Evaluating the Effectiveness of Breathing Methods During a Firefighter Out-of-Air Emergency

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Certification Statement

I hereby testify that this paper constitutes my own product, that where the language of others is set forth, quotation marks so indicate, and that appropriate credit is given where I have used the language, ideas, expressions, or writings of another.

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Abstract

Firefighters are taught to how to manage air contained in their self-contained breathing apparatus; however, in extreme circumstances firefighters can run out of air and must use some other method to find breathable air. Commonly-taught out-of-air breathing methods have not been based in research but in a best-guess philosophy. The problem is, when faced with an out-of-air-emergency, the Fishers Department of Fire and Emergency Services has not outlined the breathing methods through which a firefighter should progress in order to limit breathing contaminants of an Immediately Dangerous to Life and Health (IDLH) environment. The purpose of the research was to evaluate commonly-taught fire service out-of-air breathing methods and devices in order to assist firefighters in choosing the technique and device that allows for the greatest chance of survival. Action research was used to answer three research questions: (a) which out-of-air breathing methods best allow survival when assisted by an able firefighter, (b) which best allow survival when isolated from other resources, and (c) how breathing methods need to be prioritized or omitted based on the results. A literature review identified five main out-of-air breathing methods. These methods were tested under IDLH conditions in which an air sample was taken from a mannequin breathing through an SCBA facepiece using the selected out-of-air breathing method. The ambient environment outside the facepiece was sampled as well. The results of the air samples were compared and a decision tree made recommending which out-of-air breathing method to use under certain circumstances. It was recommended the Fishers Department of Fire and Emergency Services purchase needed breathing method devices, teach the decision tree to its members, commit to further testing, and become an advocate in the fire service for teaching not only how to prevent the out-of-air emergency, but how to best mitigate it as well.

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Introduction

For decades the fire service has employed the use of self-contained breathing apparatus (SCBA) to provide firefighters with clean, breathable air while working in an Immediately Dangerous to Life and Health (IDLH) environment. Throughout their careers, firefighters are taught that air management is a key to a successful outcome. All SCBAs have a low-air alarm set to activate at one quarter of the full cylinder pressure. This last quarter is designated as reserve, only to be used in emergency situations. Firefighters are to have exited the IDLH environment before tapping into this reserve air supply.

Firefighters are taught several different methods for survival in the case of low-air emergencies. These may include calling for additional help via a mayday transmission, attempting self-extrication, and conserving air supply with scientifically-tested breathing techniques. If a firefighter is still within the IDLH environment by the time the reserve air supply is exhausted, the situation then becomes an out-of-air emergency. The firefighter is forced to remove the regulator from the facepiece and breathe the contaminated atmosphere.

Several breathing methods are taught to be used only in out-of-air emergencies as last-chance techniques to minimize the impact of an IDLH environment. Some of these breathing methods can only be performed with the assistance of another firefighter able to give aid, while others can be performed in isolation. The problem is, when faced with an out-of-air-emergency, the Fishers Department of Fire and Emergency Services has not outlined the breathing methods through which a firefighter should progress in order to limit breathing contaminants of an IDLH environment. Previous teaching on which method gives the best chance of survival has not been based on scientific research, but on experience and a best-guess philosophy.

The purpose of the research is to evaluate commonly-taught fire service out-of-air breathing methods and devices in order to assist firefighters in choosing the technique and device that allows for the greatest chance of survival. The following research questions were answered using the action research method:

1. Which commonly-taught out-of-air breathing methods best allow firefighters to survive when they can be assisted by an able firefighter?
2. Which commonly-taught out-of-air breathing methods best allow firefighters to survive when they are isolated from other resources and firefighters?
3. How should commonly-taught out-of-air breathing methods be prioritized for use and which should be omitted from future protocols based on the data collected and the circumstance of the emergency?

Research was conducted using a literature review and through experimentation at the Central Indiana Public Safety Training and Education Center in Noblesville, Indiana. Air monitoring equipment was used to sample air contained within an SCBA facepiece secured to a breathing mannequin and simultaneously compared to a sample of the external IDLH environment. Each breathing method selected was individually tested using the SCBA facepiece and appropriate devices. Data was collected, analyzed, and used to create the Firefighter Out-of-Air Breathing Method Decision Tree.

Background and Significance

The Fishers Department of Fire and Emergency Services is located in Hamilton County, Indiana and employs 106 uniformed front-line personnel with eight chief officers and five civilian staff. The district covers approximately 50 square miles, houses five stations, and protects approximately 80,000 residents ("Quick facts," 2010). The department has strategically placed four engines, three ladder trucks, four Advanced Life Support transporting ambulances, a heavy rescue, and a battalion chief throughout the jurisdiction. The Fishers Department of Fire and Emergency Services supports a county-wide response for special rescue situations, including trench, confined space, tower, structural collapse, swift-water, and deep-water rescues by providing trained personnel and resources along with other departments within the county.

Fishers firefighters are initially trained through a recruit academy style course. At the end of this academy, the firefighter has obtained an Indiana Firefighter I and II certification along with a Hazardous Materials Operations Certification and an Indiana Emergency Medical Technician Basic Certification. This initial fire training contains extensive SCBA familiarization lessons, which include air management techniques. Consistent lesson plans across recruit academies during this initial training have been deficient due to different venues and instructors facilitating the academy at the time. This has led to discrepancies throughout the department in the quality of SCBA techniques training.

In July 2012, the Fishers Department of Fire and Emergency Services training division identified these deficiencies in training and started an aggressive incumbent firefighter training regimen to standardize actions on the fireground during normal operations, Rapid Intervention Team (RIT) deployments, and SCBA usage. These ongoing trainings consistently emphasize proper air management. Firefighters are taught to exit the IDLH environment before tapping into the SCBA reserve air supply, denoted by a series of audible and physical warning devices. This prevents the possibility of a firefighter running out of air and forcing them to breathe contaminants of the IDLH environment.

Breathing contaminants of an IDLH environment have proven to be deadly. In a study by the United States Fire Administration of firefighter fatalities from 1990 to 2000, 16% involved a firefighter wearing an SCBA at the time of death. Of these same cases, 30% were found to be in an out-of-air emergency (Gagliano, Phillips, Jose, & Bernocco, 2008). Furthermore, from 1986 to 2006, an average of twelve firefighters each year has died due to asphyxiation (Gagliano et al., 2008, table 4-4). Even if a firefighter survives after breathing contaminants of the IDLH environment during an out-of-air emergency, he or she still may "have a high probability of developing some type of cancer in the future" (Gagliano et al., 2008, p. 75). The statistics are clear. Nothing good comes from breathing smoke, and firefighters must prevent it at all costs.

Carbon monoxide (CO) and hydrogen cyanide (HCN) are two main contaminants of smoke that act upon the human body and cause significant harm or death These have been labeled as the "Toxic Twins" because they physiologically work together to shut down systems in the human body. CO inhibits oxygen from being carried on red blood cells throughout the body, while HCN inhibits the cells' ability to use any oxygen that may remain. As these two contaminants infiltrate the body, they shut down heart and brain functions, robbing firefighters of their ability to make rational decisions (Fire Smoke Coalition, 2011).

Carbon monoxide is measured in the atmosphere by parts per million (ppm). According to the National Institute for Occupational Safety and Health (1995), 1,200 ppm of CO is needed to constitute an IDLH environment. SCBA usage is mandated at levels of 35 ppm (National Institute for Occupational Safety and Health, 1995). Mild headaches occur after one hour of exposure with levels of 400 ppm. At 3,200 ppm unconsciousness occurs after 30 minutes. With concentration levels of CO at nearly 13,000 ppm, death is imminent within one to three minutes (Gagliano et al., 2008, table 4-1). A study conducted by the Phoenix Fire Department, Arizona, found that CO levels in residential house fires routinely reach more than 20,000 ppm (Gagliano et al., 2008, table 4-1).

Like carbon monoxide, hydrogen cyanide is also measured atmospherically using parts per million. The National Institute for Occupational Safety and Health (NIOSH, 1994) reports that only 50 ppm of HCN is needed to constitute an IDLH environment; therefore, SCBA usage is mandated for firefighters at levels of 5 ppm or greater. NIOSH (1994) also reports that concentrations of approximately 50 ppm can be endured by the human body for up to an hour with little effect; however, concentrations of 135 ppm can cause death in as little as 30 minutes. Concentrations of 180 to 270 ppm of HCN can cause death within six to ten minutes (Rochford, 2009). According to a study by the Columbia Fire Department, South Carolina (2010), concentrations of this level can be found within many structure fires.

The circumstances in which firefighters are forced to breathe smoke differ from case to case. In August 2007, two members of the Fire Department of New York were killed in the line of duty while fighting a fire in a high-rise structure. The two firefighters were looking for trapped colleagues and subsequently ran out of air themselves. When assisting companies found the two firefighters, they were standing up without their SCBA facepieces in place and resisted help. Due to the effects of smoke inhalation, the two firefighters refused to exit the building, lost contact with the assisting companies, and were found soon after in cardiac arrest. The cause of death was asphyxiation (NIOSH, 2010).

In Phoenix, Arizona in 2001, firefighter Bret Tarver died in the line of duty while fighting a supermarket fire. While on the hoseline, conditions deteriorated rapidly as the fire progressed. With two of the three firefighters in the company running low on air, the company members started to exit using the hoseline as a guide. Two of the firefighters, including Tarver, fell over debris and were separated from the hoseline. A mayday was called. The two became separated from each other and soon ran out of air while searching for egress. Firefighter Tarver's partner was found gasping for air by an assisting engine company and led to safety. For a short time, it was thought that all firefighters had been rescued; however, another company soon discovered Tarver's need for assistance. They located him and attempted to get him to the floor, as he was combative and standing up without his SCBA facepiece in place. Tarver proceeded to turn the opposite direction and run away from help. Another firefighter, also separated from his crew and disoriented while looking for Tarver, was running low on air. He found Tarver and was able to radio that he had been located but ran out of air himself. He removed his SCBA facepiece and put his hood over his face in an attempt to filter breathe. Approximately three minutes later, an officer from another company found the filter-breathing firefighter in respiratory distress and removed him from the building. Incident Command thought this rescued firefighter was Bret Tarver. Realizing it was not Tarver, the officer re-entered and found Tarver but was unable to move him as he was now unconscious. The officer ran out of air and removed his SCBA facepiece in an attempt to quickly find air and make egress. Another company entered, found the officer, and assisted his egress. Other companies soon found firefighter Brett Tarver, but it took 19 minutes to remove him from the building because of his size and the debris covering routes of egress (Gagliano et al., 2008).

In a situation reported to www.firefighternearmiss.com in 2009, a firefighter lost pressure on the hoseline the same time he found himself in an out-of-air emergency. His SCBA had malfunctioned and had not warned him he was using his reserve air supply. He removed his regulator hose and put it down his coat in attempt to find breathable air. He then found a window with the help of another low-air firefighter and was able to get to safety ("Reports related," 2011).

These three case studies show that firefighter out-of-air emergencies can occur in a variety of ways. Even if out-of-air-emergencies can be prevented, firefighters should not turn a blind eye to how to best manage them. As much as the fire service needs to train on the prevention of the out-of-air emergency, the mitigation of the out-of-air emergency needs to be trained for as well. There is a tremendous need to scientifically test the breathing methods that have been taught and used in the past during an out-of-air emergency. This gives the firefighter the information to make a choice, if one is available, at minimizing the exposure to the IDLH environment, limiting short and long term injury, and perhaps enabling survival from an otherwise unsurvivable environment.

As previously mentioned, the Fishers Department of Fire and Emergency Services has started to provide consistent training in how to prevent an out-of-air emergency using scientifically tested data such as the Rules of Air Management first introduced by a group of firefighters from Seattle, Washington and their professional colleagues (Gagliano et al., 2008). Fishers firefighters are also undergoing aggressive training in RIT deployment and when to call a mayday if meeting certain parameters on the fireground. The department has not trained on the practices firefighters should take if they find themselves in an out-of-air emergency. The Fishers Department of Fire and Emergency Services needs to scientifically gather data and draw conclusions to identify the preferred methods and create the decision tree the out-of-air firefighter can follow if faced with this reality.

