokit® comes with 2 vials of hydroxocobalamin (each containing 2.5 g of red powder). The powder is reconstituted with 100 mL of normal saline per vial, infused into the patient over 15 minutes.

\* 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.

## INTRODUCTION

In France, patients suspected of having acute cyanide poisoning from sources such as smoke inhalation or ingestion of cyanide salts are treated with hydroxocobalamin (Cyanokit®)<sup>(1,2,3,4)</sup>. This antidote has been used in prehospital care by various French emergency medical services, particularly the emergency medical service of the

Paris Fire Brigade. This case report describes a Paris firefighter who suffered acute cyanide poisoning and was treated with hydroxocobalamin with a favorable outcome.

## CASE REPORT

### Prehospital phase

A 31-year-old firefighter responded to the scene of a store fire on January 6, 2006. The firefighter, who carried a self-contained breathing apparatus, was trapped in the fire, and the air in his unit ran out. After some delay, he was found unconscious at about 11:40 AM.

When he was rescued, he was seen by the doctor on board the rescue ambulance at about 12:04 PM (In Paris, some rescue ambulances are staffed by paramedics and a physician). The patient was initially unconscious (Glasgow score = 3) and bradypneic (respiratory rate less than 10 per minute, with a blood pressure of 110/70) with elevated blood pressure (110/70 mmHg), tachycardia (120 bpm), and arterial hypoxia (93% with administration of 15 liters oxygen/minute). The first electrocardiogram showed no signs other than sinus tachycardia. There was no myocardial repolarization disorder.

Initial management consisted of endotracheal intubation after anesthesia (40 mg Ethomidate and 100 mg Celocurine injected intravenously). Endotracheal intubation revealed massive inhalation of smoke from the fire with a substantial quantity of soot in the oropharynx. Maintenance anesthesia was done with Midazolam 7 mg/hour and Sufentanyl 15µg/hour. The patient was administered 10 g hydroxocobalamin (Cyanokit®). The following Table shows clinical parameters after hydroxocobalamin administration:

Clinical parameters after hydroxocobalamin administration

	12:15 PM	12:30 PM	12:40 PM	1:00 PM
<b>Glasgow</b>	3	3	3	3
<b>Pulse</b>	110	110	74	72
<b>Blood pressure</b>	120/80	110/70	110/60	120/80
<b>SpO2</b>	93%	96%	97%	97%
<b>Cyanokit®</b>	5g		5g	



Photo: Rob Schnepp

### Hospital Phase

The patient was admitted to the intensive care unit (ICU) of the Val-de-Grâce military hospital at 1:10 PM, or 1 hour after the start of prehospital treatment. When he arrived at the ICU, the patient was intubated, with artificial ventilation (FiO<sub>2</sub> = 100%). Sedation with Midazolam and Sufentanyl was continued. Opening of the eyes and mobility of all four limbs after pain stimulation was noted. Blood pressure was normal. A superficial second-degree burn of the left knee and calf was noted.

The first laboratory tests showed metabolic acidosis with pH 7.20 associated with hypercapnia (PCO<sub>2</sub>=51.7 mmHg). There was no hypoxia: the pO<sub>2</sub> was 527 mm Hg (FiO<sub>2</sub> = 100%). Carboxyhemoglobin was 7.8%. Lactates were 3 mmol/l. The initial lab tests showed no myocardial dysfunction with the troponin level at 0.03. There was muscular rhabdomyolysis with elevated creatinine phosphokinase (CPK = 1629 UI/l) and myoglobin at 5421 UI/l. No other lab tests were abnormal. The second electrocardiogram, done on arrival in the ICU, showed sinus rhythm with no conduction or repolarization disorders.

The patient was given a hyperbaric oxygen session at 2.5 ATA for 1 hour. Bronchial fibroscopy, done after the hyperbaric chamber, showed substantial inhalation of smoke with soot present throughout the tracheobronchial tree.

On Day 2 (January 7, 2006), sedation was withdrawn. The patient woke up quickly, and the breathing tube was removed. The level of consciousness was normal (Glasgow = 15), and there was no sensory or motor deficit.

No respiratory distress was observed. Pulmonary auscultation revealed rales at both bases and productive coughing continued with blackish expectoration. However, the patient did not need oxygen.

The patient was apyretic with white cells 14,000 /mm<sup>3</sup>. C-reactive protein was high at about 130. Burns were dressed with Flammazine® and compresses. In an attempt to prevent posttraumatic stress disorder in this firefighter, a psychiatric session was conducted. Two days later, the patient was moved from the ICU to the Medical Department.

### DISCUSSION

Early administration of hydroxocobalamin, even before arrival at the hospital, gave favorable results for this firefighter who fell victim to severe cyanide intoxication from smoke inhalation. Hydroxocobalamin administration was based on circumstantial evidence of cyanide poisoning (fire, enclosed setting) and clinical observation (coma, bradypnea). Because of the urgency of the situation, it was not possible to draw blood to test lactates<sup>5</sup> and get prehospital lab confirmation before administering the hydroxocobalamin or subsequent lab confirmation by measuring blood cyanides.

This case report suggests that hydroxocobalamin administration must be rapid - done by the first aid or paramedical team based on clinical or circumstantial criteria. Hydroxocobalamin, which is a vitamin B12 derivative, has no major adverse effects at the doses normally in use<sup>6</sup>. The risk of acute cyanide poisoning is exceptional for a firefighter and should be borne in mind by fire and emergency services.

### CONCLUSION

Thermal Burns and smoke inhalation are major occupational hazards for any firefighter. This case illustrates the importance of having an antidote on hand for rapid administration at the fire or accident scene. It is desirable for fire and emergency services to have a cyanide antidote in their pharmacopoeia.

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**T**he Cyanide Poisoning Treatment Coalition is a 501(c)(3) non-profit made up of organizations and individuals who have direct involvement with the identification and treatment of cyanide exposure. Currently, there are few resources that raise awareness and educate professionals about the potential danger of cyanide exposure. Through joint strategic initiatives to focus the required attention and resources on the issues, the members of the CPTC aim to increase awareness surrounding the dangers of cyanide exposure. For more information on cyanide poisoning, how to obtain a CPTC membership application or become a sponsor, please visit the Coalition website at [www.cyanidepoisoning.org](http://www.cyanidepoisoning.org).