Career Fire Fighter Dies in Heavy Smoke on Second Floor of a Residential Structure—Texas

Executive Summary

On July 9, 2014, a 46-year-old male career fire fighter died while conducting interior operations in a two-story residential structure fire. At 15:55 hours, Engine 104 with a crew of four was dispatched to a shed fire. The captain observed fire and black smoke coming from the right side and rear of the structure and called in a box alarm. The crew reported hearing ammunition going off while fire fighter 1 (FF1) and fire fighter 2 (FF2) pulled a 1¾-inch hoseline off the engine. The captain and FF1 unsuccessfully attempted to force entry into the garage on the front right corner of the structure while FF2 tried knocking down the fire on the right side of the structure. The captain and FF1 were able to make forcible entry at the front door. The captain ordered the hoseline to the front door. After seeing only minimal smoke and no visible fire or civilians on the first floor, they proceeded to a narrow stairway to the second floor. The captain, FF2, and FF1 went to the top of the stairs and encountered several louvered doors and a scuttle hole to the attic. The captain opened the attic access but could only see dark, brown smoke. The captain used a thermal imager and opened doors, searching for civilians and fire. The captain used a pike pole to open the attic scuttle door and poked holes in the ceiling. The captain heard one of the fire fighters say he was getting hot, low on air, and, “Let’s go get flashlights.” The crew backed down the stairs. The captain then realized FF1 was missing. The captain radioed FF1 several times with no response, then he informed the incident commander of a missing fire fighter. The captain went back to the second floor and could hear a PASS alarm in the room on his left and notified command. His low-air alarm was going off so he had to back out. Engine 63 made entry through the rear double doors off the deck on the second floor and located FF1 just inside the double doors. Engine 63 encountered the rapid intervention crew and took him down a ladder off the rear deck to the yard. After receiving basic life support, he was transported to the hospital where he died from his injuries.

Two-story residential structure.
(NIOSH photo.)

Contributing Factors

- *Crew integrity*
- *Air management*
- *Mayday procedures*
- *Fire-fighting experience*

- *Operational characteristics of the SCBA and other life safety devices*
- *Fireground communications*
- *Ventilation timing*
- *Hoseline deployment*
- *Construction features of the residence*
- *Munition hazards*

Key Recommendations

- *Fire departments should ensure that crew integrity is properly maintained by voice or radio contact when operating in an atmosphere that is immediately dangerous to life or health (IDLH).*
- *Fire departments should ensure that fire fighters and officers are properly trained in air management.*
- *Fire departments should ensure that fire fighters understand the operational characteristics of their SCBA and other life safety devices.*
- *Fire departments should ensure that fire fighters are properly trained in out-of-air SCBA emergencies and SCBA repetitive skills.*
- *Fire departments should ensure that fire fighters are properly trained in Mayday procedures and survival techniques.*
- *Fire departments should ensure fire fighters are sufficiently retrained when transitioning from the emergency medical service back to fire operations.*
- *Fire departments should ensure that accountability officers are proficient in fire fighter tracking/monitoring systems.*
- *Fire departments should ensure that fire fighters are trained in situational awareness, personal safety, and accountability.*

Career Fire Fighter Dies in Heavy Smoke on Second Floor of a Residential Structure—Texas

Introduction

On July 9, 2014, a 46-year-old male career fire fighter died while conducting interior operations in a two-story residential fire. On July 10, 2014, the U.S. Fire Administration notified the National Institute for Occupational Safety and Health (NIOSH) of this incident. On July 14–18, 2014, a general engineer and an investigator from the NIOSH Fire Fighter Fatality Investigation and Prevention Program traveled to Texas to investigate this incident. The NIOSH investigators met with members of the career fire department, an investigator with the Texas State Fire Marshal's Office, and the dispatch center. NIOSH investigators interviewed the incident commander and fire fighters who were on scene at the time of the incident. The NIOSH investigators visited the incident site and took photographs. The self-contained breathing apparatus (SCBA) was shipped to the NIOSH National Personal Protective Technology Laboratory for evaluation.

Fire Department

The career fire department involved in this incident serves a city with a population of 2,239,000, which is the fourth largest city and the fourth largest fire department in the United States. The fire department is rated by the Insurance Services Office as a Class I fire department and is an internationally accredited department through the Commission on Fire Accreditation International.

The metropolitan population covering a 10-county-wide area is 6,200,000 residents. The city has a total area of 656 square miles that is comprised of 634 square miles of land and 22 square miles of water. The fire department provides aircraft rescue fire-fighting (ARFF) for two large commercial airports. The fire department provides automatic aid with one career fire department and one volunteer fire department, which are located in entities within the municipality. Also, the fire department is part of a regional mutual aid pact that covers transportation emergencies in the greater metropolitan area.

The fire department employs 3,907 personnel, of which 3,789 are uniformed members. The daily minimum staffing for the Emergency Response Division is 832 personnel. The Emergency Response Division operates on a 24/72 work schedule, which equates to a 47.6-hour work-week, including a 24-hour debit day, which is worked approximately once every 36 days.

The Emergency Response Division is divided into two divisions—north and south. A deputy chief staffs each division on each shift. The South Division (Shift Commander 37) contains 13 districts or battalions (District 21, 28, 59, 68, 78, 83, 20, 26, 46, 70, 71, 11 [Rescue], and 22 [Haz Mat]). The North Division (Shift Commander 15) contains 10 districts or battalions (District 4, 5, 6, 8, 19, 34, 45, 64, 102, and ARFF). District 54, which provides ARFF and emergency medical services, is under the direction of the aircraft rescue coordinator covering Fire Stations 54, 81, 92, and 99. District 22 is the department's hazardous materials unit staffed at Fire Station 22. District 11 is the department's rescue district, which has three rescue companies: Rescue 10, Heavy Rescue 11, and Rescue 42. Also, Safety 30 is housed with District 11.

The fire department operates a fire administration office, a fire marshal's office, a fire training academy, an arson division, a logistics center, a fire apparatus maintenance shop, and a fire operations division. The fire Emergency Response Division consists of 92 fire stations, staffing 87 engine companies, 37 ladder or truck companies (including 5 tower ladders), 56 basic life support ambulances with one EMT/B fire fighter and one engineer operator per unit, 34 medic units (advanced life support [ALS] with two paramedic/fire fighters per unit), 11 squads (non-transport ALS units staffed by two paramedics), 3 rescue companies (including one heavy rescue), and 3 shift safety officers. There are 23 districts or battalions in the city. The minimum staffing for each engine company, ladder company, and rescue company is an officer (senior captain or captain), an engineer operator, and two fire fighters. Each district is staffed with a district chief and an incident command technician.

The rescue companies (Rescue 10, Heavy Rescue 11, and Rescue 42) provide technical rescue services such as structural collapse, high- and low-angle rescue, trench rescue, and confined space rescue. The hazardous materials team consists of 10 members (two captains, three engineer operators, and five fire fighters) per shift and 3 operating response vehicles (HM22 Unit 1, HM22 Unit 2, and Foam Engine 22). The hazardous materials team is under the direction of a district chief (District 22) and assisted by a senior captain.

In calendar year 2014, the fire department responded to 318,630 incidents (276,880 EMS and 41,750 Fire). The average response time for a fire incident was 5.8 minutes.

The Prevention Bureau is managed by an assistant chief and consists of 126 fire inspectors (1 assistant fire marshal, 7 chief inspectors, 16 senior inspectors, and 102 inspectors) and 7 civilian positions. The members of the Fire Marshal's Office are certified to NFPA 1031 *Standard for Professional Qualifications for Fire Inspector and Plan Examiner* [NFPA 2013b] through the local community college. Each inspector must receive 20 hours of continuing education units (CEU) annually.

The Prevention Bureau consists of the following divisions and teams:

- Schools Division, including Home Day Care Facilities (Inspections)
- High-Rise Team (Inspections)
- Plans Review Division
  - Fire Alarm System
  - Sprinkler Systems through the Building Officials Office
- Liaison to the city's Building Officials Office
  - New Construction
  - Sprinkler Systems; Electrical; Plumbing; Building Construction
- Special Operations Team
  - Providing fire and EMS services for festivals and special events

- Weekend and Night Inspections
  - 24-hour coverage
  - Occupancy Load
  - Complaints

The Public Education Division of the Prevention Bureau conducts life safety training in:
- Schools
- High-rise occupancies

The Fire and Arson Investigation Bureau is a law enforcement agency under the Prevention Division. The Arson Bureau responds in the event of incendiary fires, multiple-alarm fires, fire deaths, bombings, and criminal or terrorist activity associated with fires. In many cases, investigators work with federal, state, and local agencies, such as the Bureau of Alcohol, Tobacco, Firearms, and Explosives; Federal Bureau of Investigation; and the city's police department. Other operations within the Fire and Arson Bureau are Crime Lab, Polygraphs, Photography, and the region's Arson Task Force.

Other divisions within the department include:
- Planning/Administration, which includes Office of Emergency Communication (Fire), Human Resources, Information Technology Liaison, and Planning.
- Finance, which includes Finance, Budget, Procurement, Fixed Assets, Internal Audit, Grant Accounting, Warehouse Operations and the Selection, Care, and Maintenance of SCBA.

The rank structure in the fire department is fire fighter, engineer operator, captain, senior captain, district chief, deputy chief, assistant chief, executive assistant chief, and fire chief.

Training and Experience

The fire department involved in this incident requires potential candidates for employment as a fire fighter to have a high school diploma or GED and 60 hours of college credit or 2 years of military service with an honorable discharge.

Once selected as a candidate, the fire fighter trainee begins a 15-month probation period with the fire department. As a fire fighter trainee, the initial step is to attend the 9-month Recruit Training Program at the department's fire academy. The training consists of Texas Commission of Fire Protection Basic Fire Suppression Curriculum. The Texas basic curriculum includes 468 hours of training. The curriculum covers all of the National Fire Protection Association's (NFPA) qualifications for NFPA 1001 *Standard on Fire Fighter Professional Qualifications*, Fire Fighter I, Fire Fighter II, Hazardous Materials Awareness, and Hazardous Materials Operations [NFPA 2013a]. Also, the trainee meets the requirements of NIMS 100 *Introduction to ICS*; NIMS 200 *Basic ICS*; IS 700A *The National Incident Management System, An Introduction*; and IS 800B *The National Response Framework, An Introduction*. In addition to the fire fighter training, the fire fighter trainees receive emergency medical services *Emergency Medical Technician Basic* (EMT/B) certification, which is a 150-hour curriculum.

Career Fire Fighter Dies in Heavy Smoke on Second Floor of a Residential Structure—Texas

Upon completion of recruit school, the fire fighter trainee is assigned as follows:

Phase 1: 2 months with an engine company
Phase 2: 2 months with a truck company
Phase 3: 2 months with EMS

Upon completion of probation, the fire fighter trainee becomes a fire fighter.

The department requires that all Emergency Response Division fire fighters receive 2 hours of CEU training, 1 hour of risk management training, and 24 hours of in-service training per month. The fire department uses district training officers to assist with this in-service training as well as to ensure that probationary fire fighters are obtaining the proper training during their 6-month period in the Emergency Response Division. The Texas State Fire Commission requires 20 hours of CEUs per month and the Insurance Services Office requires 8 hours of CEUs plus eight multi-company drills per month.

