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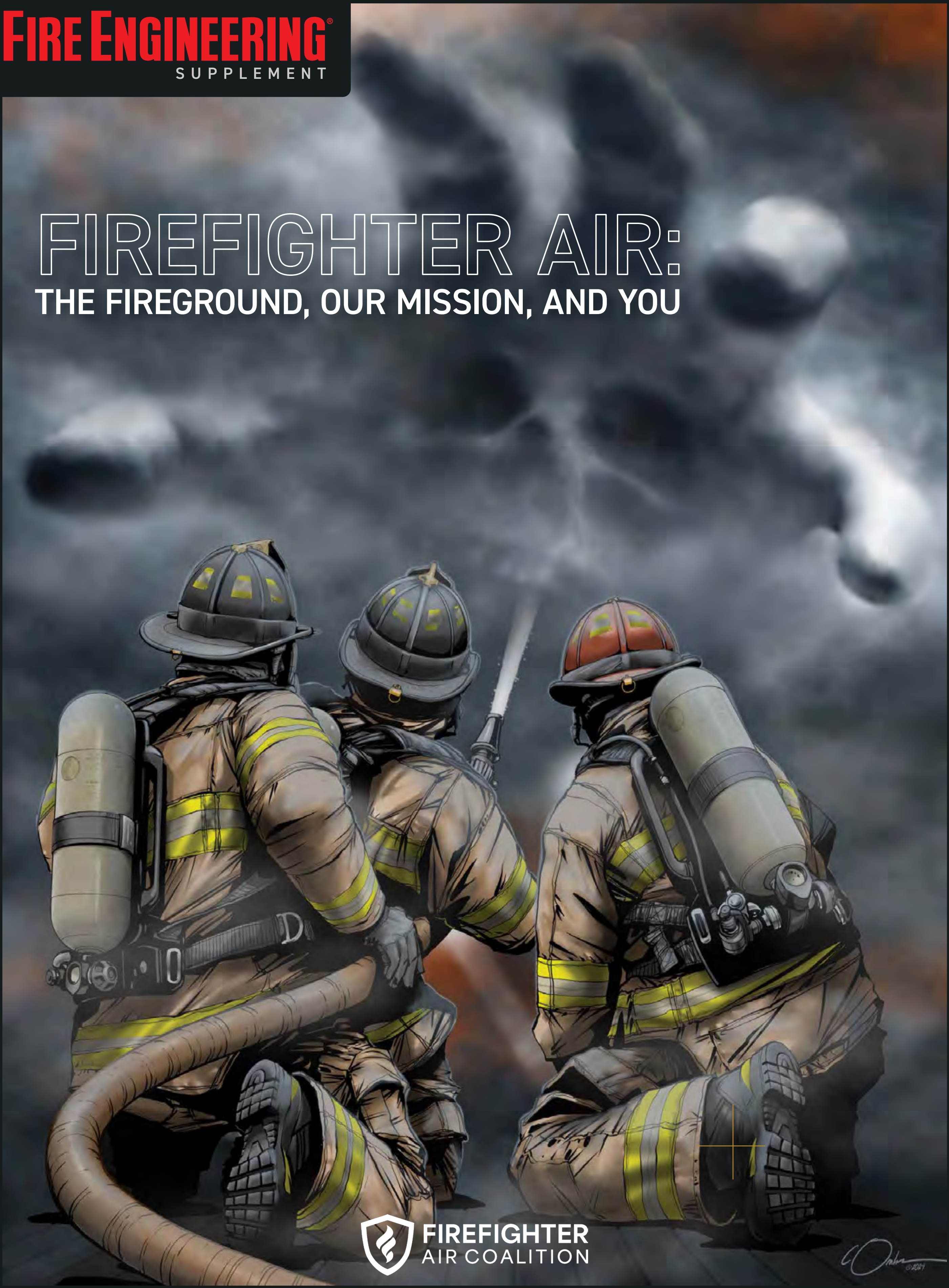
FIRE ENGINEERING®
SUPPLEMENT

FIREFIGHTER AIR:
THE FIREGROUND, OUR MISSION, AND YOU



FIREFIGHTER AIR COALITION

ILLUSTRATION BY PAUL COMBS

Message from Firefighter Air Coalition President Mark E. Fessenden

We believe in the value and importance of firefighter air and the essential role it plays in allowing firefighters to enter hazardous environments, mitigate emergencies, and save lives.

Our mission is centered around four key areas that are included in any conversation about firefighter air:

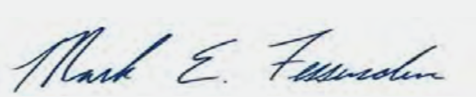
- Air management.
- Fire smoke/firefighter cancer and illness.
- Technology.
- Fire science/research.

The Firefighter Air Coalition (FAC) strives to create educational content and resources that provide cutting-edge information to improve the fire service. We also search for great work that is already being done by other organizations or individuals and highlight that work, providing a platform for groundbreaking training wherever it may be found.

This supplement includes training modules to support the FAC's entire mission from some of the most respected instructors in the world. It showcases ideas and insights that will make your department, and the individuals who serve there, better able to navigate the challenging environment of today's fireground—and perform at a high level with speed and efficiency in the safest manner possible.

I am privileged to share this material as an example of the quality and commitment you can expect from the FAC moving forward. Our team hopes you find the information compelling and will join us in our efforts to elevate firefighter air training to the level of importance it, and you, deserve.

We are honored to be at your side.



MARK E. FESSENDEN
FAC PRESIDENT

Air Management: Then and Now

BY **MIKE GAGLIANO**

AIR MANAGEMENT is going to make a huge impact on your life. Once you accept the calling of being a firefighter, there is every expectation that you will put your own well-being at risk to save others and resolve their emergencies. Those emergencies will often involve hazardous atmospheres that are toxic and carcinogenic and that will asphyxiate. The air you bring to these emergencies is what allows you to enter, work, and exit—or at least, let's hope you can exit, right?

I am among the many in the fire service who have devoted considerable effort to understanding firefighter air and the many things involved in making it work. Three good friends and colleagues—Phil Jose, Steve Bernocco, and Casey Phillips—and I pursued a change in the way air was managed on the fireground. There are many chapters to that story, but I want to take you back to a specific time when the importance of air management was starting to gain traction.

In March 2008, Fire Engineering Books published *Air Management for the Fire Service*. It was a labor of love for my three buddies and me, and our hope was to elevate the importance of air and create a solid guide to better use of that air. There had been many articles written prior to the book being published, but now those ideas were in a textbook. That book succeeded on a scale we could not have imagined. *Air Management for the Fire Service* became the standard text on the subject and influenced significant changes in the National Fire Protection Association (NFPA) standards and standard operating procedures (SOPs) for fire departments around the world.

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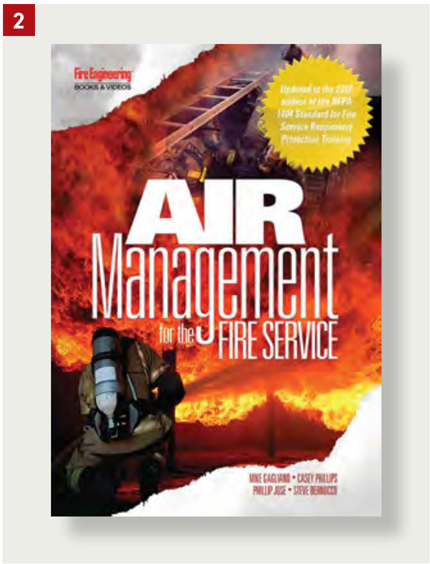

2. *Air Management for the Fire Service.* (*Photo courtesy of Fire Engineering Books*).

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1. Photo by John Odegard.

3. *Out of Air* training video by the Firefighter Air Coalition (youtu.be/vElW2vlQbDw). *(Photo courtesy of Firefighter Air Coalition.)*

In April 2014, the Firesmoke Coalition debuted a video that is still being used all over the world: *Out of Air*. This air management training resource included the wisdom of some of the finest minds in the fire service including the late Bobby Halton, the late Alan Brunacini, John Norman, and John Mittendorf. A host of other influential leaders also contributed to what became a dynamic presentation on the importance of air management and the devastating effects of doing it wrong.

Like most good sources of information or training, the ideas presented during that era can now be scrutinized with the passing of time. And, I'm happy to say, the majority of the information presented holds up just as strongly today as it did when it was published. This article intends to look at what still applies today and what are some areas that need more attention or focus.

