NIOSH Fire Fighter Fatality Investigation and Prevention Program
98 F-23
Injury in the line of duty...
A summary of a NIOSH fire fighter fatality investigation February 5, 1999

Oxygen Regulator Flash Severely Burns One Fire Fighter - Florida

See also: a joint FDA/NIOSH Public Health Advisory on this hazard ...

SUMMARY

On June 12, 1998, one male fire fighter (the victim) was severely burned when an oxygen regulator flashed while he was performing a routine check of the equipment. The victim had just started his morning shift, and was performing the daily routine equipment check on the Engine to which he was assigned. Checking through the equipment, he pulled the airway supply bags from the Engine airway equipment compartment. Department proceedures required him to open the oxygen cylinder post valve, check the cylinder's pressure to verify it was sufficiently full for service, close the cylinder's post valve, and then release the oxygen remaining in the regulator. As the victim lifted the oxygen cylinder from the airway supply bag, he opened the oxygen post valve and the system immediately flashed, releasing two 4-foot flames from the regulator. His clothes ignited from the waist up as he turned and fell to the ground. Fire fighters who were washing the Engine witnessed the incident and used a garden hose to extinguish the flames. On-duty fire fighters/paramedics administered medical treatment to the victim, who received first-, second- and third-degree burns over 36% of his body. He was transported to a local trauma center from where he was later air-lifted to a burn center.

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

- ***use oxygen regulators constructed of materials having an oxygen compatibility equivalent to that of brass***
- ***ensure that the cylinder is placed in an upright position, and that 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 is opened slowly and pointed away from the operator and other people***
- ***ensure that fire fighters are trained in 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.***

INTRODUCTION

On June 12, 1998, a 41-year-old male fire fighter (the victim) was severely burned when an oxygen regulator flashed while he was performing a routine check on it. Having just started his morning shift, the victim was performing the daily equipment check on the Engine to which he was assigned. He pulled the airway supply bag from the airway equipment compartment of the Engine, removed the oxygen cylinder from the airway supply bag, and opened the cylinder post valve to check the cylinder pressure. As the victim opened the post valve, the regulator flashed, releasing two 4-foot flames which severely burned more than 36% of the victim's upper body.

On July 9, 1998, NIOSH was notified of this incident by the International Association of Fire Fighters (IAFF) who requested that an investigation be conducted. On August 18, 1998, a NIOSH Safety and Occupational Health Specialist, and an Engineer, traveled to Florida to conduct an investigation of the incident. Meetings were conducted with the State Fire Marshal's investigator, the Captain of the department arson unit, the department training officer, the fire fighters who witnessed the incident, and the victim. Site visits were conducted at two of the department's air supply shops, including the shop that filled the cylinder that flashed, and the department's logistics building. Photographs of the incident scene were also obtained from the fire department. Records of the cylinder air samples taken on the day of the incident were reviewed and appeared to be accurate and sufficient. NIOSH investigators also met with a representative from the independent testing laboratory who was contracted by the fire department to evaluate the regulator involved in this incident.

The fire department serves a population of 165,000 in a geographical area of 85 square miles. The fire department is comprised of approximately 580 employees, of whom 525 are fire fighters who are cross-trained as Emergency Medical Technicians (EMTs). The fire department requires all new fire fighters to complete the State requirements for fire fighters, which consist of 395 hours of basic training. The basic training program covers 40 hours of first responder, Haz-Mat I and II, oxygen handling, and all aspects of Level I and Level II fire fighter training, as recommended by the National Fire Protection Association. Currently all new fire fighters are State certified as well as certified paramedics. The victim has 17 years of experience as a fire fighter.