The department conducts live fire training twice a year at the department's fire academy. The live fire training is compliant with NFPA 1403 *Standard on Live Fire Training* [NFPA 2012]. Each live fire training evolution uses four engine companies, two ladder companies, one medic unit, and a district chief.

The department provides a certification program for all emergency operators, which is a tested position. The fire academy provides the training for the 56-hour certification program, which complies with NFPA 1002 *Standard for Apparatus Driver/Operator Professional Qualifications* [NFPA 2014].

The department pays for the state certification process through the Texas State Fire Commission.

The fire department provides an officer development program for members, which is part of the department's career path, plus the opportunity to acquire a college degree. This process uses curriculum from the National Fire Academy; local community colleges, colleges, and universities; and continuing education programs.

The fire department uses the following designations for riding assignments on fire apparatus: officer is "A"; right jumpseat is "B"; left jumpseat is "C"; and the engineer operator is "D."

Table 1. Training and Experience of Key Personnel

Fire Fighter	Training Courses	Years Experience
Fire Fighter	Basic Fire Fighting (Fire Fighter I, Fire Fighter II), Live Burn Fire Fighting, Driver Operator—Pumper, various fire fighting procedures related to aircraft, and various other administrative and technical courses.	21
Captain	Basic Fire Fighting (Fire Fighter I, Fire Fighter II), Live Burn Fire Fighting, Managing Company Tactical Operations, Fire Behavior in Single Family Residence, Fire Model in Single Family Residence, Fire Chief Orientation, and various other administrative and technical courses.	25
District Chief 102 (Incident Commander)	Basic Fire Fighting (Fire Fighter I, Fire Fighter II), Live Burn Fire Fighting, and various other administrative and technical courses.	21

Note: All fire fighters must complete training equivalent to the NFPA 1001 Standard for Fire Fighter Professional Qualifications, Fire Fighter I and Fire Fighter II [NFPA 2013a].

Structure

The residential structure was built in 1963 and was wood frame construction on a slab foundation (see Photo 1). The two-story ranch had been remodeled in 2012 and consisted of 4,608 square feet of living space. The first floor consisted of a large living area, large kitchen, full bathroom, master bedroom with full bath, attached two-car garage, and an attached storage shed, which contained ammunition reloading equipment, ammunition components, and ammunition. The second floor had two bedrooms, a full bath, and a sewing room with French doors that led out onto a deck (see Diagrams 1 and 2). The first-floor exterior was covered with brick, and the second floor was oriented strand board covered with vinyl siding. In the rear of the structure, the first floor had a covered patio and the second floor had a large deck.

Photo 1. Residential structure Side Alpha.
(*NIOSH photo.*)

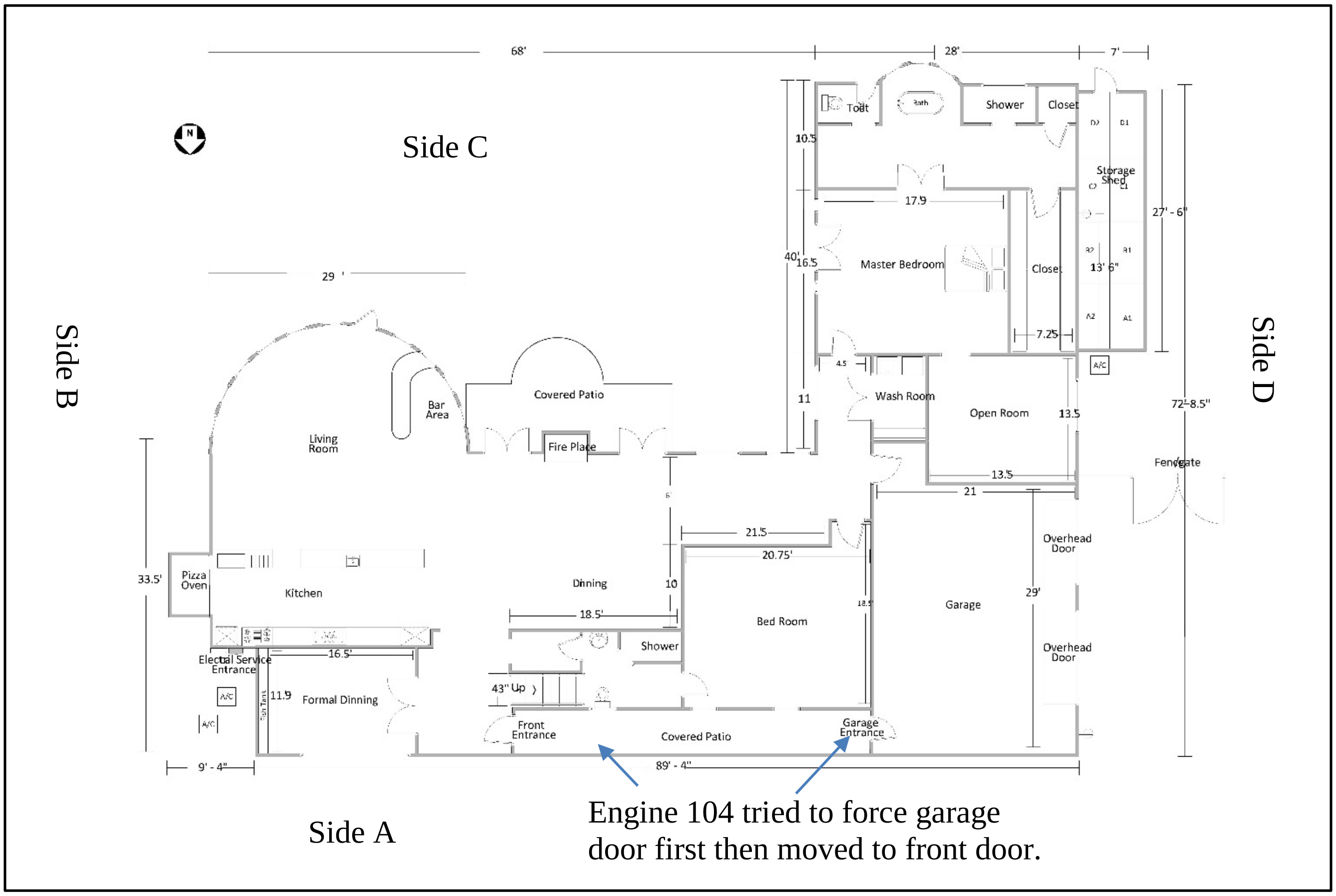

Diagram 1. First floor layout and general dimensions.
(*Courtesy of the Texas State Fire Marshal.*)

Career Fire Fighter Dies in Heavy Smoke on Second Floor of a Residential Structure—Texas

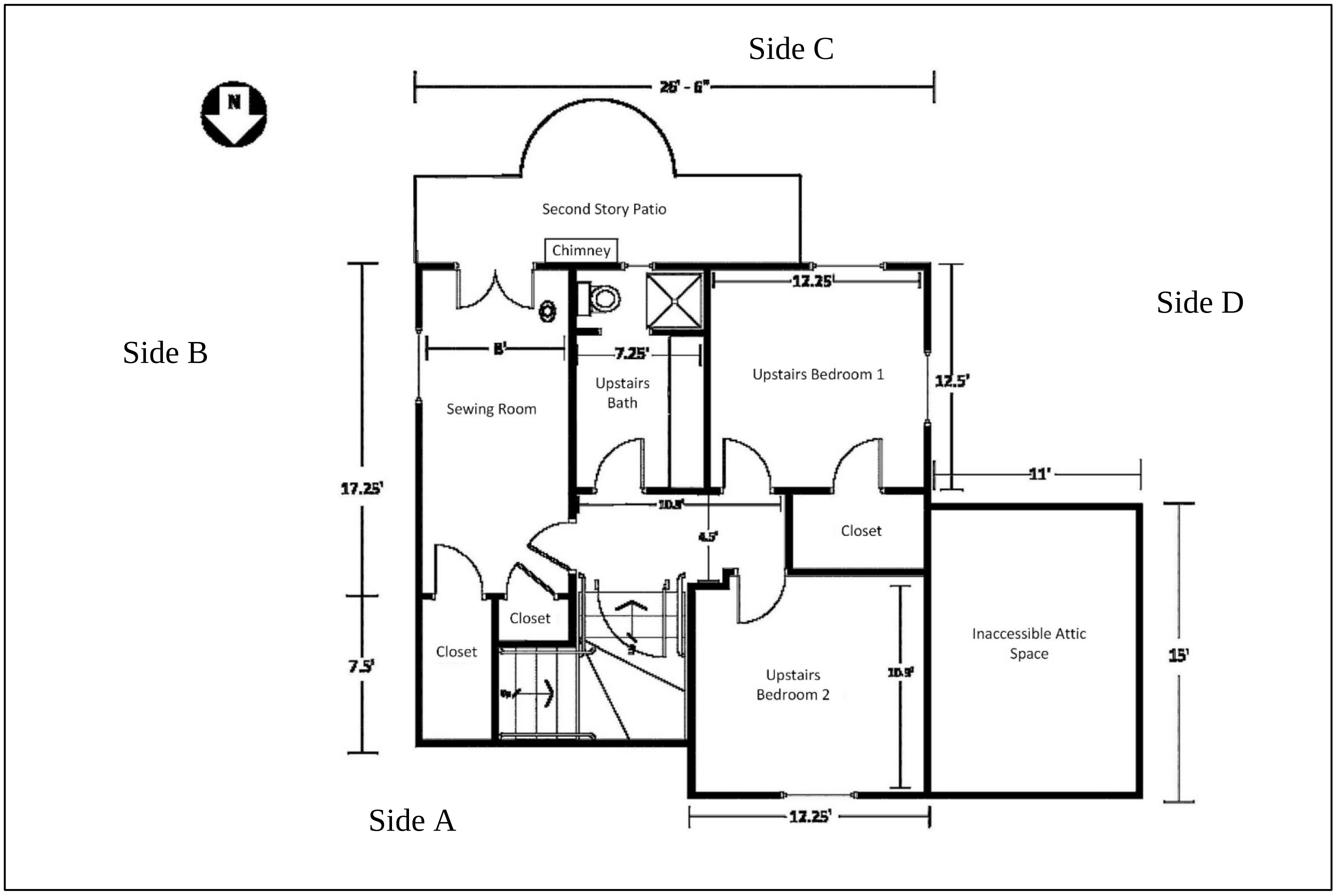

Diagram 2. Second floor layout and general dimensions.
(*Courtesy of the Texas State Fire Marshal.*)

Equipment and Personnel

On July 9, 2014, the county dispatch center transmitted a still alarm for a shed fire. The initial unit dispatched was Engine 104 and upon arrival confirmed a working fire. This upgraded the alarm to a box alarm that dispatched two district chiefs, three engines, two ladders, a squad, and an ambulance. *Note: Engine 104's station was less than a mile from the structure fire.* The table below identifies the apparatus and staff dispatched on the first-alarm assignment, along with their approximate dispatch time and on-scene arrival times (rounded to the nearest minute).