Then

The effort to change the way air management was done in the Seattle (WA) Fire Department began with the realization that how we were managing air was causing problems on the fireground. In the fire service, "problems on the fireground" usually result in injuries, "close calls," Maydays, and deaths. We were experiencing those issues in increasing numbers even though Seattle Fire was a progressive, well-trained fire department.

Three incidents occurred close together, in very different types of occupancies, that almost cost us the lives of solid, veteran firefighters. These fires occurred in a typical residential basement fire, at a mixed-occupancy/taxpayer hotel, and on a large ship. Different variables, different personnel, same outcome: firefighters getting lost, disoriented, running out of air, and coming close to perishing in the fires.

These three events coincided with the horrible loss of Pheonix (AZ) Fire Department Firefighter Brett Tarver at the Southwest Supermarket Fire. At the conclusion of the review of that fire, the late Chief Alan Brunacini was the first leader to declare the need for a departmentwide air management policy.

We heard those words and set about the task of answering that call.

The Rule of Air Management (ROAM)

The result of a significant amount of training and research led to the development of the Rule of Air Management (ROAM). The ROAM was intended to be a basic approach to air management that could be implemented by fire departments no matter their size or makeup. The concept did not require changes to the equipment being used or the purchase of expensive technology or gadgets. The ROAM was meant to be simple, trainable, and effective. It still stands today as the model for how air management should be done.

The ROAM simply says: "Know how much air you have in your SCBA and manage that air so you leave the hazardous environment before your low-air warning alarm activates." In the simplest of terms, this means the following:

- Know what you've got prior to entry.
- Manage it as you work.
- Leave before your bell hits.

All these years later, your fire department will experience the same thing Seattle Fire did when it fully implemented and trained the ROAM: Out-of-air emergencies disappeared. Those that did occur were of the kind that were primarily unavoidable or because policy was violated. I don't mean to oversimplify the reality here, but if you want to impact your firefighters and keep them from running out of air, simply train and require adherence to the ROAM.

NFPA 1404, Standard on Fire Service Respiratory Protection Training

Further strengthening of air management success came from the hard-working folks on the NFPA 1404 committee. The committee sent representatives to some training sessions we were conducting and they came away with a steadfast commitment to making changes. Those changes would be the addition of the following to NFPA 1404: All fire departments SHALL have an air management program and that program SHOULD contain the following requirements:

- Firefighters shall exit from an IDLH environment before consumption of emergency reserve air begins.
- Firefighters shall recognize that the low air alarm notification, or end-of-service-time indicator (EOSTI), indicates they are consuming their reserve air supply.
- Firefighters and the team should take immediate action on activation of the reserve air alarm (EOSTI) and shall follow their department's SOPs.

These changes to the standard required an air management program. In this version, it was recommended that other steps be taken, but they were not required. Fortunately, subsequent editions of NFPA 1404 were greatly impacted by the success departments were having when implementing the ROAM.

In the current version, NFPA 1404—2018, all the above are now REQUIRED to be trained on and performed. What that means as we look forward is that all leaders in the fire service must have an air management program that mandates all members do the following:

- Leave the IDLH environment BEFORE their bell hits.
- An alarm activation indicates a firefighter is now using his emergency reserve air.
- An alarm activation requires immediate action based on department SOP.

A significant part of the mandate came from a simple review of NFPA line-of-duty deaths (LODDs) in structure fires and evaluating the impact "running out of air" was having on those statistics. The following was observed: Deaths in Structure Fires

2000-2009: 138 total, 78 due to asphyxiation (primary cause). Those numbers were compelling when compared with the more obvious causes such as burns or collapse injuries. They made us want to make a huge dent in the total numbers and impact individuals to do better no matter what their level in the organization.

As we look at the results of our work and where we're headed in the air management world, the history above provides an important set of guideposts.

Now

As part of a training program I did in 2021, the LODDs from asphyxiation at structure fires were reviewed. Since our original statistics were from 2000-2009, I reviewed the statistics from 2010-2019. This was the next 10-year stretch that encompassed the expansion of air management getting the attention it deserved and many departments implementing the new 1404 requirements. While further study of the data is needed, here is what an overview of the NFPA numbers looked like:

- Deaths in Structure Fires 2010-2019: 156 total, 56 due to asphyxiation (primary cause).
- Approximate 20% decrease from 2000-2009.
- There were 22 fewer deaths despite the overall death rate rising by 18.

There can certainly be many statistical factors that contribute to a 20% decrease in firefighter deaths. It is not much of a stretch, however, to see that focus on doing better with our air at fires has had a significant impact. And these numbers do not take into account the reality that not every fire department is diligent in air management practices. I would simply ask you to look back to what the NFPA requires and determine whether your department is operating in accordance with accepted professional standards. Imagine what the decrease would be if everyone followed the standard.

We at the Firefighter Air Coalition want to imagine that, and we want to look forward to how we can improve on what has come before and decrease the percentage of LODDs due to asphyxiation as well as longer-term deaths due to cancer and respiratory illness. Many elements are in view here, but let's just highlight a bit of the old stuff along with some new tools and training that could make a huge impact.

Air Management Program

In both the regulatory requirements and professional obligations of leadership, there should not be a single fire department in existence that does not have an effective air management program that is trained on and implemented. None. There are numerous resources and training examples to get this done. As a foundational component of "not running out of air," you will not be effective without a legitimate program. And our numbers will not get better until you are determined to ensure your department has the best program possible.

Emergency Reserve

Of all the strategies we'll consider, I believe this one will be the most impactful, and it's the easiest one to implement: Stop allowing your firefighters to use their emergency reserve air for normal operations. Except in the case of unusual events, such as a Mayday or imminent rescue, the emergency reserve should be kept for the wearer of the SCBA. Just like it is for every other industry that uses an SCBA—the dive industry, mining, and other commercial applications—DO NOT allow the misuse of that reserve air.

We have covered this in great detail in our book, and it all still applies. Very simply, mandate your firefighters get out before their bell hits. That would so dramatically decrease the instances of firefighters running out of air, as the primary reasons for doing so would disappear. Having your reserve intact allows for the following:

- You have the air needed to make good decisions when you're disoriented, trapped, or hurt.
- There is a baseline to aid decision making on exiting, completing an assignment, or taking on a new one.
- Rapid intervention teams would have reflex time to get much-needed air resupply and rescue to you if you get in trouble.
- Communications would be "on air" and not struggling against a hot, smoky environment.

It is a reasonable standard to have two-thirds of the bottle devoted to actual work. In the super majority of scenarios you will encounter on the fireground, that should be the expectation. The current statistics indicate that far too many departments, and department leaders, have neglected enforcing the NFPA 1404 mandate, which has dramatically reduced the effectiveness of air management success.

Fitness

The recent increase in awareness and proactive training in firefighter fitness is a welcome shift. That emphasis will have significant impacts on air management programs as a force multiplier of everything else that needs to happen.

Effective utilization of the air you do have will be enhanced. Confidence in physical ability to perform will lead to less stress and more focus. Physiological breakdowns will occur at a decreased rate due to better respiratory ability, muscle/bone health, and circulatory efficiency.

Firefighter fitness should be an organizational and cultural mandate for the department and each of its members. It may be necessary to exceed what your department requires, depending on the leadership. I recommend, as a starting point, seeking training from sources like the following:

- Fit To Fight Fire (John Spera): facebook.com/fittofightfire1.
- O2X Human Performance: o2x.com.
- Ironclad Wellness (Jason Corthell): ironcladwellness.com.
- Firefighter Functional Fitness (Dan Kerrigan/Jim Moss): firefighterfunctionalfitness.com.

Whatever avenues you choose, getting going is key. The impact will be immense.

Breathing Techniques

In our book, we made a solid effort to highlight the best breathing techniques research that was available to us at the time. That research has expanded dramatically in the years since and is a recommended area of focus to aid your air management program. Two great resources to study some options are *Developing Firefighter Resiliency* (Jorge, Gillespie, Carpenter/Fire Engineering Books) and *Breathing for Warriors* (Vranich/Sabin-Macmillan Publishing). In these, and other similar resources, you'll find solid research and training on breathing techniques that can aid your efforts to maximize your air consumption rate. Gaining efficiency in breathing allows for more work, focus, and quality decision making. Those improvements will dramatically impact utilization of firefighter air and decrease the likelihood that you'll be an "out of air" statistic.

