

NEW JERSEY DIVISION OF FIRE SAFETY

Firefighter Fatality and Serious Injury Report Series

Two Firefighters are Injured in Separate Incidents when SCBA Cylinders Rupture During Filling

**Roxbury, New Jersey
Neshanic, New Jersey
*Issued September 24, 1998***



STATE OF NEW JERSEY
Christine Todd Whitman, Governor



DEPARTMENT OF COMMUNITY AFFAIRS
Jane M. Kenny, Commissioner



DIVISION OF FIRE SAFETY
William H. Cane, Director

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INTRODUCTION

The investigation of these incidents was conducted by the New Jersey Division of Fire Safety in conjunction with the New Jersey Department of Labor and the New Jersey Department of Health. This report was prepared in accordance with N.J.S.A. 52:27D - 192 et. seq., Duties of the Division. The purpose of these firefighter casualty investigations is to report the causes of serious firefighter injuries or deaths and identify those measures which may be required to prevent the future occurrence of deaths and serious injuries under similar circumstances. In some cases new information may be developed, or old lessons reinforced, in an effort to prevent similar events in the future.

Comments and/or inquiries concerning this report may be addressed to the individual at the address listed below:

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SUMMARY

On July 11, 1996 a member of the Roxbury Township, Morris County, Fire Department, Firefighter Paul Label, age 29, was in the process of recharging an aluminum 2216 psi SCBA cylinder from the department's cascade system at about 2038 hours, when it failed catastrophically resulting in serious injuries to Mr. Label.

On October 8, 1996 a similar failure of an aluminum 2216 psi SCBA cylinder resulted in injuries to Firefighter Eric Jensen, age 23 of the Neshanic Volunteer Fire Company of Branchburg Township, Somerset County. In this case as with the Roxbury incident, Jensen was in the process of recharging the cylinder from the department's cascade system at about 1930 hours, when it failed catastrophically.

The Luxfer Corporation manufactured both cylinders involved.

The remains of the cylinders were impounded by representative of the U.S. Department of Transportation who have jurisdiction over incidents involving cylinders of this type.

INVESTIGATION

The Roxbury Incident

On July 11, 1996 Firefighter Paul Label, a ten year veteran of the Roxbury Township Volunteer Fire Department was in the process of recharging an aluminum 2216 psi SCBA cylinder utilizing the department's cascade system at about 2038 hours, when the cylinder failed catastrophically. The cylinder had been used in a department training session.

The cylinder, a DOT-E6498-2216 type¹ with serial number T127279 manufactured by Luxfer USA, was incorporated into a Scott Air Pak[®] for firefighting use. The cylinder was manufactured in November of 1977 and was last hydrostatically tested July 1993. It was noted that the cylinder was within acceptable hydrostatic test dates.

The cascade system being used was comprised of eight steel cylinders and was not equipped with a pressure regulator to reduce the cascade system's maximum output pressure to 2216 psi. The cascade system cylinders were rated for a maximum pressure of 3500 psi with the exception of one cylinder, which was rated for 3600 psi.

After the cylinder failure, the fire department, the Roxbury Township Police Department and the Morris County Prosecutor's Office joined in an investigation of the incident. The initial findings were that the cylinder that failed was being filled in a plastic five gallon bucket filled with water on the floor of the apparatus room. No shielding for the operator of the system was provided. It was not readily apparent as to whether the cylinder was charged beyond its normal operating pressure of 2216 psi. Through statements obtained from the victim, the pressure reading of the gauge on the ruptured cylinder was approaching the full mark.

After the failure, the Prosecutor's office recorded the pressures remaining in the cylinders of the cascade system and found that in five of the eight cylinders, pressures exceeded the rated pressures by as much as 400 psi. One of the cylinder's pressure could not be measured due to damage to the valve area sustained in the mishap.

After the incident, the ruptured cylinder was impounded by the Prosecutor's Office, where it remained until the afternoon of July 16, 1996. The cylinder fragmented into six major pieces. The valve assembly, removed by the explosion, was intact and virtually

¹DOT E6498 is an exemption, dated July 1976, to the provisions of the U.S. Department of Transportation's then applicable Hazardous Materials Regulations granted to Luxfer, USA Ltd. to manufacture, mark and sell cylinders for the use in transportation in commerce of certain liquefied and non-liquefied compressed gases. This exemption satisfies the DOT-3Al section of 49 CFR-178.45.

undamaged. The gauge returned to the empty position after the rupture so as the pressure at the time of failure could not be determined. The rupture disk safety pressure relief mechanism was still in place and did not operate. The fragments of the cylinder appeared to be in good condition and without indications of damage or rough use prior to the explosion. No discoloration of the cylinder paint due to exposure to heat was noted. The parts of the cylinder were released by the Prosecutor's office to the investigators of the U.S. Department of Transportation, who would later initiate non-destructive metallurgical testing to attempt to discover the cause of the failure.

It was reported that Label had been qualified by the fire department in the use of the cascade system and had used it frequently in the course of his ten-year tenure with the department.

After the occurrence, the victim was flown via NJ State Police helicopter Northstar to Morristown Memorial Hospital where he was admitted. His injuries included severe damage to his right hand and severe damage to the facial area including his eyes.

The Neshanic Incident

On October 8, 1996 Firefighter Eric Jensen, a seven year veteran of the Neshanic Volunteer Fire Company of Branchburg Township was in the process of recharging an aluminum 2216 psi SCBA cylinder utilizing the department's cascade system at about 1930 hours, when it failed catastrophically. The cylinder had been found empty on one of the company's engines during a routine check of the equipment.

The cylinder, a DOT-E6498-2216 type with serial number T117362 manufactured by Luxfer USA, was incorporated into a Scott Air Pak[®] for firefighting use. The cylinder was manufactured in June of 1977 and was last hydrostatically tested February 1992. It was noted that the cylinder was within acceptable hydrostatic test dates.