Table. First-alarm Equipment and Personnel Dispatched

Resource Designation	Staffing	Dispatched (rounded to minute)	On-scene (rounded to minute)
Engine 104	captain, engine operator, and 2 fire fighters (victim)	1555 hrs	1600 hrs
District Chief 102 (incident commander)	district chief and an incident command technician	1559 hrs	1607 hrs
District Chief 64	district chief and an incident command technician	1559 hrs	1613 hrs
Engine 102	captain, engine operator, and 2 fire fighters	1559 hrs	1610 hrs
Engine 103	captain, engine operator, and 2 fire fighters	1559 hrs	1610 hrs
Engine 63	captain, engine operator, and 2 fire fighters	1559 hrs	1614 hrs
Ladder 102	senior captain, an acting engine operator, and 2 fire fighters	1559 hrs	1609 hrs
Ladder 101	senior captain, engine operator, and 2 fire fighters	1559 hrs	1612 hrs
Ambulance 56	engine operator/EMT and a fire fighter/EMT	1559 hrs	1612 hrs
Squad 64	engine operator/paramedic and a fire fighter/paramedic	1559 hrs	1612 hrs

Timeline

An approximate timeline summarizing the significant events of the incident is listed below. The times are approximate and were obtained by studying available dispatch records, photos, run sheets, witness statements, and fire department records. The times are rounded to the nearest minute. The timeline is not intended, nor should it be used, as a formal record of events.

- **1555 Hours**
  Engine 104 is dispatched on a still alarm to a shed fire.

- **1559 Hours**
  Engine 104 reports fire coming from a two-story and requests a box alarm. Dispatch upgrades to a box alarm, dispatching Districts 102 and 64; Engines 102, 103, and 63; Ladders 102 and 101; Ambulance 56; and Squad 64.

- **1600 Hours**
  Engine 104 corrects the address.

- **1601 Hours**
  District Chief 102 confirms he has a working fire. Dispatch assigns fireground channel. Engine 104 makes offense attack and reports ammunition going off.

- **1607 Hours**
  District 102 arrives on scene and assumes command. Incident command reports heavy smoke coming from two-story residence.

- **1608 Hours**
  Command assigns Ladder 101 to ventilate roof when they arrive on scene.

- **1609 Hours**
  Ladder 102 arrives on scene. Ladder 102 is assigned to ventilate roof, since Ladder 101 had not yet arrived.

- **1610 Hours**
  Engine 102 arrives on scene and is ordered to pull a second line and back up Engine 104. Engine 103 arrives on scene and is assigned the rapid intervention team (RIT).

- **1612 Hours**
  Ladder 101, Ambulance 56, and Squad 64 arrive on scene. Ladder 101 ordered to get a 1¾-hoseline to D-side.

- **1613 Hours**
  Command requests Ladder 102's engine operator to cut utilities, starting with the power. District Chief 64 arrives on scene. Command reports a 4-inch water supply is established and the accountability system is set up.

- **1614 Hours**
  Engine 63 arrives on scene.

- **1615 Hours**
  Command requests Dispatch call for the power company.

- **1617 Hours**
  Ladder 102 reports fire has broken through the roof on B-side. Command requests a status report from Engine 104.

- **1618 Hours**
  Engine 104's reply inaudible.

- **1621 Hours**
  Ladder 102 reports that the roof is vented.

- **1622 Hours**
  Engine 104 notifies Command they were coming out to change air cylinders.

- **1623 Hours**
  Engine 104 asks Command if Engine 104C (FF1) is in alarm? Accountability tried to contact FF1.

- **1625 Hours**
  District Chief 64 notifies Command that he is activating the RIT. Engine 104 captain tries to radio FF1.

- **1626 Hours**
  Engine 104 captain re-enters structure. He makes it to the top of the stairs, hears a PASS device going off in a room to the left, but is too low on air to investigate further. RIT is enroute to the second floor.

- **1628 Hours**
  District Chief 64 informs RIT to go to the top of the stairs to the room on the left. Ladder 102 is the secondary RIT.

- **1630 Hours**
  Engine 63 notifies Command that FF1 has been recovered and they had him on the second-floor balcony, C-side. RIT requested hoseline C-side to protect from fire on roof.

- **1631 Hours**
  Medic unit called to C-side.

- **1632 Hours**
  Crews lower Fire Fighter 1 down ladder, off the balcony to the ground. PARs are conducted.

- **1634 Hours**
  Medic unit starts CPR.

- **1635 Hours**
  Command calls for defensive operations.

- **1642 Hours**
  Ambulance 56 transports Fire Fighter 1 to the hospital. PARs are completed.

Personal Protective Equipment

The fire fighter was wearing a work station uniform, turnout coat and pants, gloves, hood, boots, helmet, self-contained breathing apparatus (SCBA) with an integrated personal alert safety system (PASS), and a portable radio.

The fire fighter's SCBA was evaluated by the NIOSH National Personal Protective Technology Laboratory and a summary report is enclosed as Appendix I. The evaluation showed no evidence that the performance of the SCBA, with the cylinder valve full open, was a contributing factor in the fatality. The full report is available upon request. A special test was conducted to try and simulate the effects of airflow to the facepiece when the cylinder valve is only partially opened (see Appendix II). It is believed that the fire fighter may have only partially opened his cylinder valve upon entry into the structure. This may have caused an air starvation effect that may have caused the fire fighter to lift his facepeice from his face to breathe.

Weather Conditions

According to data from the website Weather Underground, the sky conditions were overcast with 10-mile visibility. The temperature was 92 degrees F. Dew point was 73 degrees F. Relative humidity was 54%. Wind speed was 11.5 mph and wind direction was south. Since the wind speed was greater than 10 mph, it may have contributed to the fire getting into the void spaces toward the main living area of the residence. Barometric pressure was 30.05 [NOAA 2015].

Investigation

On July 9, 2014, a 46-year-old male career fire fighter died while conducting interior operations in a two-story residential fire. At 15:55 hours, Engine 104, with a crew of four, was dispatched to a shed fire. Arriving on scene, the captain observed fire and black smoke coming from Side Delta and Side Charlie of the structure and called in a box alarm. The captain corrected the address for the dispatch center and advised them that ammunition was going off. District Chief 102 was en route and heard the captain's transmission and requested a confirmation of a working fire. The captain replied with a yes. The captain attempted to do a 360-degree size-up, but, due to a fence and ammunition going off, he was unable to complete it on Side Delta (see Photo 2 and Photo 3). Fire fighter 1 (FF1) and fire fighter 2 (FF2) had pulled a 1¾-inch hoseline off the engine. The captain met up with FF1 and attempted to force entry into the garage exterior man door on Side Alpha (see Diagram 1). FF1 was using a sledgehammer but was only able to open the door a foot while FF2 tried knocking down the fire on Side Delta of the structure. When FF1 was swinging the sledgehammer, his mask-mounted regulator (MMR) was swinging freely and hitting the SCBA donning switch. The captain informed FF1 that he was losing air. This occurred several times. It is believed that FF1 may have turned off his cylinder valve at that time. The Engine 104 pump operator engaged the pump then took 100 feet of 4-inch supply hose toward the hydrant on the Alpha/Bravo corner of the street.

Photo 2. Side Delta of fire structure where the area of origin of the fire occurred. (*NIOSH photo.*)

Photo 3. A sample of ammunition and reloading supplies found on Side Delta. (*NIOSH photo.*)

At 1607 hours, District Chief 102 and his incident command technician (ICT) arrived on scene. District Chief 102 gave a report to dispatch that heavy smoke was coming from a two-story residence and assumed incident command (IC). The IC sent his ICT to assist the Engine 104 pump operator with the supply hose to connect to the hydrant. The IC was approached by a civilian, who stated he had the owner on the phone and that no one was home but their three dogs. When Ladder 101 arrived, the IC directed them to ventilate the roof. After helping establish a water supply, the ICT and Engine 103's chauffer began to set up the accountability system. The Engine 104 captain and FF1 made a forcible entry at the Side Alpha front door.

At 1609 hours, Ladder 102 arrived on scene and was ordered to ventilate the roof since they were the first arriving truck company. The Engine 104 captain then went to Side Delta to have FF2 bring the hoseline to the Side Alpha front door. The captain noticed that some of the fire was knocked down but now fire was in the attic and smoke was coming out the eaves and ridge vent on Side Delta (see Photo 4). The captain and FF2 made entry at the front door and began to search the first floor.

Photo 4. Large void space over the garage at the Alpha/Delta corner connecting the L-shaped attic structure.
(*NIOSH photo.*)

At 1610 hours, Engine 102 arrived on scene and was ordered to pull a second hoseline to back up Engine 104 (see Diagram 3**)**. Engine 103 arrived and was assigned as the RIT. The Engine 104 captain and FF1 had opened the interior man door to the garage and opened both garage doors and saw no smoke in the garage. After seeing only minimal smoke, no visible fire or civilians on the first floor, the Engine 104 captain and FF1 proceeded up a narrow stairway to the second floor where they met up with FF2, whom had tried to pull more hoseline to reach the top of the stairs. Engine 104 Captain requested a pike pole so, FF2 went and got it.

Career Fire Fighter Dies in Heavy Smoke on Second Floor of a Residential Structure—Texas

At 1612 hours, Ladder 101, Ambulance 56, and Squad 64 arrived on scene. The Engine 104 captain, FF2, and FF1 went up the stairs and encountered a louvered door at the top of stairs (see Photo 5). The captain opened it and saw a scuttle hole to the attic. The captain opened the attic access panel but could only see dark, brown smoke and used the thermal imager but did not see any fire.