In recent past, there has been no recorded Fishers firefighter in a mayday situation or an out-of-air emergency; however, this does not mean the potential does not exist for it to occur. In

2012, the Fishers Department of Fire and Emergency Services responded to 52 reported building fires (Town of Fishers, 2013). Each of these fires could have provided the setting for an out-of-air emergency. Because this project has the potential to save the lives of firefighters in out-of-air emergencies, it is very significant to the department, as well as the fire service as a whole. The findings of the Fishers Department of Fire and Emergency Services at the conclusion of this project could shape outside departments' views on training for these types of emergencies.

Because of this, the project meets the United States Fire Administration's (USFA) strategic goal to "reduce risk at the local level through prevention and mitigation" (USFA, 2010, p. 13). By educating the firefighter and the organization on how to best deal with the hazardous situation an out-air-emergency creates for all personnel on the fireground, it directly meets this strategic goal of risk reduction. The project also meets a second goal of the USFA, which is to "improve the fire and emergency services' professional status" (USFA, 2010, p. 13). By scientifically testing out-of-air breathing methods, the fire service legitimizes its techniques and teachings and therefore expands professionalism to a larger scale.

This project not only meets strategic goals of USFA, but is also tied directly to the curriculum presented during the National Fire Academy's course Executive Leadership. During this course students are taught to expand their knowledge of the differences of technical and adaptive problems and to use different methods to help aid in the resolution of the problem. One such method is to attack a problem head-on by taking risks (Federal Emergency Management Agency, 2012). The adaptive problem which drives this project has no clear answer at its beginning. Solving the issue by taking a scientific approach is not without risk. Simply from sharing preliminary ideas about the adaptive problem, some have already stated that prevention is the only answer and that educating firefighters on out-of-air emergency procedures fosters a casual attitude toward preventative air management techniques. To not take the risk of researching these methods would be avoiding due diligence in trying to save firefighters' lives in out-of-air emergencies. Scientifically testing the methods, while tedious, is the best way to exercise leadership on this problem with the hope of expanding the knowledge of the fire service both locally and professionally.

Literature Review

Through extensive review, five main breathing methods have been identified as possible ways to aid in isolating a firefighter from the IDLH environment once in an out-of-air emergency. One of the most commonly taught methods is filter breathing using the firefighter's Nomex hood. In order to accomplish this type of filter breathing, a firefighter simply removes the regulator and pulls the hood over the vacated opening in the facepiece. The firefighter then stays as low to the floor as possible to find the cleanest air possible (Gagliano et al., 2008). This method is also taught by the International Association of Firefighters (2010) as the final step in their firefighter self-survival mnemonic GRAB-LIVES where the "S" is to "Shield" one's airway with a hood or glove.

Filter breathing using a Nomex hood has been used in actual out-of-air emergencies. One instance occurred in March, 2000 in Utah where a firefighter battling a residential structure fire became disoriented while following his lieutenant outside as fire and heat conditions rapidly deteriorated. In his attempt to find egress, he ran out of air, removed his facepiece, and turned his Nomex hood around in an attempt to filter out contaminants. When the RIT company found him, he was unconscious and not breathing. He was later pronounced dead at a nearby hospital. The cause of death was determined to be carbon monoxide intoxication with at least 25% saturation (NIOSH, 2000).

In another instance, filter breathing using a Nomex hood might have made a difference. During the previously-described supermarket fire in Phoenix, Arizona, a firefighter became low on air in an attempt to find firefighter Tarver. As he was about to exit, he heard Tarver's voice and located him. At this point he was able to radio for help but his air was now depleted. The firefighter proceeded to pull his hood over his facepiece in an attempt to filter breathe. Approximately three minutes later an officer from an assisting company found and removed the out-of-air firefighter. He was treated for smoke inhalation and survived, despite a carbon monoxide saturation level of 29% (NIOSH, 2002). According to Gagliano et al. (2008), in their book, Rules of Air Management for the Fire Service, "Filter breathing is nothing but a last resort to be used in a clear mayday situation, when firefighters have failed to manage their air. Normally, such desperate measures do not yield positive results" (p.121).

Besides using a hood, a second type of filter breathing has been used in out-of-air emergencies. This method involves placing a breathing tube from the firefighter's mask into an alternate air pocket in hopes the air contained inside has fewer contaminants. Older SCBAs used a large low-pressure hose from the mask to a hip-mounted regulator that made this tactic easy to try. All current SCBAs have replaced low-pressure hoses with mask-mounted regulators. This creates an issue because the new regulator hoses are no longer large enough to use for filter breathing (Gagliano et al., 2008).

Two solutions have been found to keep filter breathing using a tube a viable choice for use during an out-of air emergency. The first solution is to use a vinyl tube sometimes called a Kaminski tube of three feet in length and of 3/8 inch inside diameter. This tubing is simply bought from a local hardware store. The hose is placed through the side of the firefighter's mask and under the nose cup, while the other end is placed at a possible air source, such as inside a coat, inside a wall, or even inside an assisting firefighter's mask (Hackett, 2011). The second solution is a product made by Mayday Air Products and uses a rubber hose and formed plastic fitting that snaps directly into the mask-mounted regulator opening. They currently have products for facepieces manufactured by Scott, MSA, Draeger, and Sperian. According to Mayday Air's website, "The sole purpose of this product is to provide the firefighter with a last ditch effort at obtaining a potential source of breathable air when no other option exists" (http://www.maydayair.com/). The website goes on to offer examples of possible breathable air sources: walls, another firefighter's facepiece, or a firefighter's coat. Other air sources for use with a breathing tube may include pipes and drains, toilet tanks, appliances with closed doors, oxygen cylinders, inside balls, or in cabinets and drawers (Gagliano et al., 2008).

In West Virginia in 1998, a supermarket fire claimed the life of a firefighter when he became disoriented with his officer. Lost and out of air, he detached his regulator hose and placed it in his turnout coat upon the instruction from his officer to do so. He immediately became unconscious and was not found until several hours into the incident (NIOSH, 1998).

During a structure fire in Michigan, in March of 2000, two firefighters became lost while rescuing a civilian. Both eventually ran out of air. One firefighter was able to place a breathing tube into his turnout coat before collapsing into a bathtub. His partner removed his own facepiece and tried to make egress out the bathroom window with no success. The firefighter was eventually pulled from the window but succumbed to his injuries due to asphyxiation. Approximately ten minutes later, moaning was heard from the bathroom by firefighters outside. The firefighter that had initiated the breathing tube method was found alive and survived, suffering smoke inhalation and burns to over 30% of his body (NIOSH, 2001).

Another method taught in the fire service during an out-of-air emergency is to have an existing firefighter share the SCBA regulator with the out-of-air firefighter. This uses whatever air is left in the assisting firefighter's SCBA while attempting to make egress for both (Gagliano et al., 2008). This method was successful in saving a civilian from an apartment fire in August of 2012. A Prince George's County, Maryland firefighter found the civilian gasping for air and disconnected his regulator, sharing his SCBA's air supply with her. They were soon found in a place of refuge and were removed to safety ("Five Maryland," 2012). This method is also taught as facepiece sharing, where the regulator remains attached to the facepiece and the entire facepiece is passed between the two firefighters (Pindelski, 2002).

The fourth main breathing method available for use during a firefighter out-of-air emergency is a product manufactured by Essex Industries called the Last Chance Rescue Filter. The filter fits directly into the SCBA facepiece regulator opening. According to the manufacturer's website, the device will filter contaminants of an IDLH environment to a survivable level for up to fifteen minutes. These IDLH contaminants include carbon monoxide, hydrogen cyanide, hydrogen chloride, hydrogen sulfide, sulfur dioxide, and acrolein. The results of laboratory testing of the Last Chance Rescue Filter provided by Essex Industries are shown in Figure 1.

Last Chance Rescue Filter® has been tested against the following toxic gases

Challenge Gas	Concentration	Allowable Breakthrough	Intermediately Dangerous to Life and Health (IDLH) Levels	Actual Breakthrough
Carbon Monoxide*	2500 ppm	200 ppm**	1200 ppm**	<200 ppm** (24 min)
Carbon Monoxide*	10,000 ppm	200 ppm**	1200 ppm**	<200 ppm** (24 min)
Hydrogen Cyanide	400 ppm	10 ppm	50 ppm	<10 ppm (60 min)
Hydrogen Chloride	1000 ppm	5 ppm	50 ppm	<5 ppm (170 min)
Hydrogen Sulfide	1000 ppm	10 ppm	100 ppm	<10 ppm (390 min)
Sulfur Dioxide	100 ppm	3 ppm	100 ppm	<3 ppm (180 min)
Acrolein (propenal)	100 ppm	0.5 ppm	5 ppm	<0.5 ppm (30 min)

Test data represents laboratory testing of Last Chance Rescue Filter, conducted at AT Labs a unit of Assay Technologies, Pleasanton, CA. Hydrogen Sulfide Test performed at AJE Testing and Research, Boalsburg, PA.

Gas Conditions: Air Flow: 30lpm Constant Flow / Temperature 20 C/ Relative Humidity: 70%
*Gas Conditions: Air Flow: 30lpm Constant Flow / Temperature 25 C/ Relative Humidity: 90%
**Time Weighted Average

Figure 1. Last Chance Rescue Filter Results from Manufacturer Laboratory Testing (http://www.lastchancefilter.com)

In a study published in March, 2010 by the Yale University School of Medicine, the Last Chance Rescue Filter was tested using 13 firefighters who wore the device into a live burn. They recorded vital signs and carboxy-hemoglobin levels of each firefighter, both before and after the burn evolution. Evolutions lasted ten minutes and firefighters performed various activities, such as sitting, walking, or breaching walls, all while wearing standard firefighter personal protective equipment with an SCBA facepiece outfitted with the Last Chance Rescue Filter. No extreme rise in carboxy-hemoglobin levels was noted in these firefighters. Included in the limitations of the report, however, was the inability to test for other chemicals such as hydrogen cyanide without further invasive testing (Cone, Van Gelder, & MacMillan, 2010).

It is important to note, according to Essex Industries (2010), the “Last Chance Rescue Filter is a single use device to be used in smoke and fire environments where there is sufficient oxygen to survive, most structural fires contain sufficient oxygen to sustain life” (p. 2). Normal room air concentration contains nearly 21% oxygen; an environment of only 19.5% oxygen is the threshold for oxygen deficiency (International Fire Service Training Association, 2008). The human body can sustain life at oxygen concentrations as low as 12%, although thought processes and muscle coordination are inhibited (International Fire Service Training Association, 2008, table 5.1). Data collected from the live-burn evolutions showed that oxygen concentrations at the floor level never decreased below 19.0% (Cone et al., 2010, table 1). These findings were mentioned in the report's limitations section stating, "because of the nature of the abandoned building, O_2 levels during the fires may not have been as low as might be seen in an actual structure fire" (Cone et al., 2010, p. 5).

The final main breathing method used by a firefighter in an out-of-air emergency requires an SCBA and the SCBA of an assisting firefighter to have capabilities to directly connect to each other. There are currently two options SCBA manufacturers offer to accomplish this: the Universal Air Connection (UAC) and the Emergency Escape Breathing Support System (EEBSS) (National Fire Protection Association, 2013). The UAC is a standard hose and fitting mandated by the National Fire Protection Association (NFPA) Standard 1981, that allows a firefighter to use a supplying SCBA system to rapidly fill the out-of-air firefighter's air cylinder. This supplying system could be from the assisting firefighter's SCBA or a separate RIT SCBA brought by assisting firefighters. Because of standardization, this connection allows firefighters with differing SCBA manufacturers to give assistance (NFPA, 2013). This line is disconnected once the rapid fill is completed to the desired level, allowing firefighters to move independently (Hackett, 2011). The UAC is only to be used if a life-threatening situation is imminent or has already occurred (NFPA, 2013).

The EEBSS is a hose attached directly to the SCBA that allows the identical hose from an assisting SCBA to be connected. The system allows air to be given from the donor SCBA to the out-of-air SCBA (NFPA, 2013). There is no rapid filling of an SCBA using this system; rather, the hoses stay connected throughout the event and breathing continues as in normal SCBA operations until both firefighters are able to make egress (Hackett, 2011).

The EEBSS is an optional system that many SCBA manufacturers offer. Up until 2013 the use of the EEBSS, even though offered by SCBA manufacturers, was not endorsed by NIOSH. A letter to SCBA manufacturers in 1984 makes this very clear:

> The use of any component, connected, interfaced, or assembled in combination with MSHA/NIOSH certified self-contained breathing apparatus (SCBA) for use as an emergency escape support breathing system or “Buddy Breather” to allow more than one individual access to the apparatus’ life support system(s) either directly or indirectly, automatically voids the applicable certification during its use. (Mozen, para. 2)

Since then, the NFPA (2013) has released a new SCBA standard that does not mandate an EEBSS system but gives approval for a manufacturer to place one on the SCBA. The standard goes on to explain that the system should only be used if more than 600 liters of air is left in the assisting firefighter’s SCBA (NFPA, 2013).

