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NIOSH Fire Fighter Fatality Investigation and Prevention Program
Injury in the line of duty...
A summary of a NIOSH fire fighter fatality investigation
January 6, 2000

Aluminum Regulator Fire Injures One Fire Fighter-Nevada

SUMMARY

On January 25, 1999, a male fire fighter (victim) received first- and second-degree burns when an aluminum oxygen regulator caught fire. The victim was performing a weekly equipment inspection on the engine to which he was assigned. As a part of the inspection, the victim was to remove the oxygen airway supply bag and check the oxygen pressure in the cylinder. Department procedures required him to open the oxygen cylinder post valve, check the cylinder pressure to verify it was sufficiently full for service, close the cylinder post valve, and release the remaining oxygen in the regulator. The victim removed the airway supply bag from the medical compartment and placed the upper half on a shelf at the rear of the engine and the bottom part against his stomach, where he began to check the cylinder's pressure. The cylinder was placed in the bag so that the regulator was away from the victim when he began to charge the regulator. Upon opening the post valve, the regulator generated a loud popping sound and emitted a ball of fire. The fire quickly spread to the airway supply bag as the victim dropped it and ran into the station bay, where he was met by other fire fighters. The fire fighters began to treat the victim as the regulator continued to burn. As the regulator burned, the post valve sheared off the cylinder, causing a second flash of fire. The post valve and regulator burned themselves out as the medical crews from nearby stations arrived to assist the victim. The victim was transported to a nearby trauma center, where he was diagnosed with first- and second-degree burns to his head, arms, and hands.

NIOSH investigators concluded that, to reduce the risk of similar incidents, fire departments should:

- ***consider the use of oxygen regulators constructed of materials having an oxygen compatibility equivalent to brass***
- ***ensure that the cylinder is placed in an upright position, the cylinder post valve is pointed in a safe direction (away from the operator), and opened then closed before the regulator is attached to the cylinder***

- ***ensure that when opening a cylinder post valve with the regulator attached, it should be opened slowly and positioned away from the operator***
- ***ensure that fire fighters are trained and aware of safe handling procedures pertaining to oxygen systems***
- ***ensure that oxygen systems (cylinders and regulators) are stored in a cool area free of dirt, oils, and grease***
- ***ensure that oxygen re-filling stations and maintenance areas where oxygen equipment is serviced, are in a locked, air-conditioned room that is clean and free of dirt, oils, and grease***
- ***ensure that any components added to the regulator, such as gauge guards, are installed so that they do not block the regulator vent holes.***

Additionally, to reduce the risk of similar incidents, manufacturers should:

- ***ensure that they provide a warning pertaining to occluding the vent ports on the regulator.***

INTRODUCTION

On January 25, 1999, a male fire fighter, 25 years of age, was performing a weekly equipment inspection on the engine to which he was assigned. The inspection required the victim to check the oxygen pressure in the cylinder, which is stored in the airway supply bag. Removing the airway supply bag, the victim opened the post valve charging the regulator. The regulator generated a loud pop and emitted a large ball of fire. The victim received first- and second-degree burns to his head, arms, and hands.

NIOSH was notified of this incident by the International Association of Fire Fighters (IAFF) and on February 23, 1999, a Safety and Occupational Health Specialist, an Engineer, and a Physical Scientist from NIOSH investigated this incident. Meetings and interviews were conducted with fire department personnel involved in the incident, which included the Battalion Chief of the department, the training officer, and the fire department's fire and arson investigators. Also, a representative from the manufacturer of the regulator involved in this incident, and a representative from the independent testing laboratory that had produced the test results for this incident, were interviewed. NIOSH investigators obtained the following from the department: copies of photographs; training records; Standard Operating

Procedures (SOPs), and the reports completed by the fire/arson investigators.