Most trainers and subject matter experts I've talked to have a consistent piece of advice when it comes to deciding what technique to use: "Use the one you're most comfortable with and trained on." I agree, and that is my experience. Here are a few to consider and try out. Each comes with its own benefits and possible deficits. Try them out and get comfortable with the one that works for you. Then, practice and practice some more, using it at all emergencies, to achieve unconscious competence. Here are a few to consider:

- Reilly Emergency Breathing Technique (REBT)/Hum Breathing.
- Box Breathing.
- Count Breathing.
- Skip Breathing.
- Straw Breathing.

Technology

Technology has many positives it can bring to our goal of doing better at decreasing the bad days. It remains true today, as it did when we wrote our book, that your air is your responsibility:

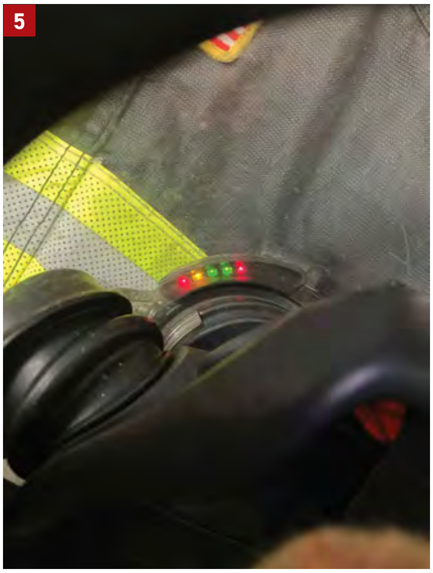
- You must monitor your air.
- You must make good decisions about when it's time to leave.
- You must train to a standard of excellence and tactical proficiency with your equipment and your skill set.

Once that is established as a baseline requirement, we can then have a productive conversation about how technology may help.

Emergency Breathing Support System (EBSS)

Buddy breathing was certainly around when we started looking at air management. It was a cruder form of sharing a mask/regulator or giving a portion of your bottle to a teammate with a transfill hose. Technology has provided a much more effective method in the EBSS that is standard on modern SCBA. And the EBSS is an effective method of helping a fellow firefighter who is low or out of air leave the hazardous area or buy vital time until help arrives.

Like all aspects of our equipment, your effectiveness with EBSS will be directly related to the amount of time you spend training on it. NFPA 1404 is clear in its mandate that you are expected to train regularly on EBSS as part of your SCBA/air management program, and that recommendation is warranted. It is difficult to recreate many of the variables that are likely to be present when the need for true buddy breathing is necessary—superheated environments, thick smoke, injured or disoriented firefighters desperate for air, and more. This is all the more reason to get your mask on, hook up to actual firefighters, and try to move around. Do the connections in limited and zero visibility or with limited movement scenarios. The key is to be so fluent in your knowledge of how to use EBSS that the other variables do not cause errors that could be deadly. Used correctly, it can be the difference between running out of air and surviving the incident.



4. EBSS allows for buddy breathing. *(Photo courtesy of Firefighter Air Coalition/Shur-Sales & Marketing-Fire Division.)* **5.** Heads-up display lights (the second red light is a battery indicator). *(Photo courtesy of Firefighter Air Coalition/Shur-Sales & Marketing-Fire Division.)*

Heads-Up Display (HUD)/ Emergency Air Indicator

Another change to our SCBA is the development of HUD capabilities that continue to advance with each new iteration of the equipment. This is a good thing and has great potential as the accuracy and elements of the HUD are developed. The specific details of what they can and cannot do are critical. The HUD can give you a visual cue of what your air consumption looks like, but those cues come with qualifiers. There are various configurations, but the most common is a series of four lights that flash to indicate how much air you have left in your bottle. Typically, it follows this pattern:

- Two green lights: full.
- One green light: 75%.
- One yellow light: 50%.
- One red light: 33% (emergency reserve).

Simple enough to follow, right? But, is the above actually true as it pertains to the actual amount of air you have? That is a critical indicator, and you want to make sure you're getting it right. And that's where the lesson lies in fully understanding what the technology is actually doing and telling you.

In fact, the lights indicate a range of actual air percentages, and those gaps are no small thing. Those ranges are essentially as follows:

- Two green lights: full to 75%.
- One green light: 75%-50%.
- One yellow light (flashing): 50%-33%.
- One red light (flashing): 33% to empty (emergency reserve).

There is a world of difference when your light is flashing yellow and you think you have half a bottle when, in reality, your low-air alarm is about to go off. Knowing it is simply a range will then cue you to check your gauge. That's the only true

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6. FARS: Firefighters connect to the Emergency Fill Panel and get a second bottle without having to go "off air" or remove their masks. *(Photo courtesy of Firefighter Air Coalition.)*

way to know what your bottle has and allows for the best decisions related to air management and remaining time. This is true for any aspect of the HUD that may be available now or in the future. Know what the technology is truly indicating or doing, and then it can provide a great benefit.

Firefighter Air Replenishment System (FARS)

It is an established fact that firefighters need air and water to put out most fires, especially if there is going to be an interior attack, which is required for most fires that are not going to be defensive in nature. It has always been challenging to get air to firefighters in large structures due to the distance and logistical challenges present.

FARS is a solid answer to the question of getting air nearer to the fire attack and enabling firefighters to stay close to where their operations are happening. It has been around for 25-plus years but is now getting more popular with its addition to the fire code.

FARS is simply a standpipe for air. Just like a water standpipe delivers water from the street to distant locations in the structure where it's needed, FARS does the same for air. Air flows through fixed piping within the building to fill stations in the stairwell or hallways, and firefighters can refill without having to remove their SCBA. The reflex time saved will have a significant impact on the efficiency and success of operations in high-rise, big box, and tunnel emergencies.

It's tough to manage air when you don't have any air to manage. FARS is a much better option than hauling bottles up the stairs or relying on elevators that often fail. And, in the best-case scenarios, stairs and elevators are time consuming, personnel-intensive, and laborious operations that typically result in "later-stage" air resupply.

"NOW" Depends on YOU

I have taken you through the history of modern air management and some of its successes and failures. We've looked at some areas that could enhance our numbers and decrease out-of-air occurrences and the subsequent line-of-duty injuries, illnesses, and deaths. And we have reaffirmed that your air is your responsibility. There is one last, critical step to take: It's time for you to get serious and lead.

At your level, whether high in the organization or just getting on the job, you can prioritize your commitment to training in air management practices. You can implement most, if not all, of the above recommendations into your SOP. You can be a messenger to those around you that air is going to play a critical role in success on the fireground and the long-term career of firefighters. All that we've covered will enable you to take action and make your department better and more effective.

The Firefighter Air Coalition and *Fire Engineering* are honored to stand at your side to make it happen. ■

MIKE GAGLIANO has more than 33 years of fire/crash/rescue experience with the Seattle (WA) Fire Department and the United States Air Force. He teaches across the country on fireground tactics/decision making, air management, leadership, and company officer development. He has written numerous articles and is coauthor of *Air Management for the Fire Service* and *Challenges of the Firefighter Marriage* (Fire Engineering Books).

Physiological Response to Firefighting: Air Consumption and Work Output

BY **RICHARD KESLER, GAVIN HORN, AND DENISE SMITH**

THERE'S NO QUESTION that firefighting requires a substantial amount of physical work. The effort needed to perform essential fireground operations is often great and is compounded by the environment you are operating in, the gear you wear, and the demanding nature of the tasks. The physical demands of the job result in rapid increases in air consumption and increased cardiovascular strain to provide for the increased need for oxygen to support the muscular work.

The firefighting self-contained breathing apparatus (SCBA) allows you to carry a limited volume of air, and you have a limited work capacity based on your physiology. Understanding how firefighting tasks, SCBA size and weight, turnout gear, and physical fitness impact your physiological response, air consumption, and work output can help inform your individual operations and inform officer and incident command level decisions to improve efficiency and safety on the fireground.

Mechanics of the Physiological Response

Performing any type of physical work or exertion requires the human body to convert chemical energy (dietary intake) to mechanical energy (movement). A combination of carbohydrates/fats and oxygen is used to produce adenosine triphosphate, which serves as the energy source for muscular contraction and allows movement. As the speed and intensity of muscular movement increase, so does the oxygen demand from the contracting muscles. When performing physically demanding tasks, such as firefighting, breathing increases to bring more oxygen into the body. At the same time, increases in heart rate and in the force of cardiac muscle contraction transport this additional oxygen to working muscles. Activation of the sympathetic nervous system during firefighting (or other work) helps coordinate the physiological changes needed to meet the increased oxygen demand.