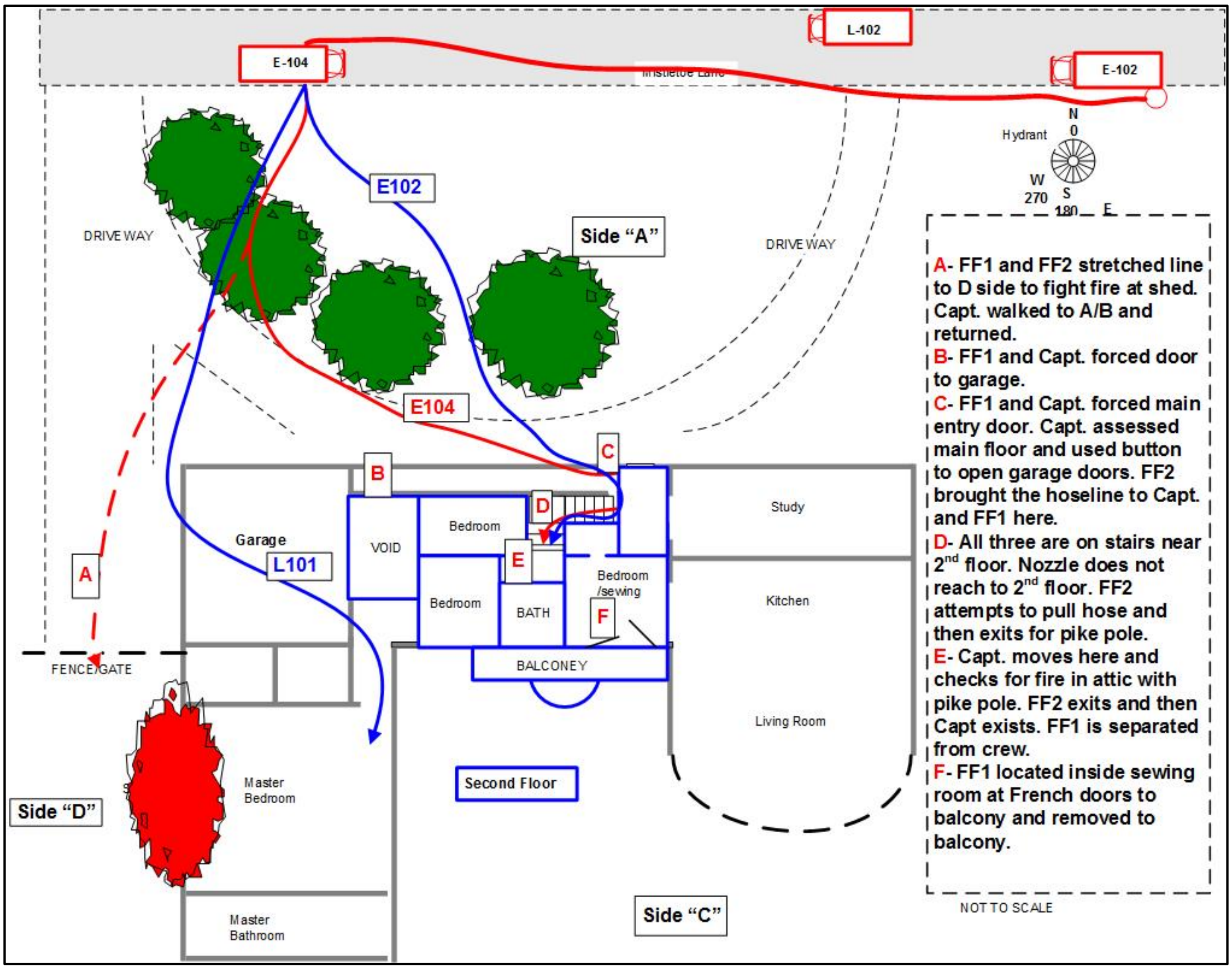

Diagram 3. Key apparatus and hoseline placement.
(*Courtesy of the State Fire Marshal's Office.*)

Photo 5. Louvered door to sewing room at top of stairs to the left. Picture taken from inside the room. The top half of the louvered closest door (right) is broken out (see *Possible scenarios*, #2).
(*NIOSH photo.*)

At 1613 hours, the IC ordered the Ladder 102 engine operator to cut the utilities, and a minute later Engine 63 arrived on scene. The IC radioed the Engine 104 captain for a status report but did not get a reply. District Chief 64 (DC64) and his ICT arrived on scene. The IC assigned DC64 to Side Alpha, and DC64's ICT assisted with accountability. The Engine 104 captain observed three other louvered doors in the hallway. He started on his left and opened each door, using the thermal imager to scan the room. He never saw any fire or civilians but he did notice that doors closed on their own after he moved back into the hallway.

At 1616 hours, Ladder 101 was ordered to take a 1¾-inch hoseline supplied by Engine 104 to Side Delta. A minute later, the Ladder 102 engine operator reported to Command that fire had broken through the roof on Side Bravo. The IC asked for a report from Engine 104. A minute later, the Engine 104 captain radioed Command but the message was inaudible. After the captain completed the bedroom search, he used a pike pole, opened holes in the ceiling, and heard a fire fighter say it's getting hot, he was low on air, and, "Let's go get flashlights." The Engine 104 captain pulled the ceiling as he worked toward the stairs and saw FF2 go down the stairs. As the captain and FF2 descended the stairs, FF2 asked where FF1 was. The captain had assumed FF1 had already gone down the stairs because he never saw FF1 go past him when he was on the second floor.

At 1621 hours, the captain radioed FF1 several times with no response. *Note: The captain had mistakenly called FF2's radio instead of FF1's.* Ladder 102 notified Command that the roof was vented on Side Charlie. The Engine 104 captain notified Command they were coming out for a bottle change. The captain saw DC64 at the front door and informed him that FF1 was missing. The Engine 104 captain radioed Command to see if FF1 was in alarm. Ladder 101 notified Command that they had a fire fighter they were sending out with a burn injury. Command notified Squad 64 to check on the burned fire fighter. The accountability officer noticed FF1 was in alarm and tried to radio FF1 for a verbal response but none came.

At 1624 hours, DC64 tried to radio FF1 with no response. Again, the accountability officer radioed FF1. The Engine 104 captain was low on air but went back up the stairs to search. FF2 went to change his bottle. At 1625 hours, DC64 notified Command that he was activating the RIT. A minute later, the Engine 104 captain heard a faint PASS device in the room to the left through a closed louvered door. The captain opened the door and could still hear the PASS but had to back out because his air was getting very low. He radioed Command about hearing the PASS and having to back out.

At 1628 hours, DC64 notified the RIT that FF1 would be in the second floor bedroom to the left. Minutes later, the Engine 63 made entry through the exterior Side Charlie double doors on the balcony to the room on the second floor (see Diagram 3, Notation F, and Photo 6). The Engine 63 engine operator notified Command they had FF1 on the balcony (see Photo 7). Engine 63 and the RIT took him down a ladder off the balcony to the yard.

Photo 6. The double glass panel doors of the sewing room that lead out to the second floor balcony. Note that the door handle on the right is a nonfunctioning handle and is bent down (see *Possible scenarios*, #3). FF1 was found on the floor at the base of the right panel door. (*NIOSH photo.*)

Photo 7. The second floor balcony where FF1 was brought out and lowered to the ground via a ground ladder.
(*NIOSH photo.*)

At 1635 hours, Command called for defensive operations while personnel accountability reports (PAR) were in progress.

At 1642 hours, PARs were completed and Ambulance 56 transported FF1 to the hospital where he was pronounced dead.

Possible scenarios. (1) FF1 was found unconscious and unresponsive on the second floor with his facepiece partially dislodged and helmet off. It is not known why his helmet was off and his facepiece dislodged but one possibility is that the fire fighter attempted to remove his facepiece (shedding the helmet) and was exposed to products of combustion due to an SCBA or out-of-air emergency. The cylinder was later discovered to have approximately 500 psi of air remaining (see Appendix II). He may have become unconscious and collapsed on the floor. (2) In Photo 5, the top half of the louvered closest door is broken out. It is possible that FF1 thought this was the door on the left being the way out and tried to break through it, causing him to become trapped. (The entry door to the room was the same louvered style.) (3) In Photo 6, the right panel door has a nonoperating handle on it but it is bent down, possibly by FF1 trying to open the door just prior to him becoming unconscious.

Fire Behavior

According to the state fire marshal, the fire started in the storage shed that contained ammunition reloading equipment, ammunition components, and ammunition.

Indicators of significant fire behavior:

- Ammunition going off
- Smoke and fire on Side Delta upon arrival
- Heat and heavy black smoke in attic and void spaces
- Second-floor hallway attic access opened and ceiling pulled, causing heat and smoke to push down
- Heavy fire on Side Charlie, both first floor and attic
- Fire under control approximately 31 minutes after arrival

Contributing Factors

Occupational injuries and fatalities are often the result of one or more contributing factors or key events in a larger sequence of events that ultimately result in the injury or fatality. NIOSH investigators identified the following items as key contributing factors in this incident that led to the fatalities:

- Crew integrity
- Air management
- Mayday procedures
- Fire-fighting experience
- Operational characteristics of the SCBA and other life safety devices
- Fireground communications
- Ventilation timing
- Hoseline deployment
- Construction features of the residence
- Munition Hazards

Cause of Death

According to the county coroner’s report, the cause of death of the fire fighter was smoke inhalation. The fire fighter had a carboxyhemoglobin of 22 percent.

Recommendations

Recommendation #1: Fire departments should ensure that crew integrity is properly maintained by voice or radio contact when operating in an atmosphere that is immediately dangerous to life and health (IDLH).

Discussion: When an engine company enters a structure, the members must remain in contact by visual (eye-to-eye), verbal (radio or face-to-face), or direct (touch) contact. NFPA 1500 *Standard on Fire Department Occupational Safety and Health Program*, 8.5.5, states, "Crew members operating in a hazardous area shall be in communication with each other through visual, audible, or physical means or safety guide rope, in order to coordinate their activities." Section 8.5.4 states, "Members operating in hazardous areas at emergency incidents shall operate in crews of two or more." Additionally, NFPA 1500 8.5.6 states, "Crew members shall be in proximity to each other to provide assistance in case of an emergency" [NFPA 2013d].

The International Association of Fire Chiefs, Safety, Health, and Survival Section has redefined the *Rules of Engagement for Structural Firefighting*. One of its objectives is to ensure that fire fighters always enter a burning building as a team of two or more members and no fire fighter is allowed to be alone at any time while entering, operating in, or exiting a building. A critical element for fire fighter survival is crew integrity. Crew integrity means fire fighters stay together as a team of two or more. They must enter a structure together and remain together at all times while in the interior, and all members come out together. Crew integrity starts with the company officer ensuring that all members of the company understand their riding assignment, have the proper personal protective equipment, and have the proper tools and equipment. Upon arrival at the incident, the company is given a task to perform by the incident commander. The company officer communicates to the members of the company what their assignment is and how they will accomplish their assignment. To ensure that crew integrity is maintained, all the members of a company should enter a hazardous environment together and leave together. If one member has to leave, the whole company leaves [IAFC 2009].

It is the responsibility of every fire fighter to stay connected with crew members at all times. All fire fighters should maintain the unity of command by operating at all times under the direction of the incident commander, division/group supervisor, or their company officer. The ultimate responsibility for crew integrity and ensuring no members get separated or lost rests with the company officer. While operating in a hazard zone, they should maintain constant contact with their assigned members by visual observation, voice, or touch. They should ensure they stay together as a company or crew. If any of these elements are not adhered to, crew integrity is lost and fire fighters are placed at great risk.

NFPA 1500, 8.4.4–8.4.6 states:

- The incident commander shall maintain an awareness of the location and function of all companies or crews at the scene of the incident.
- Officers assigned the responsibility for a specific tactical-level management component at an incident shall directly supervise and account for the companies and/or crews operating in their specific area of responsibility.

- Company officers shall maintain an ongoing awareness of the location and condition of all company members [NFPA 2013c].

If a fire fighter becomes separated and cannot immediately get reconnected with his/her crew, the fire fighter must attempt to communicate via portable radio with the company officer. If reconnection is not accomplished after three radio attempts or reconnection does not take place within 1 minute, a Mayday should be declared. If conditions are rapidly deteriorating, the Mayday should be declared immediately. As part of a Mayday declaration, the fire fighter should next activate the radio's emergency alert button (when provided), followed by manually turning on the PASS alarm. Similarly, if the company officer or the fire fighter's partner recognizes they have a separated member, they should immediately attempt to locate the member by using their radio or by voice. If contact is not established after three attempts or within 1 minute, a Mayday must be declared immediately [IAFC 2009].