The findings of others obtained while reviewing this literature are crucial to the research of this project for two main reasons. The first is that five main breathing methods were identified for isolating a firefighter from the IDLH environment during an out-of-air emergency. These breathing methods represent the standards taught throughout the American fire service as how one can try to best survive this type of scenario. In the first three breathing methods described, no scientific data could be found on their effectiveness to isolate the firefighter from the IDLH environment. The fourth breathing method, the Last Chance Rescue Filter, has been tested in a laboratory and during the Yale University live-burn study; however, the study only measured the physiological effect of CO on the testing firefighters, not the level of contaminants still permeating the filter during a live fire event. By design, the Universal Air Connection or the Emergency Escape Breathing Support System will not allow contaminants to enter as long as a proper facepiece seal is achieved. Therefore, the first four breathing methods will serve as the foundational methods used for testing throughout this project.

The second way the findings of the literature review will be used is to compare the information collected both through the aforementioned case studies and the scientific data involving the Last Chance Rescue Filter and compare it to the results of this project's research. By doing so, conclusions can be made in order to answer the research questions and formulate a decision tree in the hopes of ultimately saving firefighter lives in out-of-air emergencies.

Procedures

From the information gathered during the literature review process, it was determined that nine different out-of-air breathing methods would be tested. These nine methods are directly correlated to four of the five foundational breathing methods reviewed. They are as follows: (a) filter breathing using a Nomex hood, (b) Kaminski tube breathing from a closed wall opening, (c) Kaminski tube breathing from inside the firefighter's coat, (d) Kaminski tube breathing from the mask of an assisting firefighter, (e) Mayday Air tube breathing from a closed wall opening, (f) Mayday Air tube breathing from inside the firefighter's coat, (g) Mayday Air tube breathing from the mask of an assisting firefighter, (h) regulator sharing between firefighters, and (i) use of the Last Chance Rescue Filter. The Universal Air Connection and Emergency Escape Breathing Support System were not tested. These two systems already undergo extensive testing by the manufacturer in order to ensure no outside contaminants can enter the SCBA system during use.

In order to scientifically test the nine out-of-air breathing methods, a live burn was conducted on May 24th, 2013 at the Central Indiana Public Safety Training and Education Center in Noblesville, Indiana. The burn took place in the Fishers Fire Department Hallway Simulator. The simulator is a burn facility constructed of one shipping container, and it houses two burn rooms, a hallway, and an observation room.

Figure 2. Fishers Fire Department Hallway Simulator

The purpose of the live burn was to create a safe and controlled IDLH environment and to keep it as consistent as possible throughout all nine tests. The burn was conducted in accordance to NFPA 1403. The materials burned were pallets and straw. A burn plan was submitted and approved by the Central Indiana Public Safety Training and Education Center. Two separate water sources were secured for an attack line and an inside safety line as deemed necessary by NFPA 1403.

In order to test the nine methods scientifically, a mannequin head wearing an SCBA facepiece was assembled and made to “breathe” using a pump and hose system through the affixed out-of-air breathing method in the IDLH environment. The IDLH environment directly outside the facepiece and the air that had already passed through the breathing method were simultaneously monitored for contaminants.

To create the breathing mannequin, a head from a deteriorating Rescue Randy mannequin was donated to the project by the Chesterfield-Union Township Fire Department of Indiana. A new Scott AV-3000 facepiece was obtained from the Fishers Department of Fire and Emergency Services. The first steps of the process required the development of a breathing system that could replicate the same volume of air exchange a distressed firefighter would use, while providing an air-tight system. The first ideas for a pumping mechanism included a vacuum motor and a fireplace bellows. The vacuum motor idea was not pursued because the system would only create a constant flow of negative pressure. As this would work to draw contaminants into the mask, it would not truly simulate a breathing firefighter as there would be no pause for exhalation. The fireplace bellows idea was pursued into a preliminary testing phase; however, it was found that the bellows could not be adequately sealed. This would allow contaminants from the IDLH environment, or fresh air from outside the IDLH environment, to possibly mix with the air sample drawn through the breathing method being tested. This could have drastically skewed the results.

Ultimately a large piston-type hand pump, used for inflating air mattresses, was tested and fulfilled all the needed characteristics. The pump used two valves, an inflation valve, and a deflation valve which mimicked inhalation and exhalation. On the upstroke of the piston, air was forced into the pump through the inhalation valve and remained inside the pump until the handle was pushed downwards, at which point the inhaled air was forced through the exhalation valve. Valves were lubricated to ensure air-tight qualities.

The volume of air moved by the pump also made this a prime choice for the system. A firefighter working inside a fire with a heavy workload can consume approximately 100 liters per minute (lpm) of air (Gagliano et al., 2008, table 2-1). Conversely, the average adult at rest consumes only 6 lpm (“Normal Respiratory Rate,” n.d.). The scenario tested was to simulate a firefighter sheltering in place, not under a heavy workload, but still dealing with a stressful situation. A volume of 40 lpm was identified as the target in order to simulate this scenario. Figure 1 shows the Last Chance Rescue Filter was tested in a laboratory at a constant flow of 30 lpm (Essex Industires, 2011). The hand pump used had a volume of 1.4 liters. Therefore, during testing, the pump was cycled at a rate of 25 to 30 times a minute, which gave a total volume moved of 35 to 42 lpm.

Two pieces of clear vinyl tubing with an inside diameter of one-half inch and an outside diameter of five-eights inch, each 10 feet long, was used to transport the air exchange between the pump and the head. The transparency of the tubing allowed observation of visual contaminants flowing through the system during testing. Two holes were drilled on the front of the hollow head in the area of the mouth. Two fittings from the original hand pump hose were used to receive the vinyl tubing and create a snug fit. For transportation purposes, the two 10-foot vinyl hoses were cut near the back of the head. Two double-male fittings made to join tubing allowed the system to be reconnected for testing and usage when needed. Figure 3 shows the mannequin and breathing system ready for facepiece donning, while Figure 4 shows the routing of the vinyl tubing and connection system. The tubing and fittings were then sealed using a rubber-based, non-silicone sealant, both on the outside of the face and behind the front of the face. At this stage in the development process, the head was named the Mannequin for no-Air Respiratory Testing and Evaluation (MART-E).

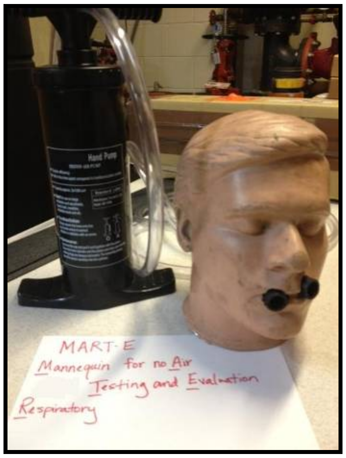

Figure 3.

Figure 4.

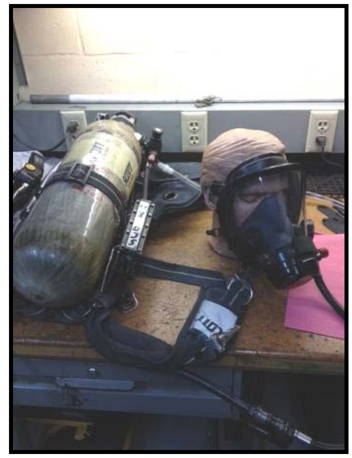

Figure 5.

The Scott facepiece was then secured to MART-E using the same sealant and allowed to cure per the manufacturer's instructions. Once cured, MART-E was placed on an SCBA and the pump cycled to simulate breathing (see Figure 5). The pump was able to easily create the needed negative pressure to open the mask mounted regulator valve and start MART-E breathing from the air cylinder. Since the SCBA is a positive pressure system, a small amount of air was able to be heard coming from a pin-hole sized leak where the facepiece sealed to MART-E under the chin. The leak was resealed and cured. Again, the SCBA was used to preliminarily test the facepiece fit. This time, no air was heard during the breathing cycles. A soap and water solution was then sprayed around the facepiece and face. No leaks were detected using this method either.

Final testing of MART-E and the breathing system required a successful fit test. The Fishers Department of Fire and Emergency Services uses a TSI Portacount Model 8020 quantitative fit testing system in order to test members per Occupational Safety and Health Administration (OSHA) standards. MART-E and the breathing system were connected to the fit testing device in the identical manner as a testing firefighter (see Figure 6). Once fit testing begins, a firefighter is prompted to breathe normally, deeply, in various head configurations, while talking, and while grimacing. Since MART-E was unable to do more than breathe normally or deeply, the other tests were not applicable and normal breathing was used during those sections. MART-E and the breathing system passed with a Fit Factor of 679; anything over 500 is passing. By passing the fit test, one can assume no outside air, whether contaminated or clean, infiltrated the system and skewed results. A copy of the fit test report is listed as Appendix A.

In order to test two of the out-of-air breathing methods, an assisting firefighter was needed. Because there was a chance of the assisting firefighter breathing contaminants, a second breathing system was constructed using an identical hand pump and tubing system; however, a 5-gallon bucket was used to hold the facepiece. In both of these breathing methods, the assisting firefighter was required to break the seal of the facepiece in order to receive the breathing tube from MART-E. Because of this, a two-inch gap was left unsealed on the right side of the facepiece when sealing the facepiece to the bucket. There was no need to fit test the assisting firefighter since an adequate fit would be broken in an actual scenario. Figure 7 shows the assisting firefighter system.

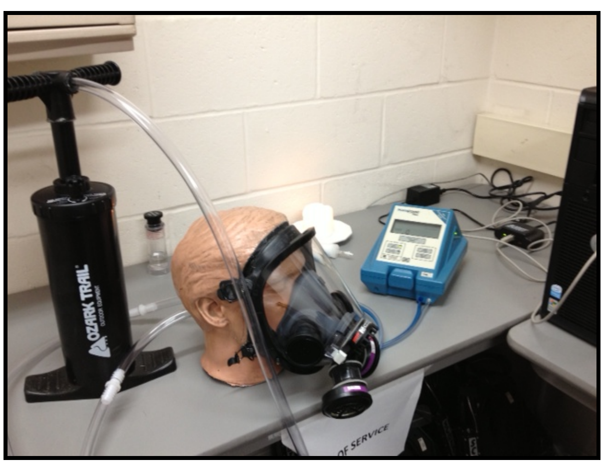

Figure 6.

Figure 7.

In the weeks leading up to the live burn, the Fishers Department of Fire and Emergency Services purchased a vinyl Kaminski tube from the local hardware store, the Mayday Air breathing device, and the Last Chance Rescue Filter from the appropriate vendors. It was imperative that the department purchase all devices outright in order to maintain a level of true independent testing.

An independent wall section was built out of 2x4s and one-half-inch drywall. The seams were sealed with duct tape to try and keep contaminants out, much like drywall mud would. The wall section was approximately seven and one-half feet in height and 18 inches wide. This replicated a normal residential wall cavity. Figure 9 shows the placement of the wall section in the Hallway Simulator.

Because of the importance of air monitoring in the outcome of this project, Jim Seneczko of AFC International Inc. was contacted as a specialist in the area. Mr. Seneczko is the factory representative for the Fishers Department of Fire and Emergency Service's Rae Systems gas monitoring equipment. Mr. Seneczko offered his expertise and attendance at the live burn. The Fishers Department of Fire and Emergency Services provided two Multi-Rae gas detectors equipped with oxygen, carbon monoxide, hydrogen cyanide, hydrogen sulfide, and Lower Explosive Limit sensors. It was determined that the air monitoring would focus on only the oxygen, carbon monoxide, and hydrogen cyanide levels due to their researched importance to provide or inhibit life. Because of this, the hydrogen sulfide and Lower Explosive Limit sensors were removed to avoid damage. Mr. Seneczko brought several more monitoring devices as well as fittings to complete the air monitoring setup.