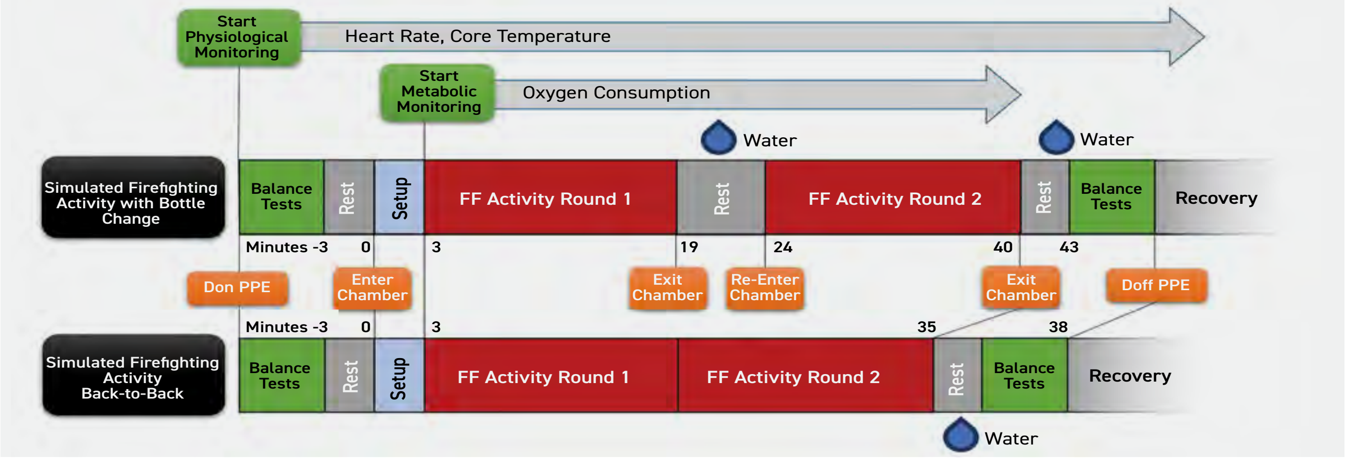
Heart rate and stroke volume both increase with the onset of increased need for oxygen from the muscles—although there is a maximum level to which these can increase. Blood vessels in the contracting muscle groups will dilate to allow for increased blood flow, while vasoconstriction will occur in the nonexercising tissues.

Both the tidal volume (volume of air per breath) and the respiration rate (number of breaths per minute) will increase to provide more available oxygen so that adequate pulmonary diffusion is maintained with the increased blood flow. Minute ventilation (the volume of air entering the lungs each minute) is the product of the tidal volume and the respiration rate, and minute ventilation can easily reach more than 100 L/min in healthy, fit individuals.

With continuing muscular work, core body temperature will begin to rise since heat is a by-product of the metabolic work of the muscles. In an attempt to counteract the increasing body temperature and cool the body, sweating rates will increase and vasodilation of the skin will occur, increasing blood flow to the skin. The increased cardiac output (heart rate × stroke volume) also results in elevated blood pressure.

There is a limit to each person's physiological response. Maximal oxygen consumption ($\dot{V}O_{2,Max}$) represents the maximum amount of oxygen that can be consumed and used by the body during maximal work and is measured in milliliters of oxygen consumed per minute per kilogram of body mass (ml/min/kg) or as a metabolic equivalent of task (MET). One MET is equivalent to 3.5 ml/min/kg of oxygen consumption. Firefighters typically do not work at maximal oxygen consumption levels, as this level of work can only be sustained for seconds. Rather, firefighters typically work at

Figure 1. SCBA Timing



Schematic of studies used to assess physiological response to firefighting operations. Firefighting activity consisted of four activities: Stair Climb, Hose Advance, Search, and Overhaul. In some trials, rest was provided to simulate a bottle change, while in others Round 1 and Round 2 were completed back-to-back with no break in between. *(Figure courtesy of authors.)*

submaximal workloads—higher-intensity work (>80% of $\dot{V}O_{2,Max}$) can only be sustained for a few minutes but lower-intensity work can be sustained for longer periods. Individuals with a higher cardiorespiratory fitness level (higher $\dot{V}O_{2,Max}$) can do more work at a given percentage of their $\dot{V}O_{2,Max}$, and they can work at a higher intensity for a longer time than unfit individuals.

The fatigue experienced by firefighters is a result of heavy muscular work, heat stress, and physiological disruption during firefighting. The strenuous nature of firefighting operations and the thermal and ergonomic constraints of working in turnout gear combine during firefighting operations to create a strain on our cardiovascular, muscular, and respiratory systems. The added weight and restrictive burden of the personal protective equipment increase the metabolic work required to perform the same tasks relative to what's required when wearing only station clothes or typical exercise clothing. In contrast to traditional exercise clothing, turnout gear that encapsulates the firefighter limits air movement for convective cooling and evaporative cooling of the sweat—leading to a condition where the body's cooling mechanisms are not effective.

While firefighters' fitness levels will not be discussed in detail in this article, it is important to note that improved fitness can help modulate the physiological response including increasing thermotolerance, improving musculoskeletal efficiency; increasing cardiovascular efficiency, allowing for greater oxygen consumption; and allowing for longer working times with higher work output.

Figure 2. Firefighting Activities

Simulated firefighting activities represent operations commonly performed on the fireground. *(Figure courtesy of authors.)*

Initial Response to Firefighting Operations

Numerous research studies have documented physiological changes while performing firefighting activities. In one study conducted at the Illinois Fire Service Institute, firefighters performed simulated fireground activities, including a stair climb, hose advance, search, and overhaul tasks, over the course of 14 minutes in a heated chamber (116°F, 47°C).[1] Each activity was two minutes long, with two-minute breaks between each session, simulating an emergency response. Firefighters' heart rates reached near maximal values (between 180 and 185 bpm) and core temperature rates of change were 0.08°F/min (0.045°C/min)—resulting in an increase in core temperature of more than 1°F (0.6°C). These changes occurred with only 14 minutes of intermittent firefighting activities.

Minute ventilation and oxygen consumption increased during the firefighting activities, resulting in more air being consumed from the SCBA and more oxygen used by the body than would have been at rest. This finding is not surprising but hard to quantify in the field. To collect this data while the firefighters were on air, we developed a system to integrate metabolic monitoring equipment with the SCBA face piece.[2] With this new tool, we found that peak oxygen consumption values during a single bout of activity were the highest during the stair climb (8.1 METs), slightly lower during the hose advance and search (6.7 to 7.2 METs), and lowest during overhaul (5.5 METs). The hose advance and search activities resulted in the highest peak minute ventilation [90 L/min (liters/minute)], followed by the overhaul task. The stair climb had the lowest minute ventilation (74 L/min).

The standard 30-minute SCBA cylinder holds approximately 1,275 liters of air. If peak ventilation rates were sustained, the entire cylinder would be consumed within approximately 14 to 17 minutes. Under these conditions, the working time until the end-of-service-time indicator or low-air alarm alert (when 33% of the air supply remains and firefighters should be out of the structure) would be approximately 9 to 11 minutes. With a 45-minute cylinder, which is typically filled with approximately 1,900 liters of air, the entire cylinder would be consumed in 20 to 24 minutes. The reported data are peak ventilation rates. This sustained rate would be unlikely due to the inverse relationship between the physiological limits of work output intensity and duration but may occur in an extreme situation where maximal work output is required over an extended period. Average minute ventilation throughout the study was lower than the peak rates as firefighters rested between activities, reflecting the intermittent nature of firefighting tasks at most incidents. It is also important to recognize that minute ventilation rates on the fireground could vary considerably, based on job assignment, fire conditions, or psychological stress levels.