In this incident, FF1 became separated in the smoky stairwell just prior to or after the captain thought the crew was leaving together. The captain and FF2 were near the front door when they realized FF1 was missing. The captain immediately returned to the second floor and reported hearing FF1's PASS but didn't have sufficient air to continue the search.

Recommendation #2: Fire departments should ensure that fire fighters and officers are properly trained in air management.

Discussion: Chief Bobby Halton, retired chief and editor in chief of Fire Engineering notes: "If you run out of air in a working fire today, you are in mortal danger. There is no good air at the floor anymore, no effective filtering methods, no matter what others may say to the contrary" [Gagliano et al. 2008]. The only protection for fire fighters in the toxic smoke environments in today's fires is the air that they carry on their backs. Like SCUBA divers, fire fighters must manage their air effectively and leave enough reserve air in case of unforeseen occurrences while inside a structure fire. Fire fighters must manage their air so that they leave the IDLH atmosphere before the low-air alarm activates. This leaves an adequate emergency reserve [air] and removes the noise of the low-air alarm from the fireground [NFPA 2013d].

Air management is a program that the fire service can use to ensure that fire fighters have enough breathing air to complete their primary mission and allow enough reserve air for the fire fighter to escape an unforeseen emergency. Fire departments and fire fighters need to recognize that the smoke in modern construction is an IDLH atmosphere and manage their air along with their work periods so the fire fighters exit the IDLH with their reserve air intact. NFPA 1404 *Standard for Fire Service Respiratory Protection Training* states that fire fighters shall exit from an IDLH atmosphere before the consumption of reserve air supply begins. A low-air alarm is notification that the individual is consuming the reserve air supply and that the activation of the reserve air alarm is an immediate action item for the individual and the fire-fighting team [NFPA 2013c].

Fire fighters and command officers need to monitor their air status and communicate it to crew members. Air management happens at the individual fire fighter level, the crew level, and the command level. Fire fighters need to ensure their air supply is adequate (full cylinder) at the start of each shift and need to monitor their air usage during an event. For example, when the 50% heads-up display (HUD) light flashes, fire fighters need to communicate that information to his/her crew members. Fire fighters need to understand principles of air management such as the need to exit the IDLH atmosphere before they go into their emergency reserve air and their end-of-service-time indicator (EOSTI) sounds. If they are not out of the IDLH atmosphere and go into their emergency reserve air, they need to immediately communicate their situation to their crew and command as this can now be considered an emergency. Fire fighters should not wait until their EOSTI sounds or they are out of air to communicate.

Fire-fighting crews need to communicate their air supply status among the crews so they can plan accordingly to notify command of the need to exit and still have their reserve or emergency air level available. One method is to have the first person on a crew who reaches their 50% air capacity notify the crew leader and he/she can then estimate the amount of work period left so they can leave the structure (or IDLH) before the person with the least amount of air goes into their emergency reserve air.

Command needs to understand air management at the command level. This means that someone at the command post is monitoring not only accountability of the crews, but how long they have been working (estimating air supply usage), checking on air status through PAR checks, and then rotating crews with enough time to ensure that crews exit the IDLH with their emergency reserve air intact.

Too often fire fighters may not pay attention to their air usage and remaining air until they get into their emergency reserve air (often referred to as the low-air alarm) and their EOSTI sounds or vibrates. This can be due to a number of reasons, including lack of familiarity with a new or different model SCBA (with an HUD) or a lack of training. Another reason may be the old culture of waiting to take an action based on when the low-air alarm sounds. Fire fighters in the past didn’t have HUDs and relied on the low-air alarm to warn them of their low-air status. It was very difficult if not impossible in some fire-fighting incidents to read the over-the-shoulder gauge. With the addition of HUDs, fire fighters now have the ability to know their approximate air supply status by reading the lights in their facepiece. The four lights in the facepiece start in the illuminated green position and then turn off as the air supply decreases. Once the SCBA air supply reaches approximately 50%, the light begins to flash. Some change color to yellow below 50% then change to red in the EOSTI mode. HUDS are designed to alert the fire fighter that they should be taking an action to ensure they have enough escape time to exit the building with their reserve air intact. Once the air supply reaches the EOSTI, the SCBA will provide another signal (bell, whistle, and/or vibration) that alerts the user that they are nearing the end of the usable air in the cylinder. On pre-2013 edition SCBAs, this level was approximately 25% (+/- 2), but on the 2013 edition and newer SCBAs this EOSTI level was increased to 33%.

In this incident, FF1 became separated from his crew and experienced a low-air emergency. His crew had already left their position due to low-air concerns of one of the members. FF1 was separated from his crew, became lost, and believed to have experienced an air starvation emergency on the second floor of the structure and was unable to escape.

NIOSH investigators have identified a lack of air management training as a contributing factor on a number of LODD investigations. Fire departments need to ensure that training on air management occurs at all levels of the fireground command structure: command level, crew level and individual fire-fighter level [NIOSH 2011, 2012].

Recommendation #3: Fire departments should ensure that fire fighters understand the operational characteristics of their SCBA and other life safety devices.

Discussion: Fire fighters need to understand and be thoroughly familiar with the specific type of SCBA they are using. It is critically important when a department changes manufacturer or model that they provide extensive time and experience in training with the new model. Training shall comply with applicable governing standards and follow manufacturer’s instructions and guidelines [NFPA 2013d]. If fire fighters have “muscle memory, repetitive skills training” based on the manufacturer’s operational instructions, they would be more able to overcome an out-of-air emergency involving their SCBA. In the aviation industry, this skill building is sometimes referred to as cockpit time. Although a pilot may have extensive experience in one aircraft, he/she needs to have sufficient “cockpit time” in the plane that they are presently flying in order to overcome and control an unanticipated issue. In the same way, a fire fighter must have sufficient “cockpit time” with their SCBA because they operate in an IDLH environment and there is little time to react so the responses have to be learned and automatic. Although the principles of different SCBA manufacturers and models are the same, controls, visual and audio signals, and valves and their locations are different in all of them.

All SCBA come with a user’s manual. Fire fighters need to take the time and read these manuals independent of the training they are given and then practice with repetitive skill building. Often manufacturers include safety precautions and recommended practices for operating the equipment. The user should read these precautions and understand what may happen if they are not followed.

In this incident, it is believed that the fire fighter may not have turned his SCBA main cylinder valve to full open as the manufacturer recommends, which may have caused an air starvation situation. The manufacturer provided a warning in the user’s manual to always fully open the main cylinder valve for the unit to function properly.

With the main cylinder valve not fully open, the SCBA would provide sufficient breathing air at the higher beginning pressures but could cause a restricted air flow at the lower pressure (approaching EOSTI pressures and below). The fire fighter may have thought he had run out of air because the partially opened cylinder valve would not allow sufficient air pressure at the facepiece even though the cylinder still had operational air at the lower pressure. The fire fighter may have been struggling to breathe while his SCBA cylinder still had emergency air in the cylinder. This air starvation due to a partially opened cylinder valve can be recognized by a higher static pressure and wide fluctuation of the analog gauge upon inhalation. For example, the static pressure may read 800–1,000 psi, but during inhalation the gauge pressure fluctuates drastically down to zero or near zero. This may also effect the operation of some of the EOSTI devices or signals such as the Vibralert®.

Recommendation #4: Fire departments should ensure that fire fighters are properly trained in out-of-air SCBA emergencies and SCBA repetitive skills.

Discussion: Repetitive skills training with SCBA is vital for fire fighters working inside an IDLH atmosphere. SCBA skills training is an ongoing process that should be performed regularly to ensure that fire fighters "know their SCBA." The benefits of repetitive skills training with SCBA are an increased comfort and competency level, decreased anxiety, lower air consumption, increased awareness of the user's air level (noticing and using the heads-up display [HUD]) and an automatic muscle memory response of the vital function controls, such as the don/doff buttons, main air valve, emergency bypass operating valve, and auxiliary air connections (i.e., rapid intervention crew/universal air connection and the buddy breather connection). Repetitive skills training can also provide the user with an increased ability to operate these functions and controls in a high-anxiety moment or an emergency. Many times these skills will be necessary with gloved hands, limited vision, and reduced ability to hear commands from others. Performed in conditions that are non-IDLH, repetitive skills training helps build the fire fighter’s muscle memory so their hands will be able to activate the controls with gloves on and the operation will be a conditioned or second-nature response. Fire fighters have died in IDLH conditions because they did not react properly to an out-of-air emergency [NIOSH 2011, 2012].

The first step in overcoming an SCBA out-of-air emergency is familiarization with your specific SCBA and your breathing air requirements and usage. Fire fighters need to recognize that many SCBA out-of-air emergencies are caused by fire fighters not recognizing the remaining air supply relative to the mission and then another event occurs, such as becoming separated from their crew or hoseline and becoming lost. Other events that can challenge a fire fighter’s ability to overcome an out-of-air emergency include facepiece becoming dislodged, hose entanglement, vomiting in a facepiece, and mechanical issues with the SCBA. A fire fighter’s ability to overcome these events is directly related to their level of repetitive skills and muscle memory, which is only achieved through training and experience with their current SCBA.

If a fire fighter has limited experience in a particular SCBA (whether it is because they are a new fire fighter or an experienced fire fighter with a new SCBA model or manufacturer), they may be concentrating so much on their SCBA that they miss fire environment signs such as fire growth, smoke behavior, orientation of the room, actions of other crew members, and other conditions that require attention. This undue concentration on the SCBA may even be subtle, and when faced with a condition that needs a trained muscle memory response, such as activating the bypass or checking the cylinder wheel, they don’t have the automatic response that is necessary to overcome the initial event. In these conditions, anxiety further complicates the steps necessary to overcome the situation. Many uncontrolled SCBA out-of-air emergencies can be overcome by repetitive skill muscle memory training.

In this incident, FF1 had tried to force an external door when his doff button accidentally activated, possibly releasing up to 400 liters per minute from his SCBA cylinder. According to his captain, this happened several times. This would have significantly reduced the volume of air in his cylinder. It is unknown if FF1 used his cylinder valve or the donning switch to stop the flow of air. Upon making entry into the structure, he may have only cracked the cylinder valve back on, and an air starvation issue may have occurred. During the NIOSH investigation, investigators were unable to ascertain who had secured FF1's SCBA after the incident and how many turns on the cylinder valve were required to turn it off. The cylinder was later discovered to have approximately 500 psi of air remaining. NIOSH investigators tried to discover why the remaining air would not have exited the dislodged facepiece after the incident and offered some possible scenarios in the following paragraphs.

Before the FF1 entered the IDLH atmosphere through the Side Alpha entrance door, he and his crew had been trying to force entry on a door on the Alpha/Delta corner. During that task, he repeatedly lost air through his disconnected MMR when it was inadvertently struck with the forcible entry tools. If he stopped the air loss by closing his cylinder valve, he would have had to turn his cylinder valve back on before he entered the main door on Side Alpha. If he only partially turned his cylinder valve on, he would have had sufficient air pressure during the initial fire fight and search operations; but he could have experienced "air starvation" once his cylinder pressure dropped close to his EOSTI pressure. If he was experiencing air starvation and pulled his facepiece away from his face, this could have dislodged his helmet and exposed him to products of combustion.