The fire department involved in this incident is comprised of 110 total employees, of whom 88 are uniformed fire fighters. The department serves a population of approximately 100,000 in a geographic area of 680 square miles. The fire department requires all new fire fighters to attend the regional fire academy to receive State certification. The certification covers all aspects of the National Fire Protection Association (NFPA) requirements for fire fighter level I training. Fire fighters are then assigned to a department where they are placed on probation. During their probationary period, the fire fighters will obtain their fire fighter level II training. Each fire fighter is also certified as an Emergency Medical Technician (EMT). As part of the EMT training, the fire fighters are trained to administer oxygen to patients. Refresher training is continued throughout the year. The victim's training records were reviewed and appeared to be sufficient. The victim had 2 + years of experience as a fire fighter and EMT. ***NOTE: After this incident occurred, the fire department provided a training course for all fire fighters, which covered the safe handling and dangers of oxygen systems. The course was instructed by a nationally recognized expert, with the assistance of a NIOSH investigator.***

INVESTIGATION

On January 25, 1999, at 1014 hours, one male fire fighter (victim) received first- and second-degree burns while performing a weekly equipment inspection. The weekly inspection requires the fire fighters to conduct an inspection of the equipment and supplies on each piece of apparatus. The engine to be inspected was parked in front of the station with the ignition turned off. The victim opened the medical compartment and pulled out the airway supply bag. He placed part of the medical bag on a small shelf below the compartment (see Photo 1). The regulator was placed in the bag in a position that when the victim removed the bag, the bottom of the cylinder was inside the bag, resting against his stomach, with the regulator facing away from his body. He unzipped the medical bag approximately halfway and slightly turned the regulator's pressure gauge to his right, away from his body. As he attempted to charge the regulator, he turned his head to the left, away from the pressure gauge (he was instructed to turn his head away from the pressure gauge during department training for safety purposes). As he opened the post valve to charge the regulator, it immediately flashed, emitting a ball of fire. The victim stated that he heard a high pressure leaking sound before he realized that he was on fire. The victim quickly jumped backwards, allowing the medical bag to fall to the ground. As he ran

towards the station's bay he removed his jacket, which was smoking from the fire, and then ran to the office of the Captain on duty.

Fire fighters performing other tasks at the time recalled hearing a loud pop and the sudden rush of air. One fire fighter, who was at the driver's side door of the engine, quickly ran to the rear of the engine to see the victim running towards the bay, in distress. He noticed that the medical bag and oxygen resuscitator were emitting flames approximately 3 feet in height. The medical bag was resting under the tail board of the Engine. He immediately jumped inside the engine and moved it forward, away from the burning bag. As he moved the engine he called dispatch for an ambulance to respond to the incident site. Additional fire fighters who were inside the station also heard the loud pop and responded. One fire fighter exited the kitchen of the station and stated that he saw the medical bag on fire in front of the station. He proceeded to get his turnout gear and alert the Captain on duty.

The victim reached the Captain's office door and began banging on it. In response, the Captain opened the door and stated that the victim ran past him and into the bathroom. Noticing that the victim had soot on his head and that his arms were burned, he exited the office to investigate the situation. As he exited he spotted a fire in front of the engine bay. As the Captain attempted to get a garden hose to extinguish the fire, a second small explosion occurred (possibly at this point the post valve had detached from the cylinder). The post valve sheared away from cylinder as the cylinder began to spin out of control. The Captain was able to obtain a hose and extinguish the fire. Soon after, the ambulance arrived and transported the victim to the local hospital with first- and second-degree burns to his head, arms, and hands.

CYLINDER/REGULATOR INFORMATION

The regulator involved was a full-bodied aluminum regulator with aluminum exposed to high-pressure oxygen throughout the flow path. The same regulator model had been involved in several incidents in the past.[15] Prior to this incident the regulator was recalled by the manufacturer. The recall was issued to replace a stainless steel screen, located under the inlet nozzle, with a sintered-bronze inlet filter. The manufacturer provided the department with a retrofit kit which contained a sintered-bronze inlet filter, an inlet screw, and a sticker to be placed on the retrofitted regulator to identify that it had been retrofitted. The regulator involved in this incident was retrofitted with the kit supplied by the manufacturer. Since this incident, the manufacturer has voluntarily recalled all regulators of the same model. The manufacturer is offering a trade-in program for these regulators. The trade-

in program allows customers to trade in the aluminum regulator for credit towards the purchase of a brass regulator.