Setup on the day of the live burn started at 8:00 in the morning. Fishers Division Chief Charlie Fadale, Captain John Mehling, Captain Scott Zelhart, Lieutenant Todd Rielage, and firefighter Robert Hackett were all in attendance at the live burn. Additionally, Wyoming, Ohio Fire Chief Robert Rielage and Jim Seneczko assisted with the live burn and testing process. Apparatus, SCBAs, and equipment were staged. It was determined that the burn would take place in the burn room at the end of the Hallway Simulator, allowing MART-E and the assisting firefighter bucket with corresponding SCBAs to be placed in a separate burn room approximately 25 feet down the hall. Both devices were placed on a pallet approximately two feet from the floor. This was to simulate the height of a crawling firefighter. The breathing tubes for each device were fed through a hole in the base of the exterior wall where the hand pumps were attached. In order to minimize the possible thermal impact upon the vinyl breathing tubes, they were wrapped in towels then dampened with water before the start of the burn (see Figures 8 and 9). A high-temperature thermometer was placed in the room at the height of MART-E to record temperatures.

Upon arrival, Jim Seneczko prepared all three Multi-Rae monitors to be used in testing by removing the unnecessary sensors, calibrating each sensor to be used to the same standard, synchronizing the times between units, and then clearing previous data. All actions taken to the monitors were per manufacturer's specifications. A table was set up 25 feet away from the hallway simulator where Mr. Seneczko could monitor the instruments from a safe distance. The first Multi-Rae was set up to monitor the Hallway Simulator IDLH environment by running a flexible tubing rated for gas monitoring inside a metal tube for protection. This tubing configuration was then fed through a small hole in the base of the exterior wall and placed one foot away but on the same level of MART-E's regulator opening. The monitor was tested using calibration gas to ensure proper operation (see Figure 10).

The second Multi-Rae was set up to sample air passing through the out-of-air breathing method. It was determined that this was best accomplished by teeing into the exhalation tubing. This allows the air pump in the monitor to have positive pressure to aid in delivering the sample to the instrument. The same flexible tubing was used to deliver the air sample from the tee. The third Mulit-Rae was stationed at the air monitoring desk to ensure those outside the Hallway Simulator did not need respiratory protection (see Figure 11). Each Muti-Rae instrument could sample a maximum reading level of 500 ppm of CO and 50 ppm of HCN and was set to record data at 10-second intervals.

Figure 8.

Figure 9.

Figure 10.

Figure 11.

During the live burn, the interior monitor data acted as a control variable throughout all nine tests. The facepiece monitor data served as the independent variable. Although it was nearly impossible to keep identical control variable readings throughout the burn, the independent variable data collection to which it would be compared was being collected at the identical time and place.

Captain Zelhart and firefighter Hackett were tasked with keeping the fire stoked with the goal of producing a smoky IDLH environment with minimal heat and fire progression. Chief Fadale was assigned Incident Command. Chief Rielage and Captain Mehling were assigned to work the hand pumps on the exterior, enabling MART-E and the assisting firefighter to breathe. Lieutenant Rielage was the test facilitator and operated the appropriate out-of-air breathing method when needed. Jim Seneczko was assigned data collection. With set-up complete, a pre-burn briefing was conducted to maximize safety and efficiency of the tests. A radio channel was secured so inside firefighters could communicate with outside personnel for both testing and live-burn information.

At 11:31, with firefighters in their positions, the straw and pallets were lit. Neither MART-E nor the assisting firefighter system had SCBA regulators in place at this time. It took only four minutes for the interior environment monitor to max out at 500 ppm CO and 50 ppm HCN. MART-E was then made to breathe the IDLH atmosphere with no out-of-air breathing method. This was done to make sure the facepiece monitor recorded the same environmental data as the interior monitor. Next, MART-E was placed on the SCBA system and was made to breathe at the predetermined rate of 30 breaths per minute. This demonstrated the recovery time needed in order to clear the facepiece monitor in between breathing method tests.

With the validation of the air monitors as well as the successful operation of MART-E in the IDLH environment, testing of the nine out-of-air breathing methods commenced. Each of the nine tests was run until the facepiece air monitor data matched the interior air monitor data or it was determined that the system could sustain a constant environment inside the facepiece, whichever came first. This would represent the time in which the firefighter would gain nothing more or less from the particular out-of-air breathing method.

Test one commenced at 11:50 and tested filter breathing using a Nomex hood. MART-E started breathing from the SCBA. The test facilitator radioed to the breathing facilitator to pause respirations. This simulates an out-of-air firefighter holding his breath while switching to the chosen breathing method. The regulator was removed while simultaneously pulling the bottom of the hood up over the vacated opening in the facepiece. Breathing was then radioed to begin again. This test lasted two minutes. At this point MART-E was placed back on the SCBA system to return the facepiece air monitoring levels to near zero.

Test two was initiated at 12:01 and tested the Mayday Air tube breathing from inside a firefighter’s coat. With MART-E still breathing from the SCBA, the Mayday Air tube was readied. The test facilitator then radioed to pause respirations. The regulator was removed and the Mayday Air tube inserted into the vacated facepiece regulator opening per manufacturer’s instructions. The tube was then placed inside the test facilitator’s turnout coat and MART-E started respirations. The test lasted one minute, at which point respirations were paused and the tube repositioned into the test facilitator’s turnout coat sleeve in hopes of finding more breathable air. This test lasted another minute. MART-E was then returned to the SCBA system and prepared for the next test.

The third test began at 12:27 and tested the Mayday Air tube into the assisting firefighter’s facepiece. Both the Mayday Air tube and the assisting firefighter were readied. The assisting firefighter was attached to a separate SCBA system. Respirations for MART-E were paused, the Mayday Air inserted into the facepiece regulator opening, and the tube inserted into the assisting firefighter's facepiece gap and under the nose cup. Both breathing system facilitators were radioed to begin respirations. The gap between the tube and the assisting firefighter's facepiece was held tightly to the bucket by the test facilitator and the assisting firefighter's bypass valve on the regulator was then slightly opened. This test lasted two minutes. MART-E was returned to the SCBA system and cleared as in previous tests.

The fourth test was of the Mayday Air tube into a wall section and began at 12:48. Like the previous two tests, the Mayday Air tube was affixed to MART-E once respirations were paused. A hole large enough for the tube to fit into was then created by the test facilitator using a Halligan tool at a height of two feet from the floor. The tube was inserted down into the wall cavity approximately six inches toward the floor. The facilitator's gloved hand surrounded the tube over the wall opening in an attempt to keep out contaminants not already in the wall section. MART-E then breathed through the tube. This test lasted one minute. The SCBA regulator was placed back in the facepiece and breathing continued. At the conclusion of this test, the wall section was removed outside of the Hallway Simulator.

The fifth test commenced at 13:14 and tested regulator sharing between firefighters. In order to test this, MART-E was breathing from the SCBA then made to pause respirations. The regulator was removed for 10 seconds while the breathing was paused. The regulator was then reattached and radioed to breathe for 10 seconds. This process was repeated for six minutes. At the end of six minutes, the method was modified by moderately opening the bypass valve on the regulator to see if this increased effectiveness. This modified test lasted an additional three minutes. At the test's conclusion, the SCBA regulator was returned to the normal operating state and reattached to MART-E for clearing of the facepiece air monitor.

The sixth test used the Last Chance Rescue Filter as the breathing method. Testing began at 13:26 when MART-E respirations were paused after an inhalation. The regulator was detached and the Last Chance Rescue Filter removed from its vacuum-sealed foil package and snapped into the vacated facepiece regulator opening. MART-E was then made to exhale forcefully as instructed by the filter's manual. Breathing then started through the filter at the predetermined rate of 30 breaths per minute. This test lasted eighteen minutes. The facepiece air monitor was then cleared using the SCBA as in previous tests.

Outside the Hallway Simulator, the atmosphere inside the wall section was tested using a Multi-Rae air monitor to ensure levels had returned to normal after its first test. The opening created in the first test was covered using duct tape. The wall section was then placed back into the Hallway Simulator in its previous location in preparation for further testing.

The seventh test began at 14:24 and used the Kaminski tube breathing method into a turnout coat. The Kaminski tube breathing method involves the tube being passed through the side of the SCBA facepiece and into the mouth of the out-of air firefighter. Breathing is done only through the mouth. To simulate this type of seal, the inhalation line was directly attached to the Kaminski tube at the back of MART-E's head using a double male connector. Upon commencement of the test, respirations were paused and the tube placed inside the test facilitator's turnout coat. This test lasted one minute. Like the Mayday Air test, the turnout coat sleeve was then tried for an additional minute in an attempt to find more clean air. The SCBA regulator was then reattached to the facepiece and breathing continued.

The eighth test was using the Kaminski breathing tube placed into an assisting firefighter's facepiece and started at 14:35. The Kaminski tube was connected in the same manner as the previous test, at the back of the head. The regulator was left in place but the

SCBA cylinder of MART-E was turned off and breathed down to simulate running out of air. The Kaminski tube was then placed into the side of the facepiece of the assisting firefighter and under the nose cup. The assisting firefighter was made to breathe while the test facilitator held the gap tightly to the bucket created by the tube. The bypass was opened moderately on the assisting firefighter's facepiece. The test lasted five minutes. The facepiece monitor was then cleared using the SCBA.

The Kaminski breathing tube into a wall was the ninth and final method tested. Testing commenced at 14:41. Breathing was paused and the Kaminski tube was attached to MART-E via the inhalation tube just as in the two previous tests. The SCBA cylinder was turned off. A hole was created by the test facilitator into the wall with a Halligan tool, two feet from the floor. The Kaminski tube was then placed six inches down into the wall towards the floor. Breathing was started. The test lasted one minute.

With testing complete, the fire was fully extinguished and the systems carefully removed from the Hallway Simulator. All equipment was inspected and no thermal or mechanical damage was noted to any piece. Jim Seneczko connected the Multi-Rae air monitors to a laptop and uploaded the data for preservation. General cleaning of the site was completed and equipment was returned to its appropriate locations.

In order to additionally validate the results, it was important to fit test MART-E after testing. On May 28th, 2013 Jim Seneczko met with Lieutenant Rielage and put MART-E to the test. Mr. Seneczko performs fit testing with a machine that uses a different method than that of the Fishers Department of Fire and Emergency Services. The OHD Quantifit machine used creates a small vacuum inside the facepiece and measures the air needed to maintain that vacuum. This method of fit testing is also approved by OSHA, just like the Portacount machine used by the Fishers Department of Fire and Emergency Services. Since the Quantifit requires the subjects to hold their breath, MART-E's inhalation and exhalation tubes were sealed using the same rubber sealant previously used in the project. MART-E was attached to the Quantifit regulator and passed with a fit factor of 3151; anything above 500 is passing (see Figure 12). By passing a fit test after the burn day, it can be assumed no outside air samples indirectly made it into MART-E's breathing system.

Figure 12.

Air monitoring data of the nine tests was carefully compared using the computer software ProRAE Studio II. This program allows the user to review the collected data from the Multi-Rae air monitors in multiple ways. The results of these nine tests are found in the Results section. This data was then compared to the case studies and data cited in the literature review. Analysis allowed conclusions to be made which ultimately led to the answering of the three research questions. Using this information, a decision tree was made in order to aid the Fishers Department of Fire and Emergency Services in the training for out-of air emergencies and possibly save the lives of firefighters.

Because of the complexity of testing and the resources required to carry out such testing, there were several limitations. The first limitation was the inability to create a constant IDLH environment within the Hallway Simulator. Various factors—ventilation properties of the hallway simulator, composition of the materials burned, and water application—all contributed to an inconsistent IDLH environment. These inconsistencies between tests made it difficult to accurately judge the effectiveness of one method over another.

Along with this limitation is the limitation of the air monitors themselves. The maximum reading levels for CO and HCN were reached quickly during some tests. Therefore, it is hard to differentiate if the out-of-air breathing method tested was still providing a better air quality than that of the IDLH environment because both the interior and facepiece monitors were showing maximum levels. Furthermore, because the harsh IDLH environment was monitored for more than three hours, the interior air monitor pump failed with three methods remaining. Since the facepiece monitor was still operational, valid results were still able to be recorded.

Another limitation was the human element of MART-E's breathing system. The breathing system was located on the exterior of the Hallway Simulator in order to keep the system cool and because it made sense logistically. The same person worked the hand pump for this system for each test; however, there was no way of knowing if the goal of moving 40 lpm was able to be maintained consistently throughout all tests. Also, since the commands to breathe and not breathe were all made over a radio, there was no way to be 100% sure that the breathing system was not operated inadvertently at the wrong time during the testing.