After the event, the fire department performed a number of manual evolutions to try and simulate an air starvation condition. They were successful in causing difficulty on inhalation at the low end of the cylinder pressure/SCBA use period by a number of users. This was done by only partially opening the cylinder valve on the SCBA. The units operated without restriction at the beginning upper air pressures, but experienced an increase in breathing resistance once the users got below their EOSTI pressures when they felt the need to remove their facepieces due to air starvation. The cylinders still had a reported 400–500 psi remaining when this starvation occurred.

NIOSH investigators tried to replicate the scenario of air starvation in the lab with the assistance of the National Personal Protective Technology Laboratory (see Appendix II for the actual tests). These replications demonstrated that there is a correlation between air flow and how far the cylinder valve is opened. Limiting the air flow to the system by not opening the valve completely, creates a reduced positive pressure to the facepiece and causes higher resistance to obtaining a breath. Both of these situations were demonstrated in these tests, and both could result in a perceived out-of-air emergency situation. **It is important to note that all SCBA manufactures have instructions in their user's manual that clearly state that users need to fully open the SCBA cylinder valve for proper operation**. It is important for fire fighters to understand that although a partially open SCBA cylinder will operate (and the fire fighter may not realize any difficulty breathing), he/she may experience air starvation when the cylinder pressure is reduced during use. The system is only designed to provide consistent breathing air with the cylinder valve fully open.

Recommendation #5: Fire departments should ensure that fire fighters are properly trained in Mayday procedures and survival techniques.

Discussion: It is essential to train fire fighters to recognize when they are in trouble and know how to call for help. Fire fighters must recognize when they are in trouble, know how to call for help, and understand how incident commanders and others must react to a responder in trouble [NFPA 2013c; Jakubowski and Morton 2001].

One of the most difficult situations a fire fighter can face is when they realize they need to declare a Mayday. The word "Mayday" is designated to identify when a member is in a life-threatening situation and in need of immediate assistance [NFPA 2013d]. Recognizing that they are or about to be in a life-threatening situation is the first step in improving the fire fighters' chances to survive a Mayday event. Many fire departments don't have a simple procedure for what to say when a fire fighter gets into trouble—a critical situation where communications must be clear [NIOSH 2011]. A Mayday declaration is such an infrequent event in any fire fighter's career that they need to frequently train to recognize the need when to declare the Mayday and what steps to take to improve their survival chances.

Fire fighters must understand that when they are faced with a life-threatening emergency, there is a very narrow window of survivability, and any delay in egress and/or transmission of a Mayday reduces the chance for a successful rescue. Knowledge and skills training on preventing a Mayday situation and how to call a Mayday should be mastered before a fire fighter engages in fireground activities or IDLH environments [IAFF 2010; Sendelbach 2003]. Fire fighter training programs should include training on such topics as air management and emergency communications; familiarity with SCBA, a radio, and personal protective equipment; crew integrity; reading smoke, fire dynamics, and fire behavior; entanglement hazards; building construction; and signs of pending structural collapse. If fire fighters find themselves in a questionable position (dangerous or not), they must be able to recognize this and know the procedures for when and how a Mayday should be called. A fire fighter's knowledge, skill, and ability to declare a Mayday must be at the mastery level of performance. This performance level should be maintained throughout their career through training offered more frequently then annually [IAFF 2010; Sendelbach 2003]. Fire fighters need to also understand that their personal protective equipment and SCBA do not provide unlimited protection. Fire fighters should be trained to stay low when advancing into a fire as extreme temperature differences may occur between the ceiling and floor. When confronted with an emergency situation, the best action to take may be immediate egress from the building or to a place of safe refuge (e.g., behind a closed door in an uninvolved compartment, in a staging area on a lower floor) and manually activate the PASS device. A charged hoseline should always be available for a tactical withdrawal while continuing water application or as a lifeline to be followed to egress the building. Conditions can become untenable in a matter of seconds.

Calling a Mayday is a complicated behavior that includes the affective, cognitive, and psychomotor domains of learning and performance [Grossman and Christensen 2008; Clark 2005]. Any delay in calling a Mayday reduces the chance of survival and increases the risk to other fire fighters trying to rescue the downed fire fighter.

Firefighters should be 100% confident in their competency to declare a Mayday for themselves. Fire departments should ensure that any personnel who may enter an IDLH environment meets the Mayday competency standards of the authority having jurisdiction throughout their active duty service. Presently, there are no national Mayday standards for firefighters and most states do not have Mayday standards. A rapid intervention team (RIT) will typically not be activated until a Mayday is declared. Any delay in calling the Mayday reduces the window of survivability and also increases the risk to the RIT [IAFF 2010; Clark 2005, 2008; USFA 2006].

There are no rules on when a fire fighter must call a Mayday, and Mayday training is not included in the job performance requirements in NFPA 1001 [NFPA 2013a]. It is up to each authority having jurisdiction to develop rules and performance standards for a fire fighter to call a Mayday. The National Fire Academy Mayday courses present specific Mayday parameters or rules for when a fire fighter must call a Mayday. The courses may help fire departments in developing and teaching Mayday procedures for fire fighters.

The National Fire Academy has two courses addressing the fire fighter Mayday Doctrine. Q133 Firefighter Safety: Calling the Mayday is a 2-hour program covering the cognitive and affective learning domain of the fire fighter Mayday Doctrine. H134 Calling the Mayday: Hands-on Training is an 8-hour course that covers the psychomotor learning domain of the fire fighter Mayday Doctrine. These courses are based on the military methodology used to develop and teach fighter pilots ejection doctrine. A training CD is available to fire departments free of charge from the U.S. Fire Administration Publications office [Clark 2005; USFA 2006].

The IAFF Fireground Survival program is another resource fire departments can use and was developed to ensure that training for Mayday prevention and Mayday operations are consistent among all fire fighters, company officers, and chief officers [IAFF 2010].

Any Mayday communication must contain the location of the fire fighter in as much detail as possible and, at a minimum, should include the division (floor) and quadrant. It is imperative that firefighters know their location when in IDLH environments at all times to effectively give their location in the event of a Mayday. Once in distress, fire fighters must immediately declare a Mayday. The following example uses LUNAR (Location, Unit, Name, Assignment/Air, Resources needed) as a prompt: "Mayday, Mayday, Mayday, Division 1 Quadrant C, Engine 71, Smith, search/out of air/vomited, can't find exit." When in trouble, a fire fighter's first action must be to declare the Mayday as accurately as possible. Once the incident commander and RIT know the fire fighter's location, the fire fighter can then try to fix the problem, such as clearing the nose cup, while the RIT is en route for rescue [USFA 2006].

A fire fighter who is breathing carbon monoxide (CO) quickly loses cognitive ability to communicate correctly and can unknowingly move away from an exit, other fire fighters, or safety before becoming unconscious. Without the accurate location of a downed fire fighter, the speed at which the RIT can find them is diminished, and the window of survivability closes quickly because of lack of oxygen and high CO concentrations in an IDLH environment [Clark 2005, 2008].

Fire fighters also need to understand the psychological and physiological effects of the extreme level of stress encountered when they become lost, disoriented, injured, or trapped or run low on air during rapid fire progression. Most fire training curricula do not include discussion of the psychological and physiological effects of extreme stress, such as encountered in an imminently life-threatening situation, nor do they address key survival skills necessary for effective response. Understanding the psychology and physiology involved is an essential step in developing appropriate responses to life-threatening situations. Reaction to the extreme stress of a life-threatening situation, such as being trapped, can result in sensory distortions and decreased cognitive processing capability [Grossman and Christensen 2008].

Fire fighters should never hesitate to declare a Mayday. There is a very narrow window of survivability in a burning, highly toxic building. Any delay declaring a Mayday reduces the chance for a successful rescue [Clark 2005]. In the book *Stress and Performance in Diving*, the author notes: "**We know that under conditions of stress, particularly when rapid problem-solving is crucial, over-learning responses is essential. The properly trained individual should have learned coping behavior so well that responses become virtually automatic requiring less stop and think performance**" [Bachrach and Egstrom 1987].

The word Mayday is easily recognizable and is an action word that can start the process of a rescue. The use of other words to declare an emergency situation should be discouraged because they may not be recognizable as an immediate action word that will start a rescue process. During this incident, the fireground radio traffic was busy and many different communications were taking place. A Mayday message transmitted over the radio may have gotten the attention of command officers and other fire fighters much earlier in the event when a rescue attempt might have had a better chance of locating the fire fighter.

In this incident, FF1 had a radio but never called a Mayday or activated his emergency button.

Recommendation #6: Fire departments should ensure fire fighters are sufficiently retrained when transitioning from the emergency medical service back to fire operations.

Discussion: In order to ensure for the proficiency and competency of fire department members, the fire department should conduct refresher or annual skills evaluations to verify minimum professional qualifications. This refresher/annual evaluation should address the qualifications specific to the member’s assignment and job description. This process should be structured in a manner that skills are evaluated on a recurring cycle with the goal of preventing skills and abilities degradation and ensuring for the safety of members. Proficiency evaluation and training provides an opportunity to ensure that all fire officers and fire fighters are competent in the knowledge, skills, and abilities in fireground operations.

NFPA 1500 *Standard on Fire Department Occupational Safety and Health Program* requires a fire department to establish and maintain a training, education, and professional development program with the goal of preventing occupational deaths, injuries, and illnesses. This ensures members are trained and competencies are maintained in order to effectively, efficiently, and safely execute all responsibilities [NFPA 2013d]. This process is consistent with the organizational statement that establishes the existence of the fire department, the services the fire department is authorized and expected to perform, the organizational structure, and the job descriptions and functions of fire department members [NFPA 2013d].

The primary goal of all training, education, and professional development programs is the reduction of occupational injuries, illnesses, and fatalities. As members progress through various job duties and responsibilities, the department should ensure the introduction of necessary knowledge, skills, and abilities to members who are new in their job titles as well as ongoing development of existing skills [NFPA 2013d].

NFPA 1410 *Standard on Training for Emergency Scene Operations* defines basic evolutions that can be adapted to local conditions and serves as a method for the evaluation of minimum acceptable performance during initial fireground operations [NFPA 2010]. Proficiency training for fireground operations and emergency incidents should be conducted annually. This training should include, but not be limited to, scene size-up, situational awareness, use of the incident management system, personnel accountability system, crew integrity, strategy and tactics, search and rescue, hoseline operations, ladder operations, ventilation, thermal imaging cameras, fireground communications, use of rapid intervention teams, and Mayday operations.

In this incident, the fire fighter had spent most of his career as an EMT riding an ambulance and detailed to the airport. He recently returned to being a fire fighter without any refresher training or structure fire experience.

Recommendation #7: Fire departments should ensure that accountability officers are proficient in fire fighter tracking/monitoring systems.

Discussion: With the development of new technological systems that can track, monitor, and communicate with every fire fighter on scene, it is necessary that accountability officers be proficient at understanding and operating the equipment. In addition, the fire department’s protocols and procedures should reflect the capabilities of the tracking system, and the accountability officers should be trained on and follow these procedures [NFPA 2013d].