INVESTIGATION

On June 12, 1998, at approximately 0730 hours, the victim arrived at his assigned station (Station 17) and prepared to start his 0800 hour shift. Arriving early, the victim decided to perform an equipment check on the Engine to which he was assigned as two additional fire fighters finished their shift by washing the Engine with a garden hose. As the victim sorted through the Engine's equipment compartments, he opened the airway equipment compartment, removed the airway bag, and prepared to perform a routine pressure check. The airway bag consisted of an aluminum cylinder filled with 99.7% pure oxygen, an aluminum regulator attached to the cylinder, and airway supplies (Photo 1). To charge the cylinder and check its oxygen pressure, the victim set the cylinder upright, from a horizontal to vertical position. As he opened the cylinder post valve, the cylinder emitted a loud popping sound and then flashed, releasing two 4-foot flames, one toward the victim and the other toward the Engine (Photo 2). The victim turned, pushing the cylinder away, and fell to the ground with his clothes ignited from the waist up. One of the fire fighters, who was washing the other side of the Engine, stated that he heard a noise which sounded like one of the brake lines had burst. As he leaned under the Engine to check the lines, he saw the victim fall to the ground surrounded by flames. The other fire fighter washing the Engine stated that he watched the victim open the cylinder valve and heard the cylinder emit a loud pop and then flash, releasing two 4-foot flames, one toward the victim and the other toward the Engine. The fire fighter who witnessed the incident called for the other fire fighter washing the Engine to bring the hose he was using around to the victim. The fire fighter stretched the garden hose around the Engine, and spraying water on the victim, extinguished the flames approximately 10 seconds after the cylinder flashed. The fire fighter then turned the hose on the cylinder, which was emitting a loud whistling sound. The cylinder continued to burn for approximately 30 to 40 seconds before the fire was completely extinguished. The fire fighter turned the hose back on the victim, trying to cool him down as the on-duty medical personnel provided assistance. They removed his shirt and wrapped him in a burn blanket, and approximately 2 to 3 minutes later, he was placed in a rescue vehicle. A fire fighter/medic who had just arrived to start his shift saw the commotion, and proceeded to the rescue vehicle. The medic entered the rescue vehicle and took over medical responsibilities. The medic stated that en route to the local trauma center, they secured the victim's airway, started intravenous fluids, and flushed his eyes. During transport, the medics reported that the victim had approximately 35 to 40 percent first-, second-, and third-degree burns. The victim was later air-lifted to an area burn center.

NIOSH investigators visited the oxygen cylinder refilling stations located at Stations 34 and 28. The cylinder involved in the incident was filled at Station 28, where the filling station is separate from all other activity, and the environment is air conditioned, organized, and clean. This filling station is kept locked when not in use. The filling station at Station 34, however, is housed in the station's bay along with the trucks and equipment. The bay is not air conditioned. After the incident, for additional safety at Station 28, the fire department installed a steel cage with a steel rolling door to enclose the cylinders while they are being filled. NIOSH investigators also reviewed the logs in which the station recorded information about filling the cylinders with oxygen, and the logs appeared to be up-to-date and sufficient. The records indicated that on the 12th of June, a Captain from the fire department, along with a representative from an independent medical service, checked the oxygen quality at both filling Stations 34 and 28. At Station 28, the readings were taken with an oxygen analyzer supplied by the independent medical service while at Station 34 the readings were taken with the station's oxygen analyzer. The oxygen purity readings for both stations were 99.7% pure oxygen. Random samples taken from cylinders in the field also proved sufficient.

The fire fighters involved in the process of filling cylinders with oxygen are trained in the proper procedures. The oxygen cylinders commonly filled by the fire department and used as medical equipment by the paramedics and EMTs are D- and E-size cylinders (Photo 3). These cylinders are filled from a cascade system of 12 M-size (300-cubic-ft.) cylinders connected in series (Photo 4). The cascade systems used at Station 34 and 28 are capable of refilling 14 D- or E-size oxygen cylinders at a time. Two banks of 7 cylinders each are arranged in a storage rack for filling (Photo 5). As cylinders are refilled, 1 out of every 14 is sampled to ensure the cylinder is filled with 99.7% pure oxygen. If a sample is found to fall below 99.7%, the entire lot of 14 is isolated until the problem is identified and corrected. After filling, each cylinder is capped with a plastic plug over the post valve opening to keep the valve clean and to identify cylinders that are ready for use.

The fire department's standard procedure requires at least 300 psi of pressure to remain in the cylinders awaiting to be filled. If cylinder pressure is less than 300 psi, the cylinder is taken out of service, flushed with nitrogen using compressed nitrogen from a size M cylinder and a Model DOA-V192-AA gas pump, and returned to the vender for hydrostatic testing and inspection. Standard procedures also require the cascade operator to check the hydrostatic date of each cylinder before it is refilled. Steel and aluminum cylinders must be inspected and hydrostatically retested every 5 years per U.S. Department of Transportation regulation Title 49, Code of Federal Regulation (CFR) Part 173.34 (e).[1]

A representative from the fire department stated that the oxygen resuscitator involved in the incident was pressure checked by a fire fighter on the earlier shift, and the resuscitator appeared to be working properly. The department also stated that the oxygen resuscitator was not used for patient care during the shift prior to the incident.