After completing the firefighting activities in the above study, firefighters completed an obstacle course designed to simulate exiting the structure and walking on the fireground. The course consisted of challenges requiring the firefighter to step over an obstacle, duck under a crossbar, maneuver through the stud space in a wall, and climb up and down a small set of stairs. There were important changes in gait mechanics and body movements as firefighters stepped over the obstacles and stair treads.[3,4] These changes are indicative of fatigued muscles and could potentially lead to increased risk of trips and falls—one of the leading causes of fireground injuries each year.[5]

Repeated Bouts and Extended-Duration Operations

Although many fires are contained and suppressed while using only one bottle of air, it is not uncommon to respond to larger incidents requiring multiple bottles of air or conduct overhaul operations for extended periods of time after suppression. Our team sought to better understand the physiological implications of these longer operations in a research setting. To do so, and to allow comparability with previous research, we conducted studies in which the firefighters completed a second round of simulated firefighting activities in the same heated chamber. After the first round, they repeated the same four activities (stair climb, hose advance, search, and overhaul). In some cases, the firefighters took a short five-minute break to change SCBA bottles, hydrate, and cool off before returning to work. In other experiments, the firefighters continued working straight into a second round, simulating the use of an extended duration SCBA (45- or 60-minute cylinder). In the second round, heart rates were higher than the first round and reached most firefighters' age-predicted maximum (185-190 bpm). Core temperatures continued to rise.

During the second round of activities, oxygen consumption was significantly lower for all activities. When firefighters had a five-minute break between rounds, peak oxygen consumption decreased from 8.2 METs in the first round to 7.0 METs in the second round on the stairs (-15.0%), from 6.8 to 5.5 METs on the hose advance (-20.1%), from 7.0 to 5.1 METs for the search (-27.0%), and from 5.3 to 4.2 METs for the overhaul task (-21.1%). This decrease in oxygen consumption clearly shows that the firefighter cannot sustain the same work intensity during longer-duration incidents—and it demonstrates that approaching $\dot{V}O_{2,Max}$ is not what causes fatigue but rather that oxygen consumption decreases because the work level cannot be sustained. While oxygen consumption was significantly lower for all activities in the second round (relative to the first round), minute ventilation was the same for all activities when rounds were completed back-to-back and slightly reduced when firefighters had the five-minute rest between rounds. These findings suggest that in the second round of activity, the firefighters had a reduced respiratory efficiency—they were consuming less oxygen from a similar volume of air from their SCBA. This is consistent with the muscles being able to produce less force and generate less work output as they become fatigued.

On average, peak minute ventilation was approximately 79 L/min, which is almost twice the standard 40 L/min consumption rate NIOSH used to estimate service time for the SCBA cylinder. Our highest observed minute ventilation was less than the 103 L/min ventilation rate used in the NFPA 1981 tests.

Physiological responses are dependent on the intensity and duration of activity. Throughout these studies, firefighters were instructed to operate at a "fireground pace." This meant working as hard (intensity) and as fast (pace) as they would on the fireground and completing as many repetitions of each activity as possible while ensuring tasks were completed as instructed and safely. Each bout of firefighting activity was intermittent and designed to last 14 minutes, reflecting a "typical" response and the approximate duration of work before exiting due to air supply limitations. During the second round of activities at this self-selected intensity and pace, firefighters had a lower work output compared to the first round (measured as the number of repetitions of each task that was completed). On average, there was a 20% decrease in work output in the second round: –10.4% on the stair climb, –22.4% for hose advance, –26.8% for search, and –18.3% during overhaul. The decrease in work output was even more substantial when the rounds of activity were completed back-to-back without a break. The percentage changes in work output were consistent with the previously discussed percent changes in oxygen consumption, indicating that muscular fatigue limits the firefighter's ability to sustain continued activity.

The instruction to work at a "fireground pace" also included stopping the simulated activity to rest as needed and ending the simulated activities protocol when they would normally call for a relief crew and exit the structure at a real event. All the firefighters were able to complete the first round of activity, but 11 of the 30 were unable to complete the second round of activity in all three of the tested conditions. The group unable to complete all the tasks had higher body mass indexes (BMI) and overall lower fitness (lower $\dot{V}O_{2,Max}$). The average BMI for those able to complete all trials was approximately the same as the threshold between normal and overweight (BMI = 25 kg/m^2), while the average BMI for those unable to complete at least one of the trials was near the threshold between overweight and obese (BMI = 30 kg/m^2). The average maximal oxygen consumption ($\dot{V}O_{2,Max}$) of those who did not complete all of the trials was $\dot{V}O_{2,Max}$ of 40.3 ml/min/kg, which is below the suggested minimum recommended level of 42 ml/min/kg in the 2022 edition of NFPA 1582. The group who successfully completed all

Figure 3. Data Summary

Parameter	Change During First Round (from rest)	Change During Second Round (compared to first round with 5-min rest)	Change During Second Round (compared to first round with back-to-back)
Heart Rate	↑	↑	↑
Core Temperature	↑	↑	↑
Minute Ventilation (Breathing Rate × Tidal Volume)	↑	↓	(same as first)
Oxygen Consumption	↑	↓	↓
Work Output	↑	↓	↓

Summary of physiological responses to performing simulated firefighting activities in the heat. Larger arrows represent a greater change. *(Figure courtesy of authors.)*

trials had an average $\dot{V}O_{2,Max}$ of 45.7 ml/min/kg, above the threshold in NFPA 1582.

The weight of the SCBA the firefighter wears can also influence the ability to complete multiple bouts of firefighting activity. We examined the impact of SCBA weight (35, 40, and 45 pounds) by having firefighters complete the same activities in the environmental chamber in two 14-minute-long rounds of activity (or until they were fatigued to the point that they would call for a relief company and exit the structure).[6] There was a trend toward decreased time until needing to exit and calling for relief as the weight of the SCBA they used increased. Average time until exit was 35.9, 35.7, and 31.2 minutes for SCBA weighing 35, 40, and 45 pounds, respectively. These weights represented the current maximum allowable weight under the 2019 edition of NFPA 1981, plus the addition of 5 and 10 pounds. This range of differences in working time between SCBA of different weights could be critical to fireground operations. A difference of more than four minutes between the lighter 35-pound SCBA and the heaviest 45-pound SCBA would significantly affect the amount of work a company would be able to complete during fireground operations.

Considerations for Fireground Operations

When firefighters are operating on the fireground—especially when activity continues beyond approximately 15 minutes of hard work and into a second air bottle—they will experience significant thermal burden (increased core temperature), which will lead to near-maximal cardiovascular strain despite being unable to sustain high oxygen consumption rates. The initial activation of the sympathetic nervous system results in elevated heart rates, stroke volume, and minute ventilation. As firefighters continue to work through the second bottle of air, core temperature continues to rise (at a greater rate of increase), heart rate continues to rise, minute ventilation remains relatively constant, but oxygen consumption and work output decrease. Effectively, the firefighter will consume nearly the same amount of air as the first round of activity but will use less of the available oxygen and be able to complete less fireground work.

NFPA 1584 suggests that firefighters should report to rehab after completing two bottles worth of work with a 30-minute cylinder or a single bout with a 60-minute cylinder. Our data suggest that significant rest and recovery should be provided after the first bout of work if operationally feasible. If this is not possible, it should be understood that overall work output will likely decrease while physiological strain will increase during a second bout. Further, firefighters with higher BMI and poorer overall fitness may reach their physiological limit prior to reaching the limit of the second bottle.

It can be challenging to quantitatively assess firefighters' fatigue level and operational readiness for additional work on the fireground. While monitoring heart rate on the fireground can give some indication of physiological status, it does not give the full picture. Heart rate may quickly start to recover to baseline after work stops, while other metrics such as core temperature and the metabolic state of the muscles will take substantially longer. Questioning how the individual feels may also not be a good indicator of status to return to work. In our studies, on average, firefighters reported feeling "fairly good" before starting the second round of activity but still had substantial declines in work output. It is also important to consider that we've recorded many of the same physiological changes in heart rate and core temperature when the firefighter isn't on air but is working on the fireground in full PPE.[7] Crews performing operations off air and then tasked to go on air (due to changing conditions or assignment) may have decreased work output similar to those who have already worked through a first bottle.

Officers, incident commanders, EMS, and other supporting groups should consider these physiological changes associated with firefighting operations when assigning tasks and evaluating firefighters. They should recognize that firefighters who are sent back to live fire activities—after a quick air bottle change for a second 30-minute cylinder or who are continuously working through a larger cylinder—may not have the same operational capabilities as those who are just beginning their work. ■

ENDNOTES

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DENISE SMITH is a professor of health and human physiology at Skidmore College. Her primary area of research is cardiovascular health, with a specific focus on the relationship between heat stress and cardiovascular function. A significant portion of her research focuses on the cardiovascular strain associated with firefighting activity. She has led several government-funded studies to investigate strategies to minimize the physiological strain associated with firefighting. She has also conducted several laboratory studies designed to identify specific components of firefighting activity (work performed, heat stress, sympathetic nervous stimulation) that are responsible for specific physiological responses to the combined stress of firefighting. Smith has coauthored several textbooks and has published more than 60 scientific papers, primarily on firefighter cardiovascular health.