Yet another limitation of this research was that each test could only be run one time. Ideally, tests such as these should be run in several identical and then different conditions in order to maximize the results. This would allow comparisons to be made between tests of the same breathing method. Due to funding, logistics, and resources, the Fishers Department of Fire and Emergency Services was able to only test each method once during a single-day burn.

A minor limitation was the inability to get pictures and video of the actual tests from the interior of the Hallway Simulator. This was due to the smoke-filled environment. While it is not necessary to have pictures to perform a valid test, it does aid in the replication of future testing.

Results

The first method tested was filter breathing using the Nomex hood. Data collected for this method is shown in Table 1. Each row denotes a data set recorded each 10-second interval until the conclusion of the test.

Table 1

Complete Results of Filter Breathing Using Nomex Hood

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	11:51:20	500	11	50	7.5
5/24/2013	11:51:30	500	273	50	33
5/24/2013	11:51:40	500	500	50	43.5
5/24/2013	11:51:50	500	500	50	49
5/24/2013	11:52:00	500	500	50	50

Within the first few breaths the filter breathing method showed signs of allowing in contaminants. Thirty seconds into the test, the CO peaked both in the interior and facepiece monitors. Fifty seconds into the test, HCN peaked as well. The color of the air traveling in the breathing tubes was brown. This is consistent with the smoke production observed exiting the Hallway Simulator.

The results of the Mayday Air breathing tube when placed into the turnout coat are depicted in Table 2.

Table 2

Complete Results of Using the Mayday Air Breathing Tube into a Turnout Coat

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	12:01:10	267	42	26.5	22
5/24/2013	12:01:20	261	293	26	50
5/24/2013	12:01:30	255	500	25.5	50

Table 2 clearly shows the facepiece data equaling the interior data within 10 seconds. The facepiece levels then surpassed the interior levels. Since the previously-recorded interior levels (see Table 1) were equivalent to the newly-recorded facepiece levels, it can be inferred that the turnout coat allowed this level of contamination to enter but did not allow it to escape, even as the ambient IDLH levels dropped. When the tube was placed inside the coat and then the sleeve, the contaminants breathed into the facepiece were nearly double that of the interior environment. The air color inside the breathing tubes during this test was observed to match the color of the smoke being produced in the Hallway Simulator.

The results of the third method tested, the Mayday Air breathing tube into an assisting firefighter's facepiece, are depicted in Table 3.

Table 3

Complete Results of Using the Mayday Air Tube into an Assisting Firefighter's Facepiece

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	12:27:40	500	29	50	12.5
5/24/2013	12:27:50	500	250	50	32
5/24/2013	12:28:00	500	345	50	29
5/24/2013	12:28:10	500	364	50	35.5
5/24/2013	12:28:20	500	467	50	42.5
5/24/2013	12:28:30	500	478	50	38.5
5/24/2013	12:28:40	500	431	50	38.5
5/24/2013	12:28:50	500	494	50	48
5/24/2013	12:29:00	500	500	50	50

The contaminant levels of the facepiece during this test spiked within the first twenty seconds, but slowed over the next minute until the interior and facepiece monitor data equalized. As the procedures explained, the method required the test facilitator to tightly hold the seal of the facepiece to the bucket around the breathing tube. The regulator bypass was also slightly opened in an attempt to keep out contaminants. The early elevation in facepiece levels could have been due to the respirations of MART-E starting before the bypass valve was opened. The test facilitator's attempt to hold a tight seal proved to be ineffective, allowing contaminants to enter the assisting firefighter's facepiece and thus to MART-E as well. Several seconds later, the bypass was slightly opened, slowing the rise of the contaminant levels. The air color within the breathing tubes was observed as nearly the same color of that being produced in the Hallway Simulator.

The Mayday Air breathing tube into the wall section was tested fourth and the results are recorded in Table 4.

Table 4

Complete Results of Using the Mayday Air Breathing Tube into a Wall

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	12:47:50	477	42	46	17.5
5/24/2013	12:48:00	500	229	49.5	37.5
5/24/2013	12:48:10	483	358	45.5	46
5/24/2013	12:48:20	442	427	43	50
5/24/2013	12:48:30	442	491	44	50

Like the results showed in the Mayday Air breathing tube using a coat, the wall section contained contaminated air that did not match the ambient environment levels. Instead of equalizing and sustaining, the facepiece monitor levels continued to rise above the interior levels suggesting the wall section trapped the contaminated air levels shown in previous tests and did not allow them to escape as quickly as the interior of the Hallway Simulator. The air observed in the breathing tubes during this test was the same color as the smoke produced in the Hallway Simulator.

The breathing method of regulator sharing was tested and the data is shown in Table 5. Since this test lasted over eight minutes, rows in Table 5 show data at one-minute intervals. The complete data set for the regulator breathing method can be found in Appendix B

Table 5

Selected Results of Regulator Sharing with an Assisting Firefighter

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	13:15:00	500	5	46	0
5/24/2013	13:16:00	500	21	50	2
5/24/2013	13:17:00	453	18	35	2
5/24/2013	13:18:00	328	10	24.5	1
5/24/2013	13:19:00	260	9	18.5	.5
Bypass valve opened on regulator					
5/24/2013	13:20:00	211	146	14.5	10.5
5/24/2013	13:21:00	184	10	12	1.5
5/24/2013	13:22:00	159	2	10.5	0
5/24/2013	13:23:00	500	0	50	0

This method was shown to be sustainable for an indefinite period of time as long as the assisting firefighter has air in the SCBA cylinder. From 13:15 to 13:19 the test was run with no bypass open. At the 13:20 mark, the bypass was opened moderately. The rise in levels at the 13:20 mark was due to an inadvertent respiration through MART-E. The levels quickly lowered once the technique was reestablished. The difference between the regulator sharing with and without the bypass in operation is minimal when analyzing strictly contaminant levels. Air color contained in the breathing tubes was observed to be clear.

Results of the test involving the Last Chance Rescue Filter are listed in Table 6. Because this test lasted twenty minutes, each row in Table 6 records data at one-minute intervals. The full set of data recorded for the Last Chance Rescue Filter is contained in Appendix C.

Table 6

Selected Results of Using the Last Chance Rescue Filter

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	13:28:00	461	0	34.5	0
5/24/2013	13:29:00	370	278	27	50
5/24/2013	13:30:00	299	251	21.5	50
5/24/2013	13:31:00	251	359	17.5	50
5/24/2013	13:32:00	500	430	50	50
5/24/2013	13:33:00	500	310	46	50
5/24/2013	13:34:00	500	359	50	50
5/24/2013	13:35:00	500	299	44.5	50
5/24/2013	13:36:00	482	240	38.5	50
5/24/2013	13:37:00	337	188	27	41
5/24/2013	13:38:00	364	144	24.5	32.5
5/24/2013	13:39:00	407	161	25	30.5
5/24/2013	13:40:00	428	171	25.5	32
5/24/2013	13:41:00	411	152	25	30
5/24/2013	13:42:00	450	171	26	32
5/24/2013	13:43:00	432	179	24	33
5/24/2013	13:44:00	412	170	22	30.5
5/24/2013	13:45:00	416	175	21	29
5/24/2013	13:46:00	438	481	23	40.5
5/24/2013	13:47:00	453	241	27	38
5/24/2013	13:48:00	500	217	32.5	36
5/24/2013	13:49:00	500	256	50	50
5/24/2013	13:50:00	495	281	41	50

The Last Chance Rescue Filter was able to convert approximately half of the CO ppm to harmless CO_2 for twenty minutes, which drastically increases a firefighter's chance at survival. The HCN, however, immediately spiked inside the mask to levels greater than those inside the Hallway Simulator. A possible explanation could be that the Last Chance Rescue Filter is converting HCN to another harmless gas that gives a false reading as HCN on the monitor. Another possible explanation is the HCN sensor could have failed. This is not as likely since the HCN readings produced for the later tests were all logical.

To finish out the burn day, the Kaminski breathing tube methods were tested, the first of which used the turnout coat as the air source. The results of this test are shown in Table 7.

Table 7

Complete Results of Using the Kaminski Breathing Tube into a Turnout Coat

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	14:24:10	--	6	--	4.5
5/24/2013	14:24:20	--	228	--	50
5/24/2013	14:24:30	--	500	--	50

Note. "--" denotes data unable to be obtained.

This test lasted only 30 seconds. The interior air monitor pump failed before this test commenced so this data is unavailable. Because the facepiece levels increased so quickly, it can be inferred that the interior of the Hallway Simulator had increased levels. One cannot easily compare the Mayday Air breathing tube using a turnout coat with this method since the Mayday Air tube facepiece levels were recorded at greater levels than that of the interior environment. Observation of the air color in the breathing tubes of MART-E was brown, identical to the smoke being produced by the Hallway Simulator.

The second Kaminski breathing tube test used the assisting firefighter as the air source. These results are shown in Table 8. Data in Table 8 is shown in one-minute intervals. Complete results of this method are found in Appendix D.

Table 8

Selected Results of Using a Kaminski Breathing Tube into an Assisting Firefighter's Facepiece

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	14:35:00	--	6	--	3.5
5/24/2013	14:36:00	--	6	--	3
5/24/2013	14:37:00	--	5	--	2.5
5/24/2013	14:38:00	--	5	--	2
5/24/2013	14:39:00	--	4	--	2
5/24/2013	14:40:00	--	4	--	1.5

Note. "--" denotes data unable to be obtained.

The testing lasted seven minutes for this method and showed that one could sustain minimal CO and HCN levels using the assisting firefighter's air supply. Like the Mayday Air tube that used an assisting firefighter, this method required the test facilitator to hold the facepiece seal tightly to the bucket around the Kaminski tube. The interior air monitor was still unavailable for this test, but smoke conditions inside were similar to previous testing conditions. Also, looking at the high facepiece levels recorded in Table 9 for the next method, only one minute after the conclusion of this method, one can assume the interior environment was high in IDLH levels. The air color in MART-E's breathing tubes was clear. The smoke coming from the Hallway Simulator was brown.

The final method tested was the Kaminski breathing tube into the wall. These results are recorded in Table 9.

Table 9

Complete Results Using the Kaminski Breathing Tube into a Wall

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	14:41:20	--	155	--	23
5/24/2013	14:41:30	--	460	--	39.5
5/24/2013	14:41:40	--	500	--	42.5
5/24/2013	14:41:50	--	500	--	43
5/24/2013	14:42:00	--	500	--	43
5/24/2013	12:42:10	--	500	--	43.5
5/24/2013	12:42:20	--	500	--	44

Note. "--" denotes data unable to be obtained.

The data for this method shows that the wall environment was filled with a high level of contaminants. Even with the interior air monitor not functional, one can still assume that the levels were moderate to high due to the amount of smoke being produced in the Hallway Simulator at the time of this test. One cannot infer, however, that the levels were as high as the levels in the wall cavity and ultimately the facepiece. This is because the Mayday Air tube data showed the wall has the ability to hold elevated CO and HCN levels even if the levels in the ambient environment were dropping. What is known is the facepiece levels for this method showed significant CO and HCN levels within 30 seconds.

Oxygen concentrations throughout all nine tests never fell below 18.5% in the interior of the Hallway Simulator. During eight of nine tests, the data showed the oxygen concentration to be over 19%. These levels would support life. Temperatures inside the room containing MART-E never exceeded 110 degrees Fahrenheit.

The first research question asks which commonly-taught out-of-air breathing methods best allow firefighters to survive when they can be assisted by an able firefighter. The breathing methods tested that use an able firefighter to aid the out-of-air firefighter are the Mayday Air breathing tube into the assisting firefighter's facepiece, the Kaminski breathing tube into the assisting firefighter's facepiece, and regulator sharing. The use of the Universal Air Connection and use of the Emergency Escape Breathing Support System were identified as additional options in the literature review and will be analyzed as well.

The UAC and EEBSS systems allow no contaminants to enter the SCBA system. The UAC allows the rapid filling of the out-of-air firefighter's SCBA while then disconnecting, facilitating independent moving of each firefighter. The EEBSS easily allows the out-of air firefighter to tap into an assisting firefighter's air supply while taking only what air is needed per the demand. The EEBSS requires the system to stay connected in order to function, limiting mobility. Because of this, the use of the UAC best allows firefighters to survive when they can be assisted by able firefighters. Ideally, the assisting firefighter can control the filling of the out-of-air firefighter's SCBA so that only enough air needed to manage the emergency is donated. This leaves more air in the assisting firefighter's SCBA for safety. Another connection can always be made if more air needs to be transferred.