In this incident, several failed attempts were made to contact the fire fighter who’s PASS was alarming before it was determined that the fire fighter was missing.

Recommendation #8: Fire departments should ensure that fire fighters are trained in situational awareness, personal safety, and accountability.

Discussion: All fire fighters operating at an incident should maintain situational awareness and conduct a continuous risk assessment throughout the incident, reporting unsafe or changing conditions to the incident commander. Fire fighters need to understand the importance of situational awareness and personal safety on the fireground. The fireground dangers and hazards can and do change as the incident becomes larger and the event duration increases.

The book *Essentials of Fire Fighting and Fire Department Operations* [IFSTA 2008] defines situational awareness as an awareness of the immediate surroundings. On the fireground, every fire fighter should be constantly alert for changing and unsafe conditions. Even though a safety officer may be designated for an incident, it is the obligation of all personnel to remain alert to their immediate surroundings. They must maintain their situational awareness and be alert for unsafe conditions. This applies not only to the conditions found within a burning structure, but to the exterior fireground as well [Clark 2008]. **In virtually every case, structural collapse results from damage to the structural system of the building caused by the fire or by fire-fighting operations. The longer a fire burns in a building, the more likely that the building will collapse [IFSTA 2008]**.

One of the most critical aspects of coordination between crews is maintaining situational awareness. The opposite of situational awareness is tunnel vision where the fire fighters become so focused on fire fighting or other operational assignments that they fail to sense changes in their environment. Fire fighters can maintain their situational awareness by looking up, down, and around themselves, as well as listening for new or unusual sounds and feeling vibrations or movement. Fire fighters and officers should communicate any changes in their environment to other members as well as to the incident commander.

The International Association of Fire Chiefs (IAFC), Safety, Health and Survival section developed the "Rules of Engagement for Structural Fire Fighting." The rules of engagement have been developed to assist both the fire fighter and the incident commander as well as command team officers in risk assessment and "Go" or "No-Go" decisions. The fireground creates a significant risk to fire fighters, and it is the responsibility of the incident commander and command organization officers to minimize fire fighter exposure to unsafe conditions and stop unsafe practices [IAFF 2010].

The rules of engagement can assist the incident commander, company officers, and fire fighters who are at the highest level of risk in assessing their situational awareness. One principle applied in the rules of engagement is that fire fighters and the company officers are the members most exposed to the risk for injury or death and will be the first to identify unsafe conditions and practices. The rules integrate the fire fighter into the risk assessment/decision-making process. These members should be the ultimate decision makers as to whether it's safe to proceed with assigned objectives. Where it is not safe to proceed, the rules allow a process for that decision to be made while still maintaining command unity and discipline.

Rules of Engagement for Fire Fighter Survival

- Size up your tactical area of operation. This causes the company officer and fire fighters to pause for a moment, look over their area of operation, and evaluate their individual risk exposure to determine a safe approach for completing their tactical objectives.
- Determine the occupant survival profile. Occupant survival should be considered as part of the individual fire fighter's risk assessment and action plan development.
- Do not risk your life for lives or property that cannot be saved. When fire conditions prevent occupant survival and significant or total destruction of the building is inevitable, do not engage in fire-fighter operations that may harm you.
- Extend limited risk to protect savable property. Risk exposure should be limited to a reasonable, cautious, and conservative level when trying to save a building.
- Extend vigilant and measured risk to protect and rescue savable lives. Search and rescue operations should be managed in a calculated, controlled, and safe manner while remaining alert to changing conditions during high-risk primary search and rescue operations where lives can be saved.
- Go in together, stay together, and come out together. Two or more fire fighters should operate as a team.
- Maintain continuous awareness of your air supply, situation, location in the building, and fire conditions. Situational awareness means knowing where you are in the building and what is happening around you and elsewhere that can affect your risk and safety.
- Constantly monitor fireground communications for critical radio reports.
- You are required to report unsafe conditions or practices. Stop, evaluate, and decide. This allows any member to raise an alert about a safety concern without penalty, and the supervisor should address the question to ensure safe operations.
- You are required to abandon your position and retreat before deteriorating conditions can harm you. Be aware and exit early to a safe area when you are exposed to deteriorating conditions, unacceptable risk, and a life-threatening situation.
- Declare a Mayday as soon as you think you are in danger. Officers should ensure that fire fighters are comfortable with declaring a Mayday as soon as they think they are in trouble. [IAFF 2010]

The Incident Commander's Rules of Engagement for Fire Fighter Safety

- Rapidly conduct or obtain a 360-degree situational size-up of the incident. Determine the safest approach to tactical operations as part of the risk assessment plan and action development plan before fire fighters are placed at substantial risk.

- Determine the occupant survival profile. Consider fire conditions in relation to the potential for occupant survival of a rescue event before committing to a high-risk search and rescue operation and ongoing risk assessment.
- Conduct an initial risk assessment and implement a safe action plan. This rule causes an incident commander to develop a safe action plan by conducting a size-up, assessing the survival profile, and completing a risk assessment before fire fighters are placed in high-risk positions on the fireground.
- If you do not have the resources to safely support and protect fire fighters, seriously consider a defensive strategy. This rule prevents the commitment of fire fighters to high-risk tactical objectives that cannot be accomplished safely due to inadequate resources on the scene.
- Do not risk fire fighter lives for lives or property that cannot be saved. Instead, seriously consider a defensive strategy. This rule prevents the commitment of fire fighters to high-risk fire-fighting operations that may harm them when fire conditions prevent occupant survival and significant or total destruction of the building is inevitable.
- Extend limited risk to protect savable property. The incident commander should limit risk exposure to a reasonable, cautious, and conservative level when trying to save a building that is believed, following a thorough size-up, to be savable.
- Extend vigilant and measured risk to protect and rescue savable lives. The incident commander should manage search and rescue and supporting fire-fighting operations in a highly calculated, controlled, and cautious manner while remaining alert to changing conditions during high-risk search and rescue operations where lives can be saved.
- Maintain frequent two-way communications and keep interior crews informed of changing conditions. The incident commander should obtain frequent progress reports, keeping all interior crews informed of changing fire conditions observed from the exterior that may affect crew safety.
- Obtain frequent progress reports and revise the action plan. Frequent progress reports enable the incident commander to continually assess fire conditions and any risk to fire fighters and to regularly adjust and revise the action plan to maintain safe operations.
- Ensure accountability of every fire fighter, their location, and status. The incident commander and command organizational officers should maintain a constant and accurate accountability of the locations and status of all fire fighters within a small geographic area of accuracy, within the hazard zone, and be aware of who is presently in or out of the building.
- If after completion of the primary search, little or no progress toward fire control has been achieved, seriously consider a defensive strategy.
- Always have a rapid intervention team in place at all working fires.

Always have fire fighter rehab services in place at all working fires. This allows fire fighters who endured strenuous physical activities at a working fire to be rehabilitated and medically evaluated for continued duty and before being released from the scene [IAFF 2010].

Recommendation #9: Fire departments should ensure all fireground ventilation is coordinated with fire-fighting operations.

Discussion: Fire departments should manage and control the openings to the structure to limit fire growth and spread and to control the flow path of inlet air and fire gases during tactical operations. All ventilation must be coordinated with suppression activities. Uncontrolled ventilation allows additional oxygen into the structure, which may result in a rapid increase in the fire development and increased risk to fire fighters due to increased heat release rates within the flow path. Underwriters Laboratories (UL) released a report on the *Impact of Ventilation on Fire Behavior in Legacy and Residential Construction*. This report addressed the impact of multiple ventilation locations and the possibility of creating fuel-limited fires. The research indicated it was not possible to create fuel-limited fires with multiple ventilation openings. The report stated, *"It is more likely that the fire will respond faster because the already open ventilation location is allowing the fire to maintain a higher temperature than if everything was closed"* [UL 2010].

The flow path of a fire is how a fire moves through the structure as determined by incoming and outgoing vents for air, since air allows fire to sustain or grow [UL 2010]. Identifying and controlling the flow path is about knowing where the air comes from and where it's headed, and its importance cannot be underestimated. The identification of flow path is an item that should find its way into every after-action review. While trying to locate the fire, it is important to cool the heated space from a safe location while ensuring the safety of the fire fighters. Once the fire is under control, the fire can be completely extinguished. The rescue and salvage operations are self-explanatory—if anything can be saved, save it. These two actions are always active, right from sizing up to extinguishing [ISFSI 2013].

The UL research was conducted on one-story and two-story houses. The data collected from this research project provides valuable insight on the impact of ventilation on fire behavior in both legacy and contemporary residential construction [UL 2010]. Based upon the UL research, the following tactical operations should be considered during fireground operations:

- **Stages of fire development**: The stages of fire development change when a fire becomes ventilation-limited. It is common with today's fire environment to have a decay period prior to flashover, which emphasizes the importance of ventilation.
- **Forcing the front door is ventilation**: Forcing entry has to be thought of as ventilation as well. While forcing entry is necessary to fight the fire, it also adds another vent that feeds air to the fire, and the clock is ticking before either the fire gets extinguished or it grows until an untenable condition exists, jeopardizing the safety of everyone in the structure.
- **Flow paths:** Every new ventilation opening provides a new flow path for the fire. This could create very dangerous conditions when there is a ventilation-limited fire.

- **No smoke showing:** A common event during the UL experiments was that once the fire became ventilation-limited, the smoke being forced out of the gaps of the houses is greatly diminished or stopped altogether. No smoke showing during size-up should increase awareness of the potential conditions inside.
- **Coordination:** If you add air to the fire and don't apply water in the appropriate time frame, the fire gets larger and safety decreases. Examining the times to untenability gives the best-case scenario of how coordinated the attack needs to be.
- **Smoke tunneling and rapid air movement through the front door:** Once the front door is opened, attention should be given to the flow through the front door. A rapid inrush of air or tunneling effect could indicate a ventilation-limited fire.
- **Vent Enter Search (VES):** During a VES operation, primary importance should be given to closing the door to the room. This eliminates the impact of the open vent and increases tenability for potential occupants and firefighters while the smoke ventilates from the now isolated room [ISFSI 2013].

At this incident, the attic access panel was opened prior to the roof being vented, which enabled the hot gases and heavy smoke to enter the second floor from the attic space.

Recommendation #10: Fire departments should ensure hoselines are deployed, staffed, and appropriately utilized to protect interior operating crews.

Discussion: Although the primary purpose of the initial attack hoseline is for fire suppression, it also protects the interior fire suppression crews if they become overrun with fire, need to cool down the area, and need to protect a fire fighter's egress point(s). A hoseline should be of sufficient length to advance the crew in their search for the fire and/or occupants.

When initial attack hoselines are deployed and charged to an area and a hoseline is needed elsewhere, another hoseline should be taken off the engine to address the need.

During this incident, the initial attack line was deployed to Side Delta of the structure where the fire was visible. Prior to making entry on Side Alpha, the officer called for the hoseline to follow his crew in search for occupants. Upon going up the stairwell to the second floor, the hoseline came up short at the top of the stairs. This prompted FF2 to go down the stairs to try and pull more hose.