The representative from the fire department stated that it had previously experienced an incident with an oxygen cylinder and regulator of the same type involved in this investigation. Although the incident did not cause serious injury, the fire department replaced all of its cylinder regulators with a different model from a new manufacturer. After the regulators were changed out, the fire department received a notice from the manufacturer of the previous regulators stating that the regulator had been associated with fire in six incidents reported over the past 3 years. The manufacturer notice indicated that a retrofit kit would be forwarded to the fire department upon request. The retrofit kit included a bronze sintered-inlet filter, a new warning label, an allen wrench, and an instruction sheet necessary to retrofit the existing regulator. The fire department's previously used regulators were listed in the notice so the fire department notified the manufacturer, who supplied the department with retrofit kits for all of the previous regulators. The fire department retrofitted all of it's regulators but did not put them back into service. Even though these regulators were not put back into service, the regulator involved in the incident (which was retrofitted) was mistakenly placed into service during a maintenance changeover.

In addition to the replacement parts, the retrofit kit contained a warning sticker that was to be placed on each regulator as soon as it had been retrofitted (Photo 6). The sticker read: *WARNING: 1. The introduction of contaminates and hydrocarbon substances into the regulator may cause combustion; 2. Open the cylinder post valve slowly. The sudden inrush of oxygen into the regulator may cause combustion if contaminates are present.* The sticker served not only as a warning but also as an identifier to indicate regulators that had been retrofitted. A retrofit sticker had been placed on the regulator involved in this incident. After the incident, the fire department sent the cylinder and regulator involved in the incident to an independent testing laboratory for further testing.

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 investigation. 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/cdrh/safety.html.

INDEPENDENT TEST RESULTS

The results reported here are from the tests and the report completed by Barry Newton, B.S.M.E., P.E.[2] at the request of the fire department. The results concluded the regulator was retrofitted with the new parts supplied by the manufacturer, and the most probable ignition mechanism was particle impact on the filter during the initial flow transient after the fire fighter opened the cylinder valve. This ignition led to the burning of the regulator's aluminum body which caused the flash. Particle impact has been shown to be one of the most efficient mechanisms for directly igniting metallic components in a high-pressure oxygen environment. Particle impact ignitions occur when a metallic particle contained in the oxygen flow contacts a rigid surface and ignites. The ignition of the particle then promotes ignition of the target material. With the exception of aluminum, testing indicates that the particle itself must ignite during the impact event for an ignition of the target material to occur. For aluminum, however, even inert particles, such as grains of sand, have been shown to cause ignition of the target material. Testing also indicates that aluminum particles, such as would be produced from the aluminum cylinder, are susceptible to ignition when they are in an oxygen flow stream. Aluminum has been proven to ignite by particle impact at low temperatures and at sonic flow rates similar to the conditions that exist in the valve and regulator assembly. The aluminum is flammable at pressures as low as 35 pounds per square inch gauge (psig) and has been shown to ignite by particle impact at the flow and temperature conditions present in the valve at the time of the incident.

In this incident, tests show that the particle traveled with the oxygen downstream (into the regulator) and ignited as it made contact with the bronze sintered-inlet filter (identified as a stainless steel screen on Diagram 1). Testing indicates that while bronze has been shown to resist ignition and sustained combustion at these pressures, the thin cross-section of the filter and the very close proximity to the aluminum body provides for a kindling path to the aluminum body for particle impact ignitions on the surface of the filter. While bronze is resistant to ignition, experience has shown that sintered filters can melt and break apart when exposed to a strong ignition mechanism like particle impact.

The regulator involved in the incident was an aluminum body regulator with a bronze sintered-inlet filter housed inside an aluminum downstream flow path. The design of the high-pressure section provides minimal protection of the highly flammable aluminum to promoted ignition mechanisms. Further, the significant amount of aluminum in this regulator, directly exposed to the high pressure environment and oxygen flow, produced a design that is susceptible to an ignition. The design also allows for combustion in the high-pressure port to punch through the main seat in the regulator (Diagram 1) directly and progress into the piston barrel leading to rapid involvement of the low-pressure components and venting of combustion by-products outward (through the vent ports), potentially towards the operator. Some regulators used by the fire and EMT services have aluminum bodies that are equipped with brass or bronze components in the downstream flow path, and these components are very resistant to particle impact. Bronze or brass, which are both non flammable at the pressures in the regulator and do not ignite by particle impact, act as a shield between the particle that ignites and the aluminum body. In this type of design, a particle ignition usually will burn itself out before kindling the ignition and combustion of surrounding materials.