Mobility is decreased with the EEBSS method, but more importantly, there is no mechanical regulation of air consumption. Unlike using the UAC, which creates two separate air supplies once complete, the EEBSS only facilitates one at a time. Breathing rates need to be managed by each firefighter no matter which method is chosen, but when using the EEBSS, the breathing rate of one firefighter in the system directly affects the outcome of the other firefighter's air status situation. This makes the usage of the UAC preferred.

Although the EEBSS system tethers the two firefighters together and is not preferred over the UAC, these two methods are both still preferred over regulator sharing and using either the Kaminski or Mayday Air tubes with an assisting firefighter because no IDLH contaminants are able to enter the SCBA system. Analyzing the data for the other three breathing methods (see Tables 3, 5, and 8), there are two that created a consistent environment to support life: regulator sharing and the Kaminski tube into the assisting firefighter's facepiece.

Regulator sharing with the bypass valve moderately open created the least contaminated environment and could be sustained as long as the assisting firefighter had air. Regulator sharing with the bypass closed only raised the CO and HCN levels slightly. With the median CO level at 13.7 ppm and median HCN level at 1.3 ppm with the bypass closed, these levels are still well within survivability levels. Furthermore, the maximum level reached of each, when regulator sharing without the bypass, does not ever approach the threshold requiring SCBA usage at 35 ppm for CO and 5 ppm for HCN. Because the bypass valve quickly depletes the air of the assisting firefighter, it needs to be used sparingly. Since the difference between using the bypass open or closed is minimal, regulator sharing with an open bypass should not be used. Air usage needs to be triaged in a low-air, or in this instance, an out-of-air emergency. The breaths saved by not using the bypass for a period of time outweigh the risks of breathing the minimal contaminants as discussed.

Additionally, recognition needs to be given to the fact that regulator sharing testing was performed without the human element. Regulator sharing takes a significant amount of discipline by both firefighters to accomplish without exposure to the ambient IDLH environment. Nothing prevents the firefighter without the regulator from inhaling except the discipline received through training. Both firefighters need to work together to breathe just enough air to keep moving before passing it to the other. The chances for failure of this method is great and should only be attempted by firefighters who have had extensive training and are still of sound mind.

Kaminski tube breathing using an assisting firefighter produced more survivable results compared to the Mayday Air breathing tube using an assisting firefighter; however, these two tests were not run identically. The Kaminski tube used the bypass valve moderately open, while the Mayday Air tube only used the bypass valve in the slightly open position. The results in Table 3 showed CO and HCN still significantly made their way into both MART-E's and the assisting firefighter's facepiece while using the Mayday Air tube. Both the Kaminski and Mayday Air tubes create a tight seal with the out-of air firefighter either by placing the tube in the mouth or by snapping a plastic adapter into the facepiece, respectively. Therefore, only two things can allow contaminants to enter: the lack of a seal on the facepiece and the amount of pressure pushing contaminants out of the facepiece through that broken seal. This is verified by the successful test of the Kaminski tube as recorded in Table 8. Because of this, the data supports that whenever an attempt is made to use a breathing tube of any nature from an out-of-air firefighter to an assisting firefighter's facepiece, the seal needs to be held as tightly as possible and the bypass at least halfway open. Had these two parameters been met during the Mayday Air breathing tube method, the results of would have been closer to that of the Kaminski breathing tube method.

Like regulator sharing, air conservation is of the greatest importance while using a breathing tube with an assisting firefighter; however, unlike regulator sharing, the use of the bypass valve is a necessity while using a breathing tube with an assisting firefighter. Further, the use of Kaminski and Mayday air tubes allow both firefighters to breathe at the same time. While this is good to ensure each firefighter has air to breathe when needed, it also can use the air much more quickly than during regulator sharing. This, coupled with the use of the bypass valve, can drain an SCBA cylinder even faster if proper breathing techniques are not used to conserve the shared air supply.

All three of these breathing methods require the firefighter to stay attached to the assisting firefighter. The Kaminski or Mayday Air tube length between both masks is the maximum distance a firefighter can stray from the other. In most cases, this is three feet or fewer. There is also a chance the tube is pulled out of one or both facepieces if the firefighters hit an obstruction or go in different directions. Regulator sharing requires the assisting firefighter to control the regulator in use as well as the out-of-air-firefighter. Maximum distance between the two firefighters is less than two feet with this method.

After careful consideration of all the data, if a UAC or EEBSS is not available, the out-of-air breathing method that best allow firefighters to survive when they can be assisted by an able firefighter is the regulator sharing without the use of the bypass if they are trained and disciplined, while still of clear mind. If an out-of-air firefighter is not of clear mind, is not trained, or is not disciplined, a Kaminski or Mayday Air breathing tube into the assisting firefighter's facepiece with the bypass valve at least halfway open is the best option. In the instances where there is an able firefighter ready to assist, the choice of breathing method needs to be made by the assisting firefighter.

The second research question asks which commonly-taught out-of-air breathing methods best allow firefighters to survive when they are isolated from other resources and firefighters. The methods tested used in out-of-air emergencies where a firefighter is alone are filter breathing using a Nomex hood, the Mayday Air breathing tube into a turnout coat, the Mayday Air breathing tube into a wall, the Last Chance Rescue Filter, the Kaminski breathing tube into a turnout coat, and the Kaminski breathing tube into a wall.

Based on the data obtained during testing, the method that best allows firefighters to survive when they are isolated from other resources and firefighters is the Last Chance Rescue Filter. The Last Chance Rescue Filter showed promise in improving the air quality entering the facepiece mainly by dropping the CO levels below 200 ppm for twenty minutes. The HCN levels obtained, which were greater than that of the interior environment, were inconsistent with the testing done by the product manufacturer. Because the filter blocked the large particulate as well as dealt with the CO effectively, it out-performs the other methods tested.

It is important to note that there is a large drop off of survival chances when the other four methods must be used instead of a Last Chance Rescue Filter or any of the methods with assisting firefighters. Studying Tables 2, 4, 7, and 9 shows that none of the remaining methods gave the firefighter more than a minute of better air quality than that recorded in the interior of the Hallway Simulator. Therefore, these methods are essentially equal in their inability to sustain life.

Other factors need to be taken into consideration in order to make an informed decision. If an out-of-air firefighter is without a Last Chance Rescue Filter and is not near an assisting firefighter, it needs to be determined whether or not the firefighter knows the way out. If the firefighter does know the way out, everything possible should be done to remain mobile and make it to the egress. This means placing the Kaminski or Mayday Air tube inside the turnout coat. As the firefighter enters what may be determined to be less of an IDLH environment, the method should be switched to filter breathing using a Nomex Hood. This is because the turnout coat could contain a high level of contaminants from the previous IDLH environment.

If the out-of-air firefighter does not know the way out, and it is determined that sheltering in place is the best option, then placing the Kaminski or Mayday Air breathing tube into a wall will possibly provide a more abundant supply of cleaner air than the turnout coat. The possibility also exists, as seen in Table 4, that the environment contained within the wall is harsher than the environment outside the wall. Therefore, the firefighter must try and choose a wall that has not been impacted as much by an IDLH environment. Walls further away from and not directly above the fire will give the best possibility of providing a survivable air supply. If at any point the firefighter needs to move, the Mayday Air or Kaminski tube should be placed into the turnout coat in the manner previously discussed. If the firefighter does not have a Kaminski or Mayday Air tube, filter breathing using a Nomex hood should commence.

The third question asks how should commonly-taught out-of-air breathing methods be prioritized for use and which should be omitted from future protocols based on the data collected and the circumstance of the emergency. Discussions of the first two research questions answered which breathing methods should be prioritized based on if the firefighter is alone or with an assisting firefighter. Also discussed was which method to use based on circumstances such as knowing where an egress is, if the firefighter has decided to shelter in place, or if the firefighters are well-trained in regulator sharing. These method priorities have been compiled into a decision tree for ease of teaching and research. The Firefighter Out-of-Air Breathing Method Decision Tree is included as Appendix E.

If firefighters truly find themselves in an out-of-air emergency, they should never lose hope. If firefighters have multiple breathing methods to cycle through as discussed, it keeps them focused on maximizing their air supply. Some methods discussed did not show favorable results during testing; however, firefighters in the past have survived using some of these same techniques. These test results were produced on one occasion with one set of IDLH circumstances. Breathing rates, breathing methods available, fire, smoke and heat conditions, structural components, training, and mental resiliency all contribute to the outcome of the out-of-air emergency. Because each out-of-air emergency is different, no breathing method can be completely omitted.

Discussion

When comparing the results of the nine tests to the information on the five breathing methods identified in the literature review, there are some distinct differences. The results for filter breathing using a Nomex hood showed the method to be very limited in its ability to filter out contaminants. No other data could be found on this method to which to compare these results; however, there have been reported cases of firefighters successfully using the filter breathing with a Nomex hood. The Phoenix, Arizona case study is one example where more than one firefighter survived using this technique (NIOSH, 2002). The results collected are logical. The Nomex hood would have no way to filter out any contaminants except large particles in smoke. The fires in which these firefighters used this technique and survived had to have either been lower in contaminant levels at the time of their out-of air-emergency, or the firefighters were found or exited within a couple minutes, as in the case with the Phoenix supermarket fire.

Methods using a breathing tube into an alternate air source such as a turnout coat or wall as outlined in the literature review also had no data found to which to directly compare the results. The results did show that both the turnout coat and the wall will hold a previous atmospheric condition. Unfortunately, as the results displayed, this means that it may hold a more contaminated environment than the ambient environment if conditions have improved. It does give the possibility, however, of the wall or turnout coat holding less-contaminated air, especially in the early stages of firefighting. The Michigan case study in the literature review shows that a firefighter could survive using the turnout coat technique (NIOSH, 2001).

Using a breathing tube into an assisting firefighter's facepiece and regulator sharing showed excellent potential in saving a firefighter's life if help was available. Research yielded no data to which to compare these results. One case study does back up these results, however. In Prince George's County, Maryland a civilian was successfully saved when a firefighter shared his regulator with her as they sheltered in place and awaited rescue ("Five Maryland," 2012).

Essex Industries, maker of the Last Chance Rescue Filter, provided results of their testing on their website as shown in Figure 1. According to manufacturer testing, CO levels were recorded to average below 200 ppm even with ambient levels as saturated as 10,000 ppm (Essex Industries, 2011). This is close to the results gathered from this project. Over twenty minutes the average CO allowed to break through was 245 ppm. This level of CO is well below the IDLH level and can be tolerated by a firefighter making egress or awaiting a RIT company.

The HCN data from manufacturer testing is also shown in Figure 1. Their results described less than a 10 ppm breakthrough into the facepiece (Essex Industries, 2011), while the results from this project showed levels peaking at 50 ppm and sometimes twice that of the environment of the Hallway Simulator. Since this result is inconsistent with the manufacturer's research, Essex Industries was contacted and the Fishers Department of Fire and Emergency Services provided the results of this test. At the time of publication, Essex Industries showed great interest and was actively trying to find a plausible answer to the result inconsistencies through further independent testing of the Last Chance Rescue Filter. Because the results of manufacturer and project testing showed the filter could minimize the impact of CO, and manufacturer testing shows that HCN is minimized as well, it is superior to the other options when a firefighter is isolated. Because a firefighter who uses the Last Chance Rescue Filter is still exposed to the contaminants of smoke, the firefighter needs to be aggressively treated for smoke inhalation, including oxygen delivery and possibly a cyano-kit, which is a proven antidote for HCN poisoning.

Another interesting comparison is that of the oxygen levels recorded through the testing. No levels fell below 18.5%. Similarly, testing with the Last Chance Rescue Filter performed by Yale University showed no oxygen levels below 19.0% (Cone et al., 2010). These two studies show that there could be sufficient oxygen to continue life within a structure fire. Each fire is different, and therefore, there can be no guarantee of these numbers. Variables such as type of material burning, amount of material burning, size and shape of container, and ventilation properties all affect oxygen concentration in fires.

When analyzing the results of the project as a whole, it is safe to state that when faced with an out out-of-air emergency, the chances of survival increase drastically when an assisting firefighter is available. The breathing methods that use an assisting firefighter tap into that firefighter's air supply and allow initially non-contaminated air to reach the out-of-air firefighter. The EEBSS and UAC allow no contaminants to enter and far outweigh any other method tested. The drawback is the assisting firefighter must donate a portion of air supply to the aid of the firefighter in need, which is an inherently dangerous choice in an IDLH environment. However, this could be the only chance at survival for the out-of-air firefighter and one would assume most firefighters would freely do this to render aid to a brother or sister firefighter in need.