The regulator involved was an aluminum regulator designed for use with a portable or fixed oxygen cylinder ("D" and "E" size). The fire destroyed most of the regulator in this incident (see Photo 2). The cylinder was a "D" size cylinder. Records confirmed that the cylinder was in good condition before this incident. The cylinder was only slightly damaged during the incident. The post valve, which attaches the regulator to the cylinder, was severely damaged. It had severed near the base of its connection with the cylinder and was found completely detached from the cylinder. The cylinder was nearly full at the time of the incident (approximately 2200 psi). The regulator and cylinder were used the night before this incident with no reported problems. The regulator and cylinder were sent to an independent forensic testing laboratory for further evaluation.

INJURY RESULTS

The victim received first- and second-degree burns to his head, arms, and hands.

RECOMMENDATIONS AND DISCUSSION

Recommendation #1: Fire departments should consider the use of oxygen regulators constructed of materials having an oxygen compatibility equivalent to brass. [2-7, 15]

DISCUSSION: Aluminum alloys are attractive candidate materials for pressure vessels because of their high strength-to-weight ratios. High-pressure-oxygen-system components for portable or flight use must be lightweight, so it may appear to be desirable to build their housings from such lightweight metals as aluminum. The use of aluminum alloys in lines, valves, and other components should be avoided whenever possible because they easily ignite in high-pressure oxygen, burn rapidly, and have very high heats of combustion. Aluminum is ignited exceptionally easily by friction because the wear destroys its protective oxide layer; it should not be used in systems where frictional heating is possible.[6]

Aluminum is easily ignited by particle impact, and aluminum particulate is a far more effective ignition source than many other metal particulates tested to date (titanium particulate has not been tested). High-pressure oxygen systems fabricated from aluminum must be designed with extreme care to

eliminate particulate. *Testing has shown that aluminum is substantially more flammable in oxygen than brass or other high copper or high nickel alloys*.[7]

Sources indicate that commonly used aluminum alloys can easily burn in the presence of high-pressure pure oxygen once an ignition source is present. Aluminum will burn in pure oxygen at a pressure of 35 psi (this is about twice the normal atmospheric pressure) whereas some brass alloys require over 5,000 psi of pure oxygen to burn. Aluminum will also produce approximately 10 times the amount of heat of copper alloys when burning.

One concern of using aluminum in the downstream flow path is the possibility of particle impact and the aluminum not being able to contain the ignition, leading to a catastrophic failure of the unit. Particles can be introduced into oxygen resuscitators in many different ways. Experts suggest the presence of a particle or particles in the cylinders is not as problematic as the design of the oxygen-flow path and the materials used.

The cylinder has a post valve that closes off the oxygen opening and allows the regulator to be attached. When the post valve is screwed into the aluminum cylinder, there is a possibility that the two metals rubbing together could create metal particles that would remain in the cylinder body. Galling is a condition involving smearing and transfer of material from one surface to the other and particles could be introduced by metal-to-metal seal contact which occurs when the post valve is opened and closed. The frictional heat of the galling could lead to ignition of the valve; or the particles generated by the galling could cause malfunction or ignition of another component downstream. Therefore, the design of the regulator's downstream flow path should be tolerant of the particle contamination, and resistant to particle generated ignitions. Experts suggest the downstream flow path should be lined with brass, bronze, or a similar material which would resist particle ignition, and that using such a material would shield the particle ignition and provide the opportunity to burn out.

***Recommendation #2: Fire departments should ensure that the cylinder is placed in an upright position, the cylinder post valve is pointed in a safe direction (away from the operator), and opened then closed before the regulator is attached to the cylinder*.[8]**

DISCUSSION: After removing the valve protection cap, the cylinder post valve should be opened slowly for an instant to clear the opening of particles of dust or dirt; care should be taken to point the valve opening away from personnel, and in a safe direction.