INJURY RESULTS

The victim received first-, second-, and third-degree burns over 36% of his upper body, including his hands, arms, chest, back, neck, and head area.

RECOMMENDATIONS/DISCUSSION

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

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 particulate 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 is present. Thus, aluminum will burn in pure oxygen at a pressure of 35 pounds per square inch (psi) (this is about twice the normal atmospheric pressure) whereas some brass alloys require over 5000 psi of pure oxygen to burn. Aluminum will also produce approximately 10 times the amount of heat provided by copper alloys when burning.

One concern of using aluminum in the regulator flow path is the possibility of particle impact and the aluminum not being able to contain the ignition. 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 attach (Diagram 2). When the post valve is screwed into the aluminum cylinder, there is a possibility that the two metals rubbing together (galling) could create metal particles that would remain enclosed 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 of seals rubbing 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 within the regulator. Therefore, the design of the regulator’s flow path should be resistant to ignition if particles should occur. Experts suggest the regulator 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. Particulate migration from the cylinder can be minimized by the installation of a standoff tube (bayonette) at the inlet of the post valve.

Experts suggest that the design of the regulator involved in this incident allowed for combustion in the high-pressure port to punch through the main seat directly and progress into the piston barrel, leading to rapid involvement of the low-pressure components and venting of combustion byproducts outward (through the vent ports).

In this incident, the regulator (with the aluminum flow path) could not contain the ignition of the particle impact. The significant amount of aluminum in this regulator, directly exposed to the high-pressure environment and oxygen flow, produced a design that was susceptible to an ignition mechanism of this nature. The testing laboratory recommended that the flow path should be constructed of a metal such as brass or bronze to reduce the risk of a flash.

For further information concerning a regulator in use, NIOSH recommends that fire department’s contact the manufacturer of the specific regulator to determine if the regulator contains any aluminum components exposed to oxygen in the high pressure end of the regulator.

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, being careful to point the valve opening away from personnel and in a safe direction. This will help prevent particles from being introduced into the regulator.

Cylinders are generally stored on the fire trucks in a horizontal position, which could allow particles to rest near the neck of the cylinder. Whenever possible, cylinders should be placed and secured 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.

In this incident, the cylinder was lying in a horizontal position when the victim opened the airway bag. When he placed the cylinder in a vertical position and opened the post valve, the regulator flashed. It is possible that particles inside the cylinder were present near the neck of the cylinder, and when the valve was opened the particles were forced into the oxygen flow path.

***Recommendation #3: 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 and other people**.*[5, 8, 9]

DISCUSSION: The Compressed Gas Association Manual, CGA G-4, Section 4.4.10,[8] recommends the following: *Never to 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 handwheels. 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 flow path of the regulator. Once the particles are introduced into the flow path, it is also possible that the particles can collide with the filter located underneath the inlet screw or an additional target (Diagram 1). The filter will then act as the target which could result in the ignition of the metal particle.

The regulator should be positioned away from the operator (and other people) when the cylinder valve is opened and to let the regulator pressurize before looking at the gauge. If possible, 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 from arms length away. 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.

In this incident it is unclear if the victim opened the valve slowly. Test results concluded that the particle ignited in the area of the bronze sintered-inlet filter. Once ignition took place, the aluminum surrounding the filter ignited and released outward, causing injury to the victim. Laboratory tests have concluded that aluminum alloys will readily sustain combustion at pressures as low as 35 pounds per square inch ambient (psia) and produce approximately 10 times the heat of copper alloys when burning.

Recommendation #4: 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 training in safe handling of oxygen resuscitators including 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 just slightly, then sees the gauge register pressure, and then doesn't 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; 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 good 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 to prevent leakage of oxygen past the seal during use.[7]

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

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, 8-10, 11-13]

DISCUSSION: Fire departments should ensure that oxygen cylinders are stored in a specific controlled 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 attachments. It is possible that these substances could be introduced into the cylinder if they are present. If a cylinder comes in contact with a flammable substance or has been around a flammable substance where a possible contaminant could be introduced into the cylinder, the cylinder 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 125°F (51.7°C) or used above 120°F (48.9°C). Cylinders should never be allowed to reach temperatures exceeding 125°F (51.7°C) , because of the rise in pressure inside 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 a plastic cap over the post valve opening to reduce the possibility of contaminate build-up around the valve opening. The plastic caps should be placed on the cylinders post valve as soon as they are re-filled. Whenever practical, the cylinders should also be stored in a secured vertical position.