Synthetics in the Modern Fire Environment: The Importance of Using Your SCBA

BY **FRANK LEEB**

THE MODERN FIRE environment has undergone significant changes, a fact well-acknowledged by the fire service. The Fire Department of New York (FDNY), for example, has published several documents addressing these changes, including a fire dynamics training bulletin in May 2021 and a ventilation bulletin more than a decade ago. These documents offer insights into the tactical and strategic adjustments required to combat the evolving fire environment and its behavior. However, these changes have also coincided with a concerning rise in firefighter cancer rates. This article explores the interrelationship between the modern fire environment, the materials currently burning in structural fires, and the importance of using your self-contained breathing apparatus (SCBA).

One of the key factors contributing to this changed fire environment is the widespread use of synthetic materials. Synthetics are artificially created products designed to replicate natural materials. They are often more cost-effective, making them popular for many household items. However, the very nature of plastics, a common type of synthetic material, sets them on a path of decomposition from the moment they are manufactured.

Plastics are derived from raw materials like natural gas, coal, oil, and wood. These materials undergo distillation and modification processes, resulting in the production of intermediate products. These intermediates are further refined and polymerized to create plastics and related additives like fire retardants and plasticizers. Different elements, such as chlorine or phosphorus, may be added to alter the properties of the substance. For instance, vinyl chloride monomer, derived from ethene and chlorine, serves as the building block for polyvinyl chloride (PVC), a common plastic used in various applications.

After manufacturing, the basic molecular building blocks are turned into plastic resin. This process is called polymerization and results in the creation of a polymer. A polymer is a large, organic, chain-like molecule made of repeating units of smaller molecules. "Poly" means many and "mer" means unit—so with a polymer, we have "many units." Polymerization generally involves heating the building blocks in a vessel with "helper" chemicals called catalysts until the building blocks join to form long chains. A great deal of heat is used in the polymerization process.

The large amounts of energy (heat), thus, must go somewhere. Much of it goes into the bonds between the atoms of the plastics and is stored there. Plastics have much denser chemical bonds than natural organic materials. The number of carbon-to-carbon bonds in a cubic inch of plastic is many times that of a cubic inch of wood, cotton fiber, or wool fiber. Thus, the energy stored in a cubic inch of plastic dramatically exceeds what is in a cubic inch of natural material. Both plastic and natural materials are combustible, but the energy released when plastic burns is enormous compared with the energy released by a similar volume of natural material.

The fundamental skeleton of plastics generally consists of carbon or carbon and oxygen. Early decomposition products are those parts extending from the main carbon chain. These are generally acidic groups, basic groups, or organic groups that can become acids or aldehydes in the air. These chemicals break off from the main molecule. Thus, the early products are not the carbon but the acidic or basic parts. The deadly acid gas hydrogen chloride (HCl), for example (in an aqueous form, it is called hydrochloric acid), comes off PVC so quickly and so easily that polymer scientists call it "unzipping."

Unzipping occurs during the early decomposition of plastics (such as during a fire where the plastics are heated). Chemicals rapidly break off from the main carbon chain. This results in toxic airborne chemicals prior to visible flames.

Flame results from a process that begins with a relatively low level of heat. With plastics, the first stage of a fire is invisible; heat causes the molecules to slip and slide and causes a significant acceleration of the aging processes of oxidation, flowing, and loss of

1. Understanding the types of materials that are burning is a primary building block to understanding the toxicity of today's fires and the importance of SCBA usage. This photo was taken at the 2019 UL FSRI Urban Fire Dynamics boot camp hosted by the FDNY at its Fire Academy. *(Photo by author.)*

additives. Eventually, the heat builds to the softening point and then to a melting point. In plastics, physical changes such as melting, deformation, expansion, and loss of strength are part of the first stage of a fire.

Nature prefers low-energy materials; high-energy-dense materials tend to release their energy by breaking and are, therefore, unstable. In addition, unlike traditional materials, the temperature at which many plastics begin to decompose is less than half their ignition temperature. Because of this significant temperature difference, there is a long period of time when gas is emitted without the presence of flame.

Firefighters must be aware of these characteristics when dealing with fires involving plastics, as they release hazardous chemicals and generate high levels of heat, smoke, and pressure. Proper ventilation and control are crucial; victims must be rescued promptly, and our SCBA must be used.

Firefighters are exposed to various cancer-causing chemicals in the fumes and smoke produced during fires involving modern materials. These chemicals include dioxins,

Everyday Asks

BY **RUSSELL OSGOOD AND DR. SARA JAHNKE**

As firefighters, we have a great deal of control over the risks we face. We have an inherently dangerous job and will be exposed to many toxins out of our control, but there are many actions we can take to remove and reduce much of the risk for cancer and many other health issues we face as firefighters. The Firefighter Cancer Support Network (FCSN) everyday asks are simple steps you can take to make a difference in your risk for not only cancer but heart disease and mental resilience.

Eat real food and drink water. Making mindful nutritional food choices and staying hydrated will provide the body with the fuel it needs to thrive and reduce your risk for heart disease and cancer. An estimated 5% of cancers are due solely to poor nutrition, making healthy eating even more important for firefighters.

Move. Make physical fitness a priority. It is not only good for the heart and mind but also great at boosting the immune system and assisting with sleep. A half hour of moderate exercise daily can reduce your cancer risk by 20%.

Connect. Chronic stress affects immune function and inflammatory response, which increases cancer development risk. Connecting with others can reduce stress and build healthy relationships.

Prioritize your sleep. Poor sleep has been connected to long-term risk for developing cancer. Sleep rejuvenates our bodies and minds. Strive to get seven hours each night.

Limit substance use. If you smoke, chew, or vape, stop! If you drink more than one to two alcoholic drinks per day, stop! Limiting alcohol consumption and not using tobacco products remove substantial risks factors for cancer.

Access healthcare regularly. Build a relationship with a provider you trust, get annual exams, get screened when recommended, and be sure to get changes in your health checked quickly.

Respect your gear. Maintain your PPE, isolate PPE when you can, wear only when necessary, and keep the firehouse and gear room clean.

Reduce the exposures you can. Wear and use all your PPE in any environment where you could be exposed to the products of combustion.

Decontaminate what you can't eliminate. Use best practices to reduce continued exposure through on-scene decontamination and rehab procedures.

Clean what you can when you can. Shower as soon as possible following exposure. Keep your PPE and equipment clean.

Make your numbers count. Join the National Firefighter Registry for Cancer to help researchers understand more about this epidemic facing the fire service.

It's important to understand that cancer is a complex disease with multiple factors that contribute to its development. As firefighters, we must do what we can every day to reduce the risks we face. Do it for yourself and for the ones you come home to.

Russell Osgood, a more than 35-year veteran of the fire service, is the chief of the Ogunquit (ME) Fire Department. He has been in the forefront of the fire service cancer epidemic since 2011 and was a key developer of the Firefighter Cancer Support Network cancer prevention education program Taking Action Against Cancer in the Fire Service. He educates firefighters across the nation on cancer prevention.

Sara Jahnke, Ph.D., is director and senior scientist for the Center for Fire, Rescue & EMS Health Research at the National Development & Research Institutes-USA. With more than a decade of research experience on firefighter health, she has been the principal investigator on ten national studies as well as dozens of studies as a co-investigator. Her work has focused on a range of health concerns including the health of women firefighters, behavioral health, risk of injury, cancer, cardiovascular risk factors, and substance use with funding from the Assistance to Firefighters Grant R&D Program, the National Institutes of Health, and other foundations. She has more than 100 publications in peer-reviewed medical literature.

2. One of the best ways you can protect yourself is to use your SCBA anytime smoke is present. *(Photo by John Odegard.)*

furans, benzene, fire retardants, and other irritants. Soot particles released by burning plastics can carry these harmful chemicals into the deep lung and onto the skin, further amplifying the risks faced by firefighters. The interrelationship between the modern fire environment and firefighter cancer rates is becoming increasingly evident. One of the best ways you can protect yourself is to use your SCBA anytime smoke is present.

Firefighters must be mindful that the decomposition of plastics during a fire is accelerated as the plastics unzip and release both large quantities of dangerous chemicals and heat. Additionally, they must understand that plastics are energy-dense and have a high heat release rate, especially when compared to natural materials. As the heat release rate increases, the heat, smoke production, and pressure within the fire area will increase.