With the other assisting firefighter methods, such as regulator sharing and breathing tubes into the facepiece, the same non-contaminated potential exists but technique, training, and availability could hamper these efforts, allowing in harmful contaminants to one or both firefighters. These methods also hold the potential to deplete the assisting firefighter's air supply as in EEBSS and UAC methods. Because of this potential, the Last Chance Rescue Filter is recommended for use when a firefighter does not have an EEBSS or UAC available. The Last Chance Rescue Filter has proven to filter out enough contaminants to give an out-of-air firefighter additional time to find an egress or be rescued. Even though the Last Chance Rescue Filter is in use, an assisting firefighter should lead the way to safety, always remaining accountable for the out-of-air firefighter. By using the Last Chance Rescue Filter, the assisting firefighter's air supply is not affected. Breathing at a normal consumption rate aids in decisions on routes of travel and navigation of potential hazards while leaving the IDLH environment.

If a breathing tube or regulator sharing is the best option, self-discipline by both firefighters is essential to survival. The results of the Kaminski tube with an assisting firefighter proved that these techniques can be successful. The drawback is both firefighters' lives are now at stake when these techniques are employed. They should therefore only be performed when both firefighters have been trained and are proficient in their use. They must both be of sound mind as well. If one firefighter is irrational for whatever reason, the other must choose the best option for aiding egress without over committing to an irreversible situation.

If a firefighter is alone and without a Last Chance Rescue Filter, chances of survival decrease, especially if the exit is not known. The results show that the best option at this point of putting a breathing tube into your turnout coat or into a wall will only give you approximately a minute or less of air with the final option being the use of a Nomex hood to filter breathe. Regardless of the method tried, it is imperative that the firefighter try to remain as calm as possible and think through the situation. Maintaining situational awareness and controlling one's breathing, no matter what breathing method is employed, will aid the chances of the firefighter's survival.

The implications of these results for the Fishers Department of Fire and Emergency Services are two-fold. The first is the department needs to determine what stance to take with out-of-air emergency prevention verses mitigation. The department has aggressively started teaching air management techniques over the last several months. Adding in the teachings of these tested breathing methods could be seen as a deviation from an out-of-air emergency prevention strategy. Careful thought needs to go into where to put the emphasis in training so that firefighters understand the importance of both.

The other implication is the Fishers Department of Fire and Emergency Services needs to decide what equipment, if any, to issue in order to employ several of the out-of-air breathing methods tested. The department does have the capability of using the EEBSS installed on the SCBA; however, there is no standard operating guideline on its usage. The UAC is available but can only be used when a RIT company arrives with a bag containing an alternate air cylinder equipped with this valve. No breathing tubes are endorsed by the department, and very few firefighters carry one. The department has also not yet purchased any Last Chance Rescue Filters for emergency use. Cost of the Last Chance Rescue Filter is significant and could be prohibitive.

Recommendations

There are four main recommendations based on the research. The first is for the Fishers Department of Fire and Emergency Services to purchase a Last Chance Rescue Filter for each apparatus seat in the fleet. As the data shows, the Last Chance Rescue Filter surpasses all other methods when a firefighter is isolated from other resources. Because the department has the ability to use an EEBSS through their SCBAs, there would be minimal need for the Last Chance Rescue Filter to be used if the out-of-air firefighter was assisted by another firefighter.

If the purchase of the Last Chance Rescue Filter is delayed, it is recommended that the department endorse the use of a breathing tube method, such as a Mayday Air tube or Kaminski tube for instances when an out-of-air firefighter is isolated. Testing only occurred with two possible air sources, a wall and a turnout coat. Many more possibilities exist for finding air, such as an exterior window, oxygen tanks, pipes, and toilet tanks. These tubes could be used to extract air from many possible locations. Having this option available far outweighs the alternative.

The second recommendation is for the Fishers Department of Fire and Emergency Services to continue stringent air management training followed by the use of the Firefighter Out-of-Air Breathing Method Decision Tree. Fishers firefighters need to be proficient in these methods because emergency situations are unpredictable. Every effort can be made to prevent the out-of-air emergency, and while this ideology needs to be at the forefront, some situations can occur which create this danger regardless of preparation. Training on how to use the decision tree and how to best utilize each out-of-air breathing method is essential for the survivability of the firefighter. Both prevention and mitigation need to be taught as a unified approach to SCBA air usage.

The third recommendation is for further testing of the out-of-air breathing methods described. These results were derived from one live-burn testing day where each method was tested only once. Tests need to be run multiple times in order to get a result average. Variations are suggested for future testing: differing smoke conditions, heat conditions, and timing conditions.

Differing smoke conditions should be utilized in order to test the same method several times to observe if the performance of the method is affected. It is possible that a method may perform well up to certain levels but then fail, while others may show their worth in environments with higher contaminant levels. Heat condition variations need to be made for the same reason. At some point a breathing method could break down due to pyrolysis, thus adding to the contaminant level and rendering it ineffective. Timing of the method test also needs to be varied, especially in the methods involving an alternate air source such as a wall or turnout coat. Results may vary if used within the first five minutes of IDLH exposure verses after thirty minutes. It is also recommended that future testing involve more alternative trapped air sources, such as ovens, refrigerators, and toilet tanks. Based on this data, a separate list could be generated on which alternative trapped air sources are preferred.

Furthermore, the Fishers Department of Fire and Emergency Services needs to continue to work with Essex Industries to come to a conclusion regarding the inconsistent HCN results shown in the Last Chance Rescue Filter testing. At the time of publication, Essex Industries had shown interest in possibly aiding the department in future test burns. Results of their expanded independent testing prompted by this project's data were not yet complete.

The final recommendation is that the Fishers Department of Fire and Emergency Services take a leadership role in the areas of out-of-air emergency prevention and mitigation. This entails publicizing the results and recommendations of this research and actively taking part in future research and development. This also means championing the need nationally for firefighters to be trained and proficient in the use of both out-of-air emergency prevention techniques and mitigation methods.

Future readers need to realize that this research was performed when the Emergency Escape Breathing Support System and Universal Air Connections were not available on all SCBAs in use in the United States. Furthermore, the out-of-air breathing methods described are meant for life-threatening situations only. This research was performed with the intention of aiding the Fishers Department of Fire and Emergency Services as well as the future reader by expanding the knowledge base on this topic so that informed decisions can be made regarding the best mitigation of these emergencies. Future readers need to analyze the data and come to their own conclusions based on the needs and resources of their particular fire departments.

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Appendix A

Fit Test Record

05/13/2013

LAST NAME HEAD
FIRST NAME MART-E

FIT TEST REPORT

ID NUMBER	TEST		
LAST NAME	HEAD	**PFT**	N
FIRST NAME	MART-E	**GLASSES**	N
COMPANY	EFO	**SIZE**	L
LOCATION	RIELAGE	**CUSTOM4**	TEST
NOTE			
TEST DATE	05/13/2013	**PORTACOUNT S/N**	80246487
TEST TIME	20:53	**N95-COMPANION**	N
DUE DATE	05/13/2014		
RESPIRATOR	SCOTT AV3000 AV3000 [500	**PROTOCOL**	OSHA 29CFR1910.134
MANUFACTURER	SCOTT	**PASS LEVEL**	500
MODEL	AV3000		
MASK STYLE	AV3000	**APPROVAL**	
MASK SIZE	L	**EFFICIENCY <99%**	N

EXERCISE	DURATION (sec)	FIT FACTOR	PASS
NORMAL BREATHING	60	522	Y
DEEP BREATHING	60	774	Y
HEAD SIDE TO SIDE	60	804	Y
HEAD UP AND DOWN	60	566	Y
TALKING	60	732	Y
GRIMACE	15	Excl.	
BENDING OVER	60	786	Y
NORMAL BREATHING	60	691	Y
OVERALL FIT FACTOR		679	Y

FITTEST OPERATOR ______________________ **DATE** __________
CAPTAIN ZELHART

NAME ______________________ **DATE** __________
MART-E HEAD

Appendix B

Complete Results of Regulator Sharing with an Assisting Firefighter

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	13:15:00	500	5	46	0
5/24/2013	13:15:10	500	5	48.5	0
5/24/2013	13:15:20	500	10	50	0
5/24/2013	13:15:20	500	11	50	0
5/24/2013	13:15:40	500	12	50	0.5
5/24/2013	13:15:50	500	11	50	0
5/24/2013	13:16:00	500	13	50	1.5
5/24/2013	13:16:10	500	21	50	2
5/24/2013	13:16:20	500	24	49	2.5
5/24/2013	13:16:30	500	29	45	3
5/24/2013	13:16:40	500	29	41	2.5
5/24/2013	13:16:50	484	23	38	1.5
5/24/2013	13:17:00	453	18	35	2
5/24/2013	13:17:10	426	20	33	2
5/24/2013	13:17:20	401	17	30.5	1.5
5/24/2013	13:17:30	380	16	29	2
5/24/2013	13:17:40	361	15	27	1.5
5/24/2013	13:17:50	343	9	25.5	0.5
5/24/2013	13:18:00	328	10	24.5	1
5/24/2013	13:18:10	314	9	23	1
5/24/2013	13:18:20	302	10	22	1
5/24/2013	13:18:30	289	8	21	1
5/24/2013	13:18:40	278	7	20	0.5
5/24/2013	13:18:50	269	11	19	1
5/24/2013	13:19:00	260	9	18.5	0.5
5/24/2013	13:19:10	252	5	18	0
5/24/2013	13:19:20	244	3	17	0.5
5/24/2013	13:19:30	237	3	16.5	0
5/24/2013	13:19:40	229	3	16	0
5/24/2013	13:19:50	223	45	15.5	9.5
5/24/2013	13:20:00	217	136	14.5	24.5
5/24/2013	13:20:10	211	146	14.5	10.5
5/24/2013	13:20:20	205	79	14	6.5
5/24/2013	13:20:30	200	47	13.5	4
5/24/2013	13:20:40	194	25	13	2.5
5/24/2013	13:20:50	189	14	12.5	1.5
5/24/2013	13:21:00	184	10	12	1.5
5/24/2013	13:21:10	179	7	12	1.5
5/24/2013	13:21:20	175	5	11.5	1
5/24/2013	13:21:30	170	4	11.5	1
5/24/2013	13:21:40	166	3	11.5	1
5/24/2013	13:21:50	162	2	11	0
5/24/2013	13:22:00	159	2	10.5	0
5/24/2013	13:22:10	155	2	10.5	0.5

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	13:22:20	151	0	10	0.5
5/24/2013	13:22:30	339	0	31	0.5
5/24/2013	13:22:40	486	0	35	0
5/24/2013	13:22:50	500	0	47	0
5/24/2013	13:23:00	500	0	50	0
5/24/2013	13:23:10	500	0	47	0
5/24/2013	13:23:20	500	0	43	0
5/24/2013	13:23:30	500	0	39.5	0
5/24/2013	13:23:40	500	0	36.5	0
5/24/2013	13:23:50	500	0	34	0.5

Appendix C

Complete Results of Using the Last Chance Rescue Filter

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	13:28:10	461	0	34.5	0
5/24/2013	13:28:20	439	24	32.5	32.5
5/24/2013	13:28:30	420	151	31	50
5/24/2013	13:28:40	402	218	29.5	50
5/24/2013	13:28:50	385	249	28	50
5/24/2013	13:29:00	370	278	27	50
5/24/2013	13:29:10	356	287	26	50
5/24/2013	13:29:20	344	287	25	50
5/24/2013	13:29:30	332	272	24	50
5/24/2013	13:29:40	321	262	23	50
5/24/2013	13:29:50	309	249	22	50
5/24/2013	13:30:00	299	251	21.5	50
5/24/2013	13:30:10	290	265	20.5	50
5/24/2013	13:30:20	281	286	20	50
5/24/2013	13:30:30	273	302	19.5	50
5/24/2013	13:30:40	265	328	19	50
5/24/2013	13:30:50	258	345	18	50
5/24/2013	13:31:00	251	359	17.5	50
5/24/2013	13:31:10	244	370	17	50
5/24/2013	13:31:20	237	386	16.5	50
5/24/2013	13:31:30	370	402	37	50
5/24/2013	13:31:40	500	415	50	50
5/24/2013	13:31:50	500	429	50	50
5/24/2013	13:32:00	500	430	50	50
5/24/2013	13:32:10	500	413	48.5	50
5/24/2013	13:32:20	500	384	47.5	50
5/24/2013	13:32:30	500	371	50	50
5/24/2013	13:32:40	500	365	50	50
5/24/2013	13:32:50	500	337	48	50
5/24/2013	13:33:00	500	310	46	50
5/24/2013	13:33:10	500	320	50	50
5/24/2013	13:33:20	500	330	50	50
5/24/2013	13:33:30	500	336	50	50
5/24/2013	13:33:40	500	336	50	50
5/24/2013	13:33:50	500	332	50	50
5/24/2013	13:34:00	500	359	50	50
5/24/2013	13:34:10	500	360	50	50
5/24/2013	13:34:20	500	406	50	50
5/24/2013	13:34:30	500	407	50	50
5/24/2013	13:34:40	500	344	48.5	50
5/24/2013	13:34:50	500	314	45.5	50
5/24/2013	13:35:00	500	299	44.5	50
5/24/2013	13:35:10	500	297	43	50
5/24/2013	13:35:20	500	286	41.5	50