Additionally, all unused ports on the regulator should be capped off when in storage or in use to reduce the possibility of contaminates entering the regulator.

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 dedicated 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 tank 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 is 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.

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. Although not a contributing factor in this incident, if a fire would occur on the interior of the regulator, it would not be able to vent properly which could result in a significantly larger amount of damage.

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INVESTIGATOR INFORMATION

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Photo 1: This photo depicts the airway bag which contained an aluminum cylinder filled with 99.7% pure oxygen, an aluminum regulator attached to the cylinder, and airway supplies.

Photo 2: This photo depicts the incident scene where the victim was severely burned.

Photo 3: This photo depicts a D-size cylinder similar to the one that was involved in the incident.

Photo 4: This photo depicts the cascade system used by the fire department to refill the oxygen cylinders. The cascade system is composed of 12 M-size (300 cubic

foot) cylinders connected in series.

Photo 5: This photo depicts the cascade system at station 34 which is capable of refilling 14 D-size oxygen cylinders at a time. Two banks of 14 cylinders (27 total) are arranged in a storage rack for filling.

Photo 6: This photo depicts the warning label that is placed on the retrofitted regulator. The sticker serves as a warning as well as an identifier that the regulator has been retrofitted.

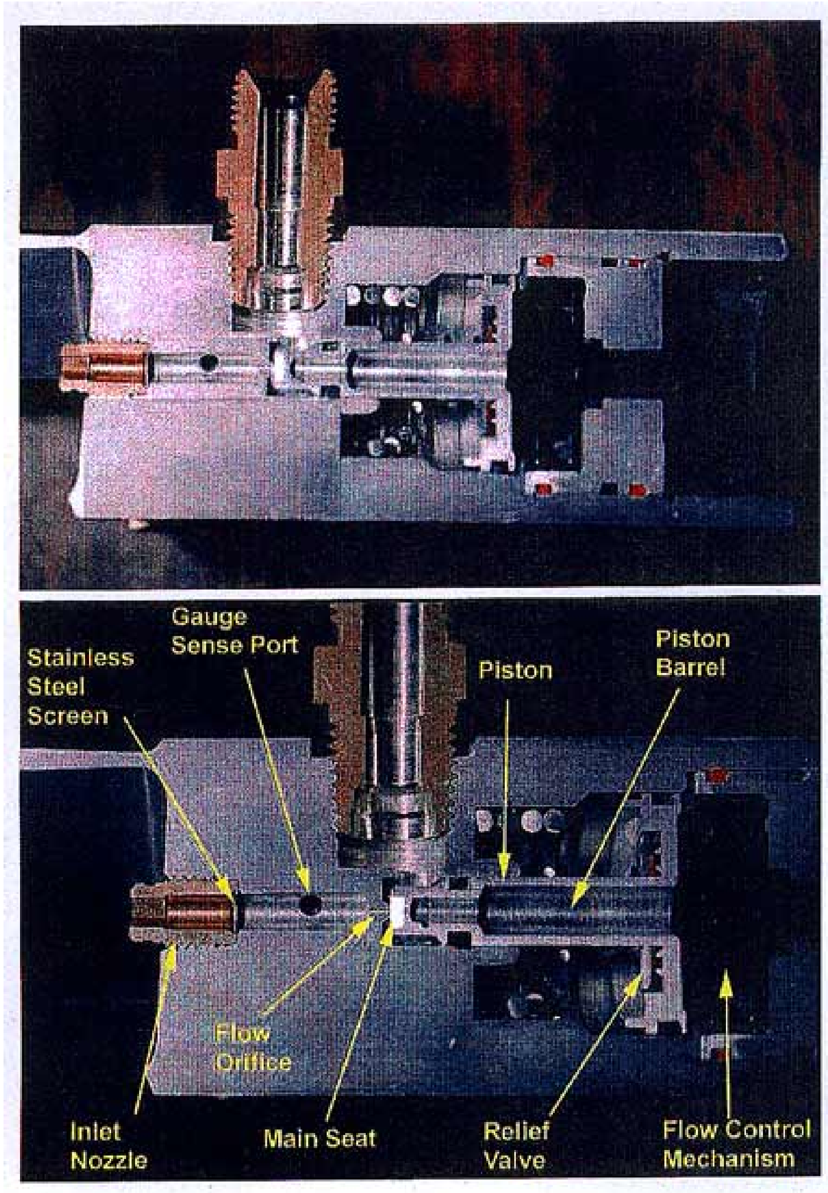

Diagram 1: Cut-away section from a regulator similar to the one that was involved in the incident.