In the modern fire environment, which includes an abundance of plastics, it is critical that ventilation be coordinated and controlled. However, with a very rapid release of large quantities of toxicants, it is also vital that victims in a structure on fire be located and removed as quickly as possible, and it is vital that firefighters use their SCBA whenever they are operating within this environment. Firefighters need to understand the interrelationship between the toxic hazards of burning plastics, fire behavior, and how to best protect themselves. SCBA usage every time you are operating within a fire environment must be part of this strategy. ■

FRANK LEEB, in a more than 30-year career, has held several senior staff positions in the Fire Department of New York including the chief of the Fire Academy, chief of training, and chief of safety. He has also been a member of the East Farmingdale (NY) Fire Department since 1983.

An SCBA Air Management Solution for Tall Building Vertical Challenges

BY **JACK J. MURPHY AND JERRY TRACY**

INCIDENT COMMANDERS (ICs) have a lot on their plates, being accountable for the life safety of building occupants, firefighters, and any other first responders called for a fire or other emergency in tall buildings and large complexes. Our mission and service often require us to enter atmospheres contaminated with smoke or other toxins. As ICs gather "building intelligence," systems status, and confirmation of the event location, they must also be keenly aware of the existing status of the firefighters operating and if they have or will be entering atmospheres considered immediately dangerous to life or health (IDLH). That will start the clock for time pacing to keep track of time on air.

These firefighters have limited operational time on their self-contained breathing apparatus (SCBA) and will require rotation and relief if they have not accomplished their mission and the area of operations is still contaminated. The average operational time of traditional SCBA is 10 minutes with a factor for egress to safety and clean air. That is with the understanding that the end-of-service-time indicator (EOSTI) will sound when the SCBA diminishes to 35% of the cylinder's capacity. This will equate to less than five minutes to evacuate and reach an area of refuge with clean, fresh air. Other teams must be available with full SCBA equipment to assume the unfinished duties. This function of rotation and relief may have to continue until the space and the entire building are cleared of smoke and other contaminants.

High-rise buildings as well as other large-area structures pose a great challenge to extinguish and mitigate fires, institute a smoke management and control plan, maintain SCBA air management, and stabilize other issues including all-hazard (nonfire) events. These tall structures become increasingly more challenging and complex, with mixed-use occupancies and physical heights considered super and mega tall buildings.

The IC is further challenged to provide resources of personnel and equipment to support the operations until conclusion, which includes a complete air exchange of the space or building. The scope of operations is vast and extends well beyond what may be considered the "fire sector" (FS) or "emergency sector" (ES). The statistics of fire deaths due to smoke inhalation may only provide the number of fatalities and the height of the structures but not the location of victims.

Many of these victims are found in hallways and stairwells above the fire floor/sector. They either perceived their life was in danger or their apartment or space was becoming contaminated because of failed passive fire protection features and systems. Either way, these circumstances require an expansion of the incident command system (ICS) to establish an "Evacuation, Search, and Rescue" (ESR) group to enter and search all floors that may be contaminated. Firefighters will also have to don SCBA and go on air, and the ESR supervisor will be responsible for time pacing to keep track of these individuals, considering their distance and travel to an area of refuge may be great.

The IC must be cognizant of the demands for a continuous SCBA air supply, especially for the search and rescue efforts above the fire sector and elsewhere due to internal air flows with the migration of contaminants. When elevator cars fail, the movement of air bottle supply to the upper floors becomes an arduous task involving many firefighters. How logical and difficult will it be to transport full SCBA bottles up to a floor for exchange in an elevator, which may have to pass the fire sector, or to manually haul bottles up in a stair shaft, which may also be contaminated? On paper, this may seem feasible; in reality, it is not.

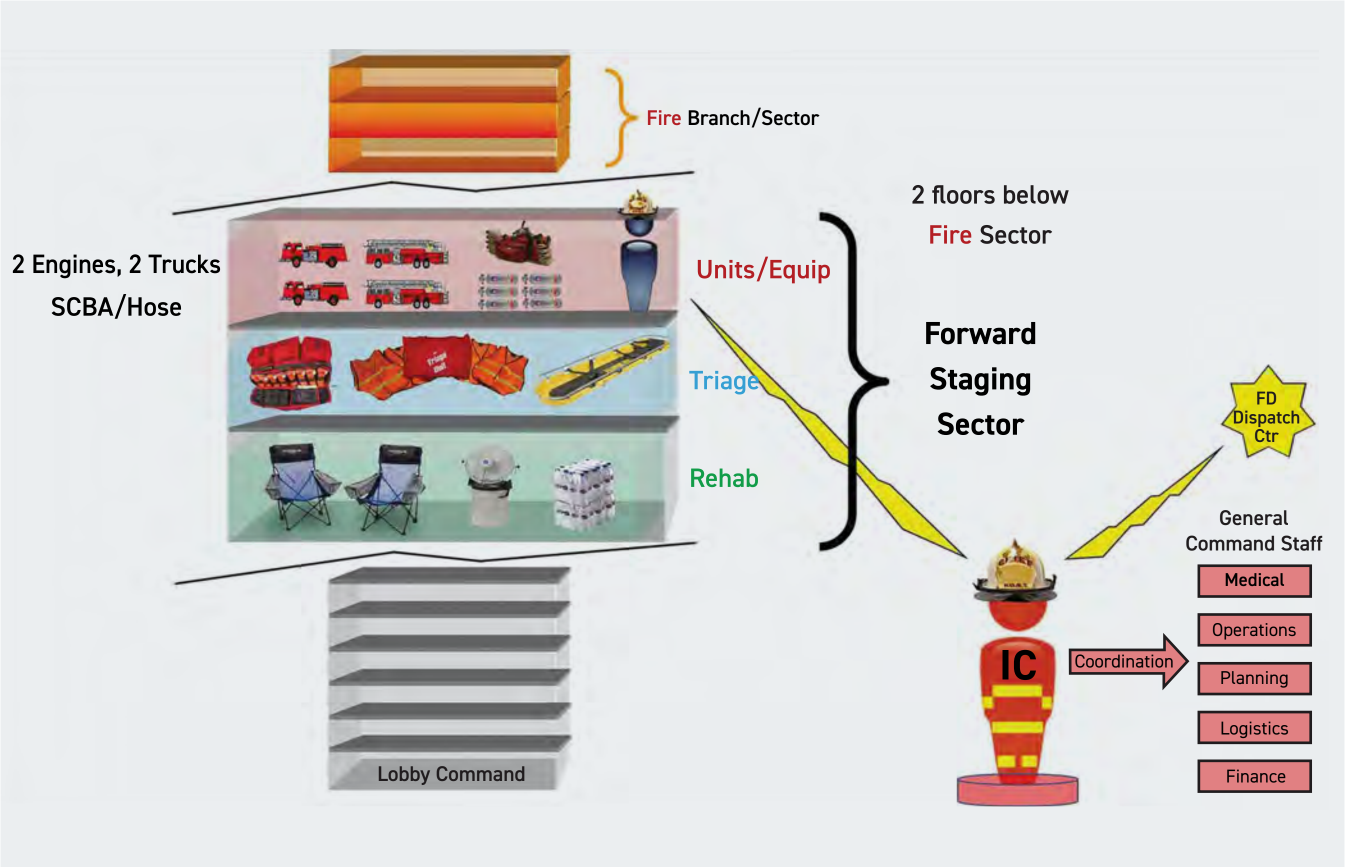
Forward Staging (FwS) Demand for Full Air Cylinders

Significant fires are those that necessitate the escalation to a higher alarm and call for the personnel resources that will be required to support and maintain ongoing operations. Already established domains that will require additional resources (tools/equipment/SCBA) and personnel are the FS, the ESR group, and possibly other groups established for a specific purpose (rescue/confined space/hazmat/Other). These resources need to be near these domains. The distance needs to be minimal for teams/fire units deployed for firefighter relief and rotation.

A location best suited for the FwS is most often three floors below the fire or two floors below the FS. This is when the smoke migration is not subject to a "negative stack" action. It is the policy of some departments that the investigative unit arriving at the target floor, two floors below the fire/alarm floor, would advise the IC if this floor were suitable for staging. It would be the IC's or logistics officer's responsibility, if established, to supply and maintain the tools and equipment resources to be delivered and additional fire units directed to FwS.