Cylinders are generally stored on fire trucks in a horizontal position, which could allow particles to rest near the neck of the cylinder. Whenever possible, cylinders should be placed in an upright position not only when in storage, but also when in use. If cylinders are stored in an upright manner, any particulate in the cylinder would generally settle in the bottom of the cylinder and not as easily entrain in the oxygen-flow discharge path.

In this incident, the cylinder was lying in a horizontal position when the victim opened the medical bag. When he removed the medical bag and opened the post valve, the cylinder flashed.

Recommendation #3: Fire departments should ensure that fire fighters are trained and aware of safe handling procedures pertaining to oxygen systems.[8, 10]

DISCUSSION: Fire departments should provide fire fighters with adequate techniques for safe handling of oxygen resuscitators. The training should include areas such as the safe handling of oxygen resuscitators, operating procedures, maintenance, cleaning, visual inspections, and hazards that can occur. The operation of oxygen resuscitators is not a complicated task; therefore, training is sometimes overlooked. The operators should not only be able to operate oxygen resuscitators, but also know how to care for them and be aware of hazards involved with their use. Fire fighters are sometimes put in complicated situations where they have to administer oxygen to patients in the vicinity of grease, oil, gas, or other dangerous substances. Fire fighters should be trained to know what to do in these complicated situations and understand the proper maintenance procedures as well as when to report that a system needs repair.

Additionally, operators should be instructed to first open the cylinder valve slowly, letting the regulator pressurize, and then fully open the cylinder valve. What often happens is that the operator opens the valve slightly, sees the gauge register pressure, and then does not fully open the cylinder valve. *Fully opening the cylinder valve has two positive effects: (1) when the valve is not fully opened it can cause deformation of the cylinder seat valve, and this has been suspected to be an ignition source; and 2) opening the cylinder valve against the stem gasket (i.e., fully opening and back-seating the valve) helps keep oxygen from leaking past the stem gasket during use*.[7]

Operators should also use care when installing the inlet gasket. Installation of this gasket is a possible way of contaminating the regulator/cylinder valve if the operator's hands or components are not clean. Care should also be used to tighten the regulator onto the cylinder valve rigidly to prevent leakage of oxygen past the seal during use.[7]

The fire department involved in this incident provided a training course for the fire and medical service. The course was open to the State of Nevada and covered the following: safe handling procedures, hazards involved with oxygen, oxygen fires, maintenance, inspections, cleaning, storage, and the operation of the systems.

To further assist in the understanding of these areas, fire departments can refer to the Compressed Gas Association's CGA G-4[8] manual, and additionally, ASTM's documents regarding training.[10]

NOTE: The following recommendations do not apply to this investigation. The recommendations are included to remind users of the proper operation of oxygen cylinders.

Recommendation #4: Fire departments should ensure that when opening a cylinder post valve with the regulator attached, it should be opened slowly and positioned away from the operator.[5, 8, 9]

DISCUSSION: The Compressed Gas Association Manual, CGA G-4, Section 4.4.10,[8] recommends the following: *Never permit oxygen to enter the regulator suddenly. Always open the cylinder valve slowly. Stand to one side and not in front of or behind the regulator when opening the cylinder valve. Never use wrenches or tools except those provided or approved by the oxygen regulator manufacturer. Avoid the use of a wrench on valves equipped with hand wheels. Never hammer a valve handwheel in attempting to open or to close the valve. If a valve cannot be opened by hand, notify the supplier.*

The fast opening of the valve could subject passageways or components to adiabatic compression (rapid compression with an associated rise in gas temperature, potentially to a material's ignition point), which could result in hot spots and possible ignition of nonmetallic or particulate contaminates. Fast opening of the valve also provides the possibility of particles being forced into the downstream flow path. Once the particles are introduced into the downstream flow, it is also possible that the particles can collide with the filter located underneath the inlet screw or an additional target. Collision of the particles with the filter can cause an ignition.