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	13:35:30	500	271	40	50
5/24/2013	13:35:40	494	258	39	50
5/24/2013	13:35:50	488	248	39	50
5/24/2013	13:36:00	482	240	38.5	50
5/24/2013	13:36:10	463	232	37	50
5/24/2013	13:36:20	426	224	33.5	48.5
5/24/2013	13:36:30	375	217	30	47.5
5/24/2013	13:36:40	350	212	28.5	46
5/24/2013	13:36:50	342	204	27.5	44
5/24/2013	13:37:00	337	188	27	41
5/24/2013	13:37:10	337	174	27	39
5/24/2013	13:37:20	335	164	26	36
5/24/2013	13:37:30	333	155	25.5	35
5/24/2013	13:37:40	336	150	25	33.5
5/24/2013	13:37:50	346	146	24.5	33
5/24/2013	13:38:00	364	144	24.5	32.5
5/24/2013	13:38:10	378	142	25	31
5/24/2013	13:38:20	396	142	25	31
5/24/2013	13:38:30	400	143	25	30.5
5/24/2013	13:38:40	403	147	25	30.5
5/24/2013	13:38:50	409	154	25	30.5
5/24/2013	13:39:00	407	161	25	30.5
5/24/2013	13:39:10	407	163	25	30.5
5/24/2013	13:39:20	409	164	25	31
5/24/2013	13:39:30	430	162	26.5	29.5
5/24/2013	13:39:40	434	163	25.5	30.5
5/24/2013	13:39:50	431	167	26.5	31
5/24/2013	13:40:00	428	171	25.5	32
5/24/2013	13:40:10	361	176	22.5	33
5/24/2013	13:40:20	333	181	21	33.5
5/24/2013	13:40:30	327	172	21.5	27.5
5/24/2013	13:40:40	365	159	23	31
5/24/2013	13:40:50	392	156	24.5	30.5
5/24/2013	13:41:00	411	152	25	30
5/24/2013	13:41:10	428	154	25.5	30
5/24/2013	13:41:20	436	161	25.5	30.5
5/24/2013	13:41:30	435	166	25.5	31.5
5/24/2013	13:41:40	445	171	26	32
5/24/2013	13:41:50	438	172	25	32
5/24/2013	13:42:00	450	171	26	32
5/24/2013	13:42:10	457	170	26	32
5/24/2013	13:42:20	449	172	25	32.5
5/24/2013	13:42:30	446	173	25	32.5
5/24/2013	13:42:40	443	177	24.5	33.5
5/24/2013	13:42:50	437	180	24.5	33.5
5/24/2013	13:43:00	432	179	24	33
5/24/2013	13:43:10	407	181	23	32.5
5/24/2013	13:43:20	385	181	22	33

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	13:43:30	396	180	22.5	32
5/24/2013	13:43:40	408	178	22.5	31.5
5/24/2013	13:43:50	409	173	22.5	30.5
5/24/2013	13:44:00	412	170	22	30.5
5/24/2013	13:44:10	407	172	21.5	30
5/24/2013	13:44:20	408	172	21.5	30
5/24/2013	13:44:30	404	174	21	30
5/24/2013	13:44:40	405	176	21	29.5
5/24/2013	13:44:50	398	176	20.5	29
5/24/2013	13:45:00	416	175	21	29
5/24/2013	13:45:10	423	172	21.5	28
5/24/2013	13:45:20	426	172	21.5	28
5/24/2013	13:45:30	424	173	21.5	28
5/24/2013	13:45:40	443	229	22.5	34
5/24/2013	13:45:50	425	402	21	39.5
5/24/2013	13:46:00	438	481	23	40.5
5/24/2013	13:46:10	459	500	24	41.5
5/24/2013	13:46:20	473	483	25	38.5
5/24/2013	13:46:30	464	349	24.5	34.5
5/24/2013	13:46:40	459	258	24	35
5/24/2013	13:46:50	461	226	27	36
5/24/2013	13:47:00	453	241	27	38
5/24/2013	13:47:10	464	231	26.5	37
5/24/2013	13:47:20	480	210	28	36.5
5/24/2013	13:47:30	459	203	26.5	38.5
5/24/2013	13:47:40	488	206	29.5	41
5/24/2013	13:47:50	480	209	30	42.5
5/24/2013	13:48:00	500	217	32.5	46
5/24/2013	13:48:10	500	224	38.5	48.5
5/24/2013	13:48:20	500	229	45	49.5
5/24/2013	13:48:30	500	231	48	50
5/24/2013	13:48:40	500	243	50	50
5/24/2013	13:48:50	500	258	50	50
5/24/2013	13:49:00	500	265	50	50
5/24/2013	13:49:10	500	268	50	50
5/24/2013	13:49:20	500	273	50	50
5/24/2013	13:49:30	500	275	50	50
5/24/2013	13:49:40	500	276	48	50
5/24/2013	13:49:50	500	277	44.5	50
5/24/2013	13:50:00	495	281	41	50
5/24/2013	13:50:10	453	301	39.5	50
5/24/2013	13:50:20	412	448	36.5	50

Appendix D

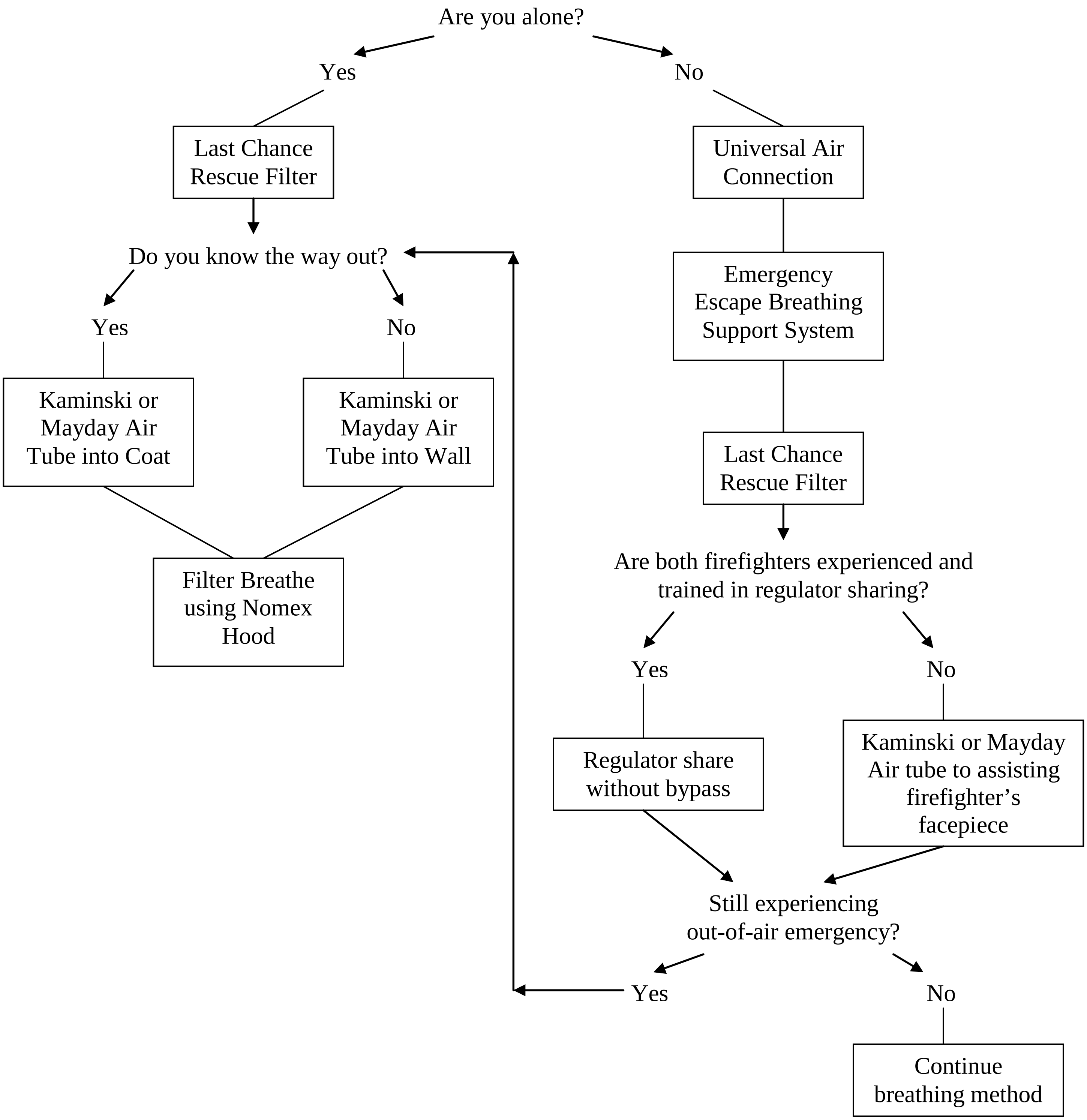
Complete Results of Using a Kaminski Breathing Tube into an Assisting Firefighter's Facepiece

Date and Time		Interior CO (ppm)	Facepiece CO (ppm)	Interior HCN (ppm)	Facepiece HCN (ppm)
5/24/2013	14:35:00	--	6	--	3.5
5/24/2013	14:35:10	--	5	--	3.0
5/24/2013	14:35:20	--	5	--	3.0
5/24/2013	14:35:30	--	6	--	2.5
5/24/2013	14:35:40	--	6	--	2.5
5/24/2013	14:35:50	--	6	--	3.0
5/24/2013	14:36:00	--	6	--	3.0
5/24/2013	14:36:10	--	6	--	2.5
5/24/2013	14:36:20	--	6	--	3.0
5/24/2013	14:36:30	--	5	--	2.5
5/24/2013	14:36:40	--	7	--	2.5
5/24/2013	14:36:50	--	6	--	2.5
5/24/2013	14:37:00	--	5	--	2.5
5/24/2013	14:37:10	--	5	--	2.5
5/24/2013	14:37:00	--	5	--	2.0
5/24/2013	14:37:20	--	5	--	2.0
5/24/2013	14:37:30	--	5	--	2.0
5/24/2013	14:37:40	--	5	--	2.5
5/24/2013	14:38:50	--	5	--	2.0
5/24/2013	14:38:00	--	5	--	2.0
5/24/2013	14:38:10	--	5	--	2.0
5/24/2013	14:38:20	--	5	--	2.0
5/24/2013	14:38:30	--	5	--	1.5
5/24/2013	14:38:40	--	5	--	1.5
5/24/2013	14:39:50	--	4	--	2.0
5/24/2013	14:39:00	--	5	--	1.5
5/24/2013	14:39:10	--	4	--	1.5
5/24/2013	14:39:20	--	4	--	1.5
5/24/2013	14:39:30	--	4	--	1.5
5/24/2013	14:39:40	--	4	--	1.5
5/24/2013	14:40:50	--	4	--	1.5
5/24/2013	14:40:00	--	4	--	1.0
5/24/2013	14:40:10	--	4	--	1.5
5/24/2013	14:40:20	--	4	--	1.5
5/24/2013	14:40:30	--	4	--	1.5
5/24/2013	14:40:40	--	4	--	1.5
5/24/2013	14:41:50	--	4	--	1.0

Note. "--" denotes data unable to be obtained.

Appendix E

Firefighter Out-of-Air Breathing Method Decision Tree



Note: If preferred breathing method is not available, progress to the next lower level of the decision tree.