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Investigator Information

This incident was investigated by Matt E. Bowyer, General Engineer, and Stephen Miles, Investigator, with the Fire Fighter Fatality Investigation and Prevention Program, Surveillance and Field Investigations Branch, Division of Safety Research, NIOSH, located in Morgantown, West Virginia. An expert technical review was provided by Daniel Rossos, Chief (Retired), Portland Fire and Rescue. A technical review was also provided by the National Fire Protection Association, Public Fire Protection Division.

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Appendix I

Self-Contained Breathing Apparatus

National Personal Protective Technology Laboratory
Technology Evaluation Branch

Disclaimer

Investigator Information
The SCBA inspection and this report were written by Thomas D. Pouchot, General Engineer, Technology Evaluation Branch, National Personal Protective Technology Laboratory, National Institute for Occupational Safety and Health, located in Bruceton, Pennsylvania.
The purpose of Respirator Status Investigations is to determine the conformance of each respirator to the NIOSH approval requirements found in Title 42, *Code of Federal Regulations*, Part 84. A number of performance tests are selected from the complete list of Part 84 requirements and each respirator is tested in its "**as received**" condition to determine its conformance to those performance requirements. Each respirator is also inspected to determine its conformance to the quality assurance documentation on file at NIOSH.

In order to gain additional information about its overall performance, each respirator may also be subjected to other recognized test parameters, such as National Fire Protection Association (NFPA) consensus standards. While the test results give an indication of the respirator's conformance to the NFPA approval requirements, NIOSH does not actively correlate the test results from its NFPA test equipment with those of certification organizations which list NFPA-compliant products. Thus, the NFPA test results are provided for information purposes only. Selected tests are conducted only after it has been determined that each respirator is in a condition that is safe to be pressurized, handled, and tested.

Respirators whose condition has deteriorated to the point where the health and safety of NIOSH personnel and/or property is at risk will not be tested.

Status Investigation Report of One
Self-Contained Breathing Apparatus
Submitted By the
NIOSH Division of Safety Research
NIOSH Task Number 19738

The National Institute for Occupational Safety and Health (NIOSH) has concluded its investigation conducted under NIOSH Task Number TN-19738. This investigation consisted of the inspection of a Scott Health and Safety AirPak 4.5, 45 minute, 4500 psig, Self Contained Breathing Apparatus (SCBA). The SCBA unit in question was contained inside an individual cardboard shipping box and was delivered to the NIOSH facility in Bruceton, Pennsylvania, on July 22, 2014. The package was taken to the NPPTL, Technology Evaluation Branch (TEB) Respirator Equipment Storage Area (building 20) and stored under lock until the time of the examination and evaluation.

SCBA Inspection:

An initial general inspection of the SCBA unit was conducted on July 22, 2014. The unit was identified as the Scott Health and Safety AirPak 4.5 model. In addition, Scott Health and Safety performed a down loading of the data logger present on the SCBA with NIOSH personnel present on August 27, 2014

A complete visual inspection of the SCBA unit was conducted on August 19, 2014. The unit was examined, component by component in the condition received, to determine conformance to the NIOSH-approved configuration. The visual inspection process was photographed.

The complete SCBA inspection is summarized in Appendix I of the enclosed Status Investigation Report. The condition of each major component was photographed with a digital camera. Images of the SCBA unit are contained in the Appendix III of the report.

The SCBA unit in question, Unit #1, exhibited some signs of wear and tear; and the unit was covered lightly with general dirt and grime. The cylinder valve as received on the unit was in the closed position. The cylinder gauge could be read and indicated approximately 500 psig remaining. The cylinder valve hand-wheel could be turned.

The regulator and facepiece mating and sealing area on the Unit #1 facepiece was relatively clean. The unit had only slight scratches on the lens. Visibility through the facepiece lens of Unit #1 was good as the lens condition was good. The facepiece head harness webbing on the Unit #1 was in fair to good condition with only a slight amount of dirt. The PASS on the Unit #1 functioned. The NFPA SCBA approval label on Unit #1 was present and readable.

Personal Alert Safety System (PASS) Device

The Personal Alert Safety System (PASS) device on Units #1 was operable and functional. The PASS device was activated and appeared to function normally. However, the unit was not tested against the specific performance requirements of NFPA 1982, *Standard on Personal Alert Safety Systems, (PASS),* 2007 Edition. Because NIOSH does not certify PASS devices, no further evaluation was performed.

SCBA Compressed Air Cylinder Contents

During the inspection, it was noted that the compressed air cylinder of the unit contained some air pressure, approximately 500 PSIG. An air sample was collected for analysis. The results of that analysis are contained in Appendix II.

SCBA Testing

The purpose of the testing was to determine the SCBA conformance to the approval performance requirements of Title 42, *Code of Federal Regulations*, Part 84 (42 CFR 84). Further testing was conducted to provide an indication of the SCBA conformance to the National Fire Protection

Association (NFPA) Air Flow Performance requirements of NFPA 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus for the Fire Service*, 1997 Edition.

NIOSH SCBA Certification Tests (in accordance with the performance requirements of 42 CFR 84):

1. Positive Pressure Test [§ 84.70(a)(2)(ii)]
2. Rated Service Time Test (duration) [§ 84.95]
3. Static Pressure Test [§ 84.91(d)]
4. Gas Flow Test [§ 84.93]
5. Exhalation Resistance Test [§ 84.91(c)]
6. Remaining Service Life Indicator Test (low-air alarm) [§ 84.83(f)]

National Fire Protection Association (NFPA) Tests (in accordance with NFPA 1981, 1997 (Edition):

7. Air Flow Performance Test [Chapter 5, 5-1.1]

The testing of the unit was conducted on October 3, 2014. SCBA Unit #1 passed all the testing.

Appendix II of the Status Investigation Report contains complete NIOSH and NFPA test reports for the SCBA Unit #1. Tables One and Two summarize the NIOSH and NFPA test results.

Summary and Conclusions

One SCBA unit was submitted to NIOSH by the NIOSH Division of Safety Research for the Texas Fire Department for evaluation on July 22, 2014. The SCBA was initially inspected on July 22, 2014. The unit was identified as a Scott Health and Safety AirPak 4.5, 45 minute, 4500 psig SCBA (NIOSH approval number, TC-13F-212CBRN). In addition on August 27, 2014, the SCBA data logger for SCBA Unit #1 was downloaded by personnel from Scott Health and Safety with NIOSH personnel present. An in-depth inspection of the SCBA was conducted on August 19, 2014. The unit was in mostly fair to good condition. The unit suffered very slight amount of damage but exhibited other signs of wear and tear and the unit was slightly covered with general dirt. The cylinder valve as received on Unit #1 was in the closed position. The cylinder gauge could be read. The cylinder valve hand-wheel could be turned. The regulator and facepiece mating and sealing areas on Unit #1 were relatively clean. The unit had only slight scratches on the lens. Visibility through the facepiece lens of Unit #1 was good as the lens condition was good. The NFPA approval label on Unit #1 was present and readable.

The air cylinder on the Unit #1 had a manufactured date of 03/08. Under the applicable DOT exemption, the air cylinder is required to be hydro tested every 5 years. For the air cylinder on Unit #1, a retest date before the last day of 03/13 is required. The retest label was readable on Unit #1 with a retest date of 4/13, therefore the cylinder was within the hydro certification when last used. The cylinder on Unit #1 was in fair to good condition with only minor surface scratches present on the outer coating.

The integrated PASS unit on Unit #1 was activated and appeared to function normally.

Approximately 500 psig of air remained in the cylinders and an air sample was taken and analyzed.

The SCBA Unit #1 was tested on October 3, 2014. Unit #1 did meet all the requirements as tested.

After the inspection and testing of the SCBA unit, the respirator was placed back into storage pending the final disposition from the Texas Fire Department.

If this SCBA unit is to be placed back into service, then the units should be cleaned thoroughly and any damaged components replaced and tested by a qualified SCBA technician.

From the information obtained during this investigation, NIOSH proposes no further action on its part at this time. The investigation under task number TN-19738 will be considered closed.

Appendix II

ADDENDUM

TN-19738

Air Starvation Test

Discussion:

The Fire Department requested NIOSH to conduct testing to determine what affects a partially closed cylinder valve may have on the air flow of a SCBA. The Fire Department conducted similar test with their fire fighters wearing a Scott Health and Safety Self Contained Breathing Apparatus (SCBA), and breathing normally throughout the duration of the 45-minute cylinder to determine if the turns of the cylinder valve regulated the air flow to the user.

The testing was done using a mechanical breathing machine and anthropometric head that are used in the certification and testing of SCBA in the NIOSH lab in Morgantown, WV. A mechanical pressure gauge was inserted inline in between the cylinder and the first stage regulator (reference Photos 1 and 2.) The cylinder valve was opened to different partial revolutions. Two and one half turns of the hand wheel opened the cylinder valve completely. The breathing machine was also set at different rates in liters/minute (LPM).

Observations/Summary of Air Starvation Tests

Test #1, ½ turn on cylinder valve, 40 LPM.

Face piece pressure .4 inches of water-positive

The test ran 47 minutes and 18 seconds before the pressure in the facepiece went negative and the pressure gauge read empty. During this test, there was not a significant drop in pressure to record.

Test #2, ¼ turn on cylinder valve, 40 LPM.

Face piece pressure .4 inches of water positive

At 2200 psi dropped to .35 inches of water-positive

At 1950 psi dropped to .3 inches of water-positive

At 1100 psi dropped to .25 inches of water-positive

At 1100 the VibrAlert came on and the positive pressure increased to .4 inches of water-positive

A noticeable 200 – 300 psi swing in the needle on the gauge was witnessed.

The test ran 45 minutes before the pressure in the facepiece went negative and the pressure gauge read empty.

Test #3, ¼ turn on cylinder valve, 75 LPM.

Face piece pressure .25 inches of water positive

A 200 psi swing in the needle on gage at 4500 psi.

3000 psi - .15 inches of water-positive

2250 psi - .10 inches of water-positive

1350 psi - .05 inches of water-positive

1100 psi vibe alert and 300 psi swing in the needle

600 psi - .00 inches of water-but remainded positive

500 psi – 400 to 500 psi swing in the needle

Test #4, 1/8 turn on cylinder valve, 40 LPM.

Face piece pressure .4 inches of water positive

800 psi swing in the needle (Photo 3)

3800 psi - .35 inches of water-positive

3500 psi - .3 inches of water-positive (Approximately 2 minutes)

3300 psi - .25 inches of water-positive

2800 psi - .19 inches of water-positive (Approximately 10 minutes)

1200 psi - .15 inches of water-positive (Approximately 21 minutes)

1000 psi - .1 inches of water-positive (Approximately 25 minutes)

800 psi- VibrAlert in/out

500 psi - .2 inches of water-positive

At this time during test #4, the cylinder valve was turned completely open. The pressure climbed to 1000 psi and remained steady. The VibrAlert stayed on.

Conclusions

The tests represented that there is a correlation between air flow and how far the cylinder valve is opened. Limiting the air flow to the system, by not opening the valve completely, creates a reduced positive pressure to the facepiece and a higher resistance to obtain a breath by the wearer. Both of these situations were demonstrated in these tests and both could result in a perceived out-of-air emergency situation.