The regulator should be positioned away from the operator when the cylinder valve is opened in order to let the regulator pressurize before looking at the gauge. The cylinder should be positioned upright and placed between the operator and the regulator (regulator barrel pointed away from

the operator). This way an operator can open the cylinder valve at arm s length from the operator. Operators typically look at the gauge when the cylinder valve is opened. It is recommended that operators not try to read the gauge until the regulator has fully pressurized and they have waited until the pressurization transients settle out.

In this incident the regulator was placed in the medical bag so that it was pointed away from the operator, as recommended. When the regulator flashed, the victim was able to release the medical bag and quickly retreat. By keeping the cylinder between the victim and the regulator, the victim escaped with partial burns to his head, arms, and hands. The injuries in this incident were not as significant as experienced in similar NIOSH investigations. However, the remains of the regulator and cylinder were comparable or in worse condition than those in the other NIOSH investigations.

Recommendation #5: Fire departments should ensure that oxygen systems (cylinders and regulators) are stored in a cool area free of dirt, oils, and grease.[4, 8-13]

DISCUSSION: Fire departments should ensure that oxygen cylinders are stored in a specific location. Oxygen cylinders should be kept free of flammable material, especially oil, grease, or any other readily combustible substance. Oxygen cylinders should also not be placed where oil can drip on the cylinder, its valve, or other system components. It is possible that these substances could be introduced into the system if they are present. If a system component comes in contact with a flammable substance or has been around a flammable substance where a possible contaminant could be introduced into the system, the component(s) should be removed from service and the supplier contacted.

Cylinders should remain in a cool area while not in use. Cylinders should not be stored above 125EF (51.7EC) or used above 120EF (48.9EC). Cylinders should never be allowed to reach temperatures exceeding 125EF (51.7EC) , because of the rise in pressure in the cylinder with increasing temperature. Therefore, cylinders should never be placed near furnaces, radiators, or any other source of heat.

Cylinders should also be stored with plastic caps over the post-valve openings to reduce the possibility of contaminate buildup around the valves openings. The plastic caps should be placed on the cylinder's post valves as soon as the cylinders are refilled. The cylinders should also be stored in a secured vertical position.

Recommendation #6: Fire departments should ensure that oxygen-refilling stations and maintenance areas where oxygen equipment is serviced, are in a locked air-conditioned room that is clean, and free of dirt, oils, and grease.[8, 9]

DISCUSSION: Some fire departments refill their own cylinders, while other fire departments contract out the process. Departments that refill their cylinders should have an area for the refilling system that can be locked when not in use. This will reduce the risk of tools used for the process being removed, contaminated, and reintroduced to this environment. This area should be kept clean and free of oils, grease or any other combustible substance. During the refilling process, the post-valve opening is generally left uncovered until the cylinder is refilled, leaving the valve available to collect contaminants. Keeping the area separate, locked, and clean should reduce the possibility of contaminants entering the area.

The refilling process should be completed by an individual who has been properly trained. The individual should have clean hands, free of any contaminants, and if using gloves, should use a clean pair that are used only for this process. All tools and materials used in this process should be routinely cleaned and used only for this process. The area of the refilling station should be air-conditioned to maintain adequate temperatures.

Maintenance areas should be kept clean, especially when gauges are being replaced. After the gauge is removed the gauge port should be inspected for signs of contamination, and the gauge should be inspected for contamination (oil coming from gauge port) etc.

Recommendation #7: Fire departments should ensure that any components added to the regulator, such as gauge guards, are installed so that they do not block the regulator vent holes.[7]

DISCUSSION: Gauge guards can be installed on regulators to protect the gauge from being damaged. However, if any additional components (such as a gauge guard) are installed on the regulator, they should be supplied by the manufacturer and installed so as not to block the regulator vent holes. Covering of the vent holes could restrict the vents from functioning properly and possibly cause a blowback condition if a fire would occur.