The two previous diagrams depict a close-up view of the internal regulating mechanism and oxygen flow path. The flow path and oxygen-wetted components are described below. The regulating piston is shown in a closed position with the main seat against the primary flow control orifice.

Both diagrams depict the same view; however, the bottom diagram illustrates the various parts of the regulator's interior. The oxygen flow enters the regulator from the oxygen cylinder valve at the inlet nozzle. A non-metallic gasket provides a seal between the CGA (Compressed Gas Association) 870 adapter on the cylinder valve and the regulator. The flow then passes through an inlet filter (a stainless steel screen is shown here but the regulator involved in the incident is reported to have had a sintered bronze filter and is directed toward a flow orifice). The flow orifice and main seat provide the primary pressure regulation. Pressure upstream of this point (i.e., toward the cylinder valve) is nominally consistent with cylinder pressure. Pressure downstream is normally 50 psig or consistent with the set point of the regulator. The piston mechanism strokes to the right to allow flow to enter the piston barrel and left to hinder or stop flow when the pressure under the piston reaches the regulator's set point. Oxygen then flows into an orifice in the flow control mechanism and is delivered at the rate set by this mechanism.

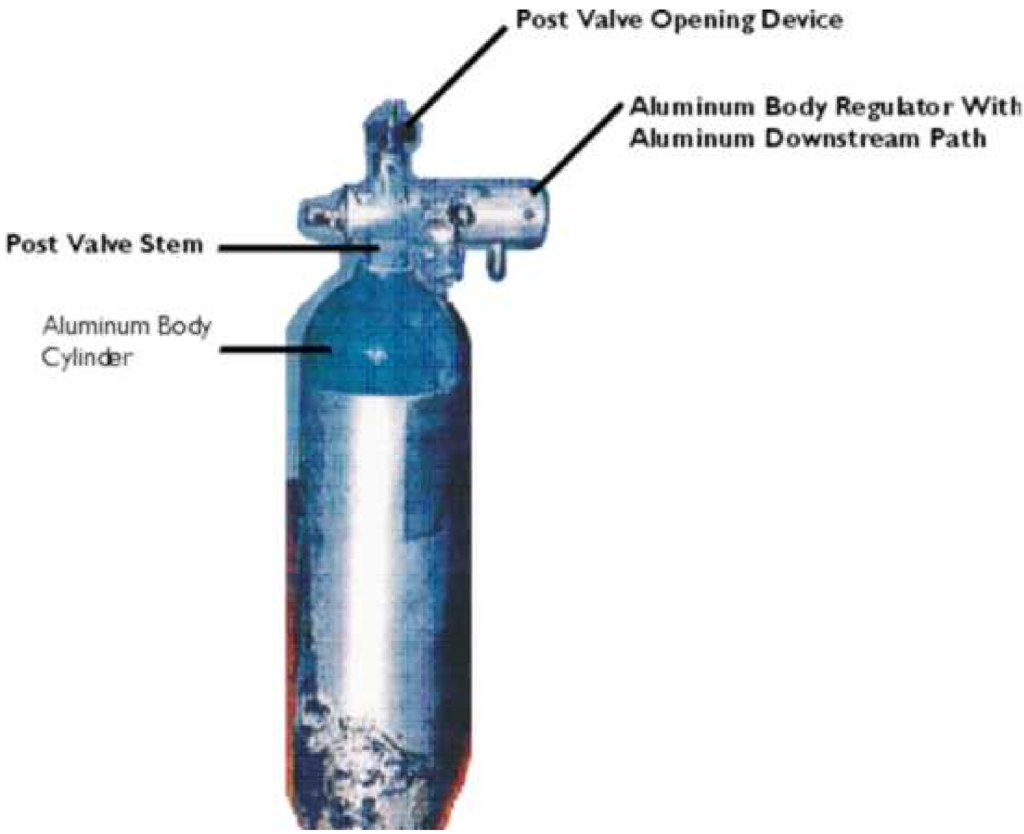

Diagram 2: This diagram depicts the cylinder involved in the incident and the location of the post valve stem.