The primary resource in great demand will be (full) SCBA air cylinders to replenish those spent from use. These replacement cylinders may be delivered to the scene by a fire unit specializing in SCBA replenishment with firefighters assigned who have the ability (carts/hand trucks) to transport multiple cylinders to the FwS location (Figure 1).

Figure 1. Forward Staging Sector with Triage and Rehab Groups



Source: Jerry Tracy.

Some departments have a policy that each firefighter arriving beyond the initial first alarm units will bring with them an extra SCBA cylinder. This extra bottle will either be amassed in a location on entering the building or brought up to FwS.

Local departments that have a Firefighter Air Replenishment System (FARS) installed in the building are relieved of the enormous challenge and responsibility of time and personnel having to physically transport what could be hundreds of SCBA cylinders. Most departments do not have the personnel resources to accomplish this. This should be a priority for the authority having jurisdiction (AHJ) to require local codes be changed to require a FARS installation, especially when departments lack sufficient staffing.

The chief officer assuming the supervisory function of organizing and managing the FwS will be challenged to assemble teams and their equipment in a space where they can easily deploy up to the FS and either relieve those firefighters standing by as Attack Staging or proceed directly to the fire floor to be rotated into the action of operations. The FwS supervisor would be monitoring the FS tactical operations channel to determine what progress is being made. These circumstances will determine the mode of dress for the fire units being staged at FwS—whether to stand at the ready or to dress down by removing their SCBA and opening or taking off their PPE bunker jackets to lessen fatigue and core body temperatures.

This supervisor should have a firefighter assigned as an assistant or aide to monitor the tactical channel or command channel. This aide would also perform the administrative function of recording units entering the FwS and those deployed, with times noted in the Forward Staging Log. The aide may have the ability to survey the floor for any available resources that could be used for comfort and hydration replenishment, a water source and drinking cups, as well as restroom facilities. Lacking these resources, the IC or logistics officer should be notified of the need to provide drinking water to FwS and the entire sector as well as the Triage and Rehab subgroups.

The fire service has evolved with its commitment to firefighter health and safety. The need for hydration, chairs, misting fans, and other resources would have been considered in the Response Matrix as alarms escalate to maintain health and well-being by providing all the supplies and replenishment resource needs.

Establish an area or space for SCBA bottle replacement. This cylinder cache needs to separate both the full bottles and the empty ones. The firefighters delivering full cylinders would collect the empties to be transported back for refilling.

Labor-Intensive SCBA Refills

For many departments, air replenishment of depleted SCBA cylinders is

1. Labor-intensive bottle brigades deplete fireground staffing for fire control, search and rescue efforts, and more, especially in departments with limited personnel. (*Photo courtesy of FAC.)*

accomplished with additional cylinders delivered or carried into a high-rise building by arriving fire units. The fire units arriving above the first-alarm assignment may have each firefighter carry one extra cylinder, which would be deposited into a cache area chosen by the IC. The location that would require the greatest number of SCBA cylinders for exchange and rotation of members would be close to the FS. Those fire teams that are deployed to the FwS would carry one extra cylinder per firefighter into the building and deposit the cylinders at the target floor, two floors below the fire floor (photo 1). Ultimately, the FwS sector will become the cache for air cylinders, tools, and equipment in addition to fresh fire teams ready to deploy.

Bottle Brigade PPE Dress Down

A policy that requires members to carry extra equipment and weight above their normal complement of tools is placing great physical stress on these firefighters. An SCBA air refill method may start at a remote department SCBA and mask service facility or a mobile air support unit (refill capability at the unit only) at the scene. Both efforts are cumbersome and time consuming, and firefighters transporting equipment will become fatigued before receiving any assignment of operations (photo 2).

2. Refilling SCBA bottles at a remote facility and transporting them to a high-rise building fire is both labor intensive and time consuming and not a sufficient on-scene air supply system. When elevators are rendered inoperable, a stairwell bottle brigade will have to carry the supplemental cylinders up to FwS. *(Photo by James Murtagh.)*

Some departments have incorporated into their standard operating procedures (SOPs) a system where an IC has the option to assign fire units/teams (bottle brigades) whose primary duty will be to transport tools, equipment, and cylinders needed for operations. These firefighters will be allowed to discard their full PPE and dress down to their work duty station wear and shoes to reduce fatigue and raise core body temperatures while they haul this equipment up stairwells. The concept is to position a firefighter at alternative levels to transport equipment to another firefighter on an upper level. Lack of resources may prohibit this system.

FARS: an SCBA Air Management Solution

An SCBA air management solution would be to have a means of replenishing depleted SCBA equipment on site. The FARS method is a piped system installed within a building, often in or near a stairwell. It is considered an air supply system comparable to the water supply in a standpipe system. It provides the fire service with a dedicated safe, reliable, and constant supply of air to replenish depleted cylinders. This eliminates the need for bottle brigades or rapid ascent teams (RATs) to haul and transport cylinders up into a high-rise building or have a stored cache prior to fire and emergency operations. Small fire departments do not have the resources to fully support the duties involved in producing

Appendix L: Foundation for a Continuous Air Supply

Over the years, many fire departments have adopted a local ordinance to install a FARS. To help standardize a FARS installation, in 2015 the *International Fire Code (IFC)* adopted Appendix L-Requirements for Firefighters Air Replenishment Systems. This appendix provides a foundation for the design, installation, and maintenance of a FARS in buildings designated by the AHJ. This FARS Code Adoption Guide and Code Adoption Checklist (aircoalition.org/fars-code-adoption) will help benchmark the FARS installment process and provide the resources necessary for success.

New Frontiers: Super Tall, Mega Tall, and "Groundscraper" Buildings

These very tall structures that were predicted for the future are now appearing in the skylines of large cities worldwide. They are no longer being called skyscrapers because of their extreme height but are being referred to as super tall (> 984[ft]) or mega tall (> 1968[ft]) buildings.

The declaration was that these super and mega tall structures will present even greater challenges that established SOPs do not characterize, provide a management plan applicable to them, or address all the issues and perils of fire suppression and evacuation from the uppermost levels of these structures. The fire service of today has to be more progressive to stay current with the understanding of building construction types and materials, building systems, smoke management and control, fire protection systems and their limitations, fire dynamics, heat release rates of available fuels, and code requirements for these tall structures.

Because of the enormous height of these buildings, the "reflex time" factor for emergency intervention and fire suppression will be protracted. The fire service must rely on the building's construction and fire protection systems (active and passive) to withstand fire exposure for the minimum time ratings. While life safety and water supply will be major factors, it cannot be stressed enough that without a FARS, the time on air (SCBA) will be limited. A FARS can continually supply SCBA bottles for suppression, evacuation, and search and rescue.

Beside a FARS in tall vertical buildings, the local fire service should also consider adopting the *IFC* Appendix L for buildings that identify as large box stores and warehouses, shopping malls, and airport terminals, all of which are basically high-rise "groundscraper" buildings lying on their sides.

The value of a tall building FARS is also featured in the new book *High-Rise Buildings: Understanding the Vertical Challenges* in "Other Building Systems" (Chapter 6); "Command, Management, and Administration of High-Rise Fires and Emergencies" (Chapter 8); "Firefighter Fire Unit Response" (Chapter 9); and "Looking Ahead to New Tall Building Designs and Techniques" (Chapter 12), published by Fire Engineering Books.

extra SCBA bottles. If buildings were equipped with a FARS to refill SCBA equipment, it would reduce the burden of logistics and physical demands placed on our personnel. Personnel could fulfill other duties to save lives and extinguish fire.

While these systems exist in many districts throughout the country, they are slow to be adopted in most jurisdictions. Firefighters would have the ability to refill their SCBA cylinders inside a building at designated refill stations in under two minutes while wearing their ensemble before their cylinder is fully depleted. This feature would be a tremendous resource for those fire teams who will be assigned the duties of ESR above the Fire Branch/Sector where an IDLH may exist. These firefighters can refill their cylinders to increase their work time or time to exit if an uncontaminated atmosphere were distant. The IC should be aware of and follow the guidelines of NFPA 1584, *Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises.*

The loss of one life is immeasurable, but the savings to property loss can pay for these air supply systems tenfold. In the meantime, our firefighters are operating in these dangerous and difficult arenas and doing the best they can with the resources at hand. Still to this day, they will be subject to the limitations of air supply in the performance of their duties with the additional task of locating firefighters who may become lost and disoriented and who may run out of air in thick, toxic smoke. ■

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