Recommendation #8: Manufacturers should ensure that they provide a warning pertaining to occluding the vent ports on the regulator.[2, 14]

DISCUSSION: Manufacturers should provide a warning not to occlude the vent ports on oxygen regulators. If a fire would occur in a regulator, the vent ports would be a relief opening for the fire to properly vent. Blocking the ports could cause the fire to start burning in a backwards direction into the cylinder, which is known as "blowback". In a past investigation that NIOSH has completed, the vent ports were blocked by a gauge guard which protected the pressure gauge. When the fire occurred, the gauge guard blocked the fire vent path, causing a blowback condition. The fire then began burning into the cylinder, causing the cylinder to rupture. The fire became more intense and consumed most of the interior of an ambulance involved. The Emergency Medical Service received no warning which pertained to occluding the vent ports on the oxygen regulators.

Oxygen resuscitators are medical devices which come under the jurisdiction of the Food and Drug Administration (FDA). NIOSH has been working with the FDA on the issues identified through the NIOSH investigations. In February, 1999, the FDA recently issued a Public Health Advisory jointly with NIOSH entitled *Explosions and Fires in Aluminum Oxygen Regulators.* A copy of this advisory is available on the FDA homepage at www.fda.gov or by calling NIOSH at 1-800-356-4674.

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INVESTIGATOR INFORMATION

This incident was investigated by the following: Frank C. Washenitz II, Safety and Occupational Health Specialist, Surveillance and Field Investigations, Division of Safety Research Tim Merinar, Engineer, and Thomas McDowell, Physical Scientist, Respirator Branch, Division of Respiratory Disease Studies.

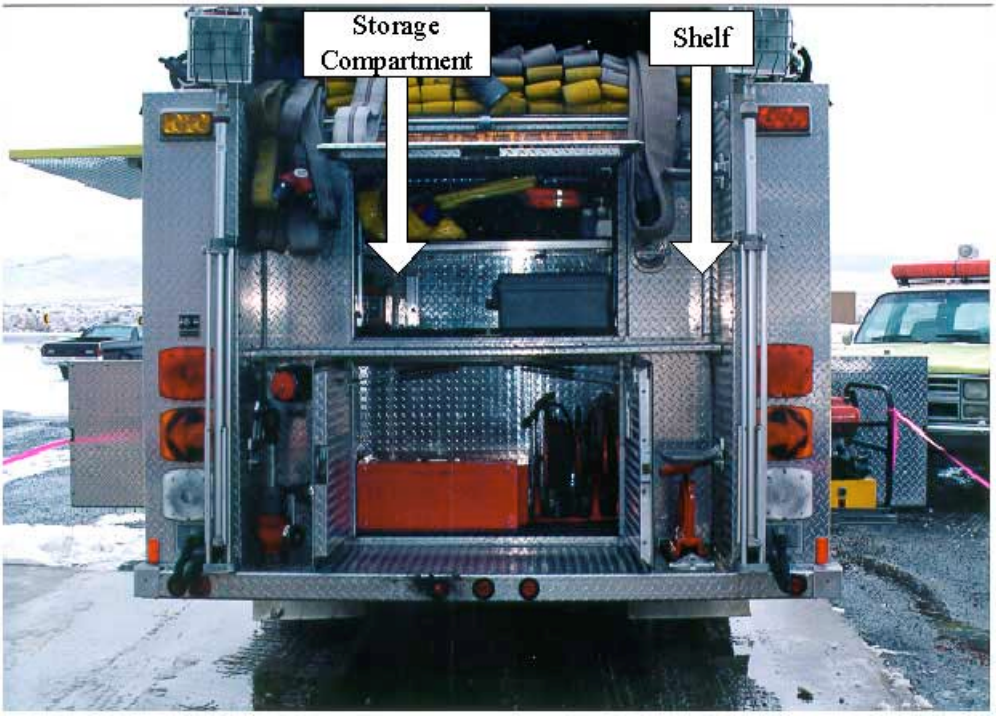

Photo 1: *This photo depicts the storage compartment and shelf*

Photo 2: *This photo depicts the damaged oxygen system*

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