The cascade system that was used to fill this cylinder consisted of six steel cylinders rated for pressures variously of 2015 psi, 2300 psi, and 2400 psi and was not equipped with a pressure regulator to reduce the cascade system's maximum output pressure to 2216 psi. The system's air reserve was discharged as a result of damage caused by the explosion making it impossible to determine what pressures had been in the cylinders at that time. Additionally, no shielding for the operator of the system was provided.

Jensen stated that he was filling the cylinder on the apparatus room floor at the time of the failure. It was not readily apparent as to whether the cylinder was charged beyond its normal operating pressure of 2216 psi, however, Jensen related that the pressure on the cylinder's gauge was approaching 2000 psi when he began to hear air leaking. He believed the air was leaking from the "O" ring in the high pressure fill line. At this point, he went to

the master valve on the cascade system and began to close the valve. It was then, he stated that the cylinder ruptured.

After the incident, the fire company impounded the ruptured cylinder, where it remained until the afternoon of October 11, 1996. Upon inspection of the remains of the cylinder, it was found to have fragmented into three main pieces. The valve assembly, removed by the explosion, was intact and virtually undamaged. The gauge returned to the empty position after the rupture so as the pressure at the time of failure could not be determined. The rupture disk safety pressure relief mechanism was still in place and did not operate. The fragments of the cylinder appeared to be in good condition and without indications of damage or rough use prior to the explosion. No discoloration of the cylinder paint due to exposure to heat was noted. The parts of the cylinder were released by the fire company to the investigators of the U.S. Department of Transportation.

It was reported that Jensen had been qualified by the fire company in the use of the cascade system.

The cylinder failure resulted in injuries to Jensen that included a deep laceration to his left leg and partial hearing loss. He was treated and released from the Emergency Room of the Somerset Medical Center.

ANALYSIS

Safety Issues Relating to the Recharging of SCBA Cylinders

It is important to note that in both of these incidents, the SCBA cylinders were being filled from cascade systems that were not equipped with pressure regulators or fragmentation shields. It is not known whether or not these occurrences would have taken place if the charging stations had been equipped with regulators and effective shielding, however, the probability of such serious injuries would have been significantly reduced.

The Public Employees Occupational Safety and Health (PEOSH) Standards for Firefighters has requirements (N.J.A.C. 12:100-14)² for filling SCBA cylinders. The purpose of these requirements is to minimize the potential for injury to firefighters or near-by personnel in the event that an SCBA cylinder should fail while filling.

The PEOSH Standards for Firefighters as a minimum require:

- personnel filling SCBA cylinders receive training;
- the charging station must be equipped with facilities to ensure the safety of the charging station operator and nearby personnel; and
- the air used to fill the cylinders must comply with requirements for Grade D breathing air.

Training must include:

- procedures for inspecting the SCBA cylinder for damage;
- information to ensure that the cylinder has the proper hydrostatic test date;
- information to ensure that composite cylinders older than 15 years are not refilled and removed from service;
- procedures to safely operate the charging station;
- the fill station manufacturer instructions for safe filling;
- information on the importance of using at least Grade D air; and
- information on the consequences of cylinder failure.

The PEOSH Program requires that the charging station be equipped with:

- an adjustable pressure regulator;
- a regulated pressure gauge;

² N.J.A.C. 12:100-10.10 Standards for Firefighters; Filling Air Cylinders; NJ Department of Labor, Trenton, NJ.

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- an inlet pressure gauge;
 - a fill control valve;
 - isolation valves (for cascade filling);
 - fill hose with bleed valves; and
 - a fragmentation shield that would contain the cylinder in the event of failure.

If a cylinder is found empty and it is not known how it was emptied (used in training, during a response, etc.), do not re-fill the cylinder until it is determined that the cylinder can be safely re-filled. It is possible that the cylinder has a flaw that caused the cylinder to leak.

Violations Cited

Roxbury Township

On September 20, 1996 orders to comply were issued to Roxbury Township by the NJ Department of Labor as the enforcing agency for the NJ Department of Health and Senior Services for the following violations of the PEOSH Act:

1. N.J.A.C. 12:100-10.10(e)(3)³: The employer did not establish and maintain a respiratory protection program which included the requirements of ANSI Z88.5-1981, Respiratory Protection for the Fire Service⁴. A written respiratory protection program was not available for review. All components of an acceptable respiratory program had not been implemented.
2. N.J.A.C. 12:100-10.14(c): The charging station was not equipped with proper facilities to ensure the safety of the charging system operator and nearby personnel. The cascade system did not have a fragmentation container to prevent injury to personnel in the event of component failure while recharging. The cascade system did not have an adjustable pressure regulator to reduce the pressure of the cascade bottles to the allowable pressure of the SCBA bottle.

All violations have since been abated.

Branchburg Township

On April 11, 1997 orders to comply were issued to Branchburg Township by the NJ Department of Labor as the enforcing agency for the NJ Department of Health and Senior Services for the following violations of the PEOSH Act:

³ N.J.A.C. 12:100-10.10 Standards for Firefighters; Respiratory Protection Devices; NJ Department of Labor, Trenton, NJ.

⁴ ANSI Z88.5-1981, Respiratory Protection for the Fire Service; American National Standards Institute, New York, NY

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1. N.J.A.C. 12:100-10.10(e)(3): The employer did not establish and maintain a respiratory protection program which included the requirements of ANSI Z88.5-1981, Respiratory Protection for the Fire Service. A written respiratory protection program was not available for review. All components of an acceptable respiratory program had not been implemented.
 2. N.J.A.C. 12:100-10.10(g): The employer did not have a written plan to assure that there would be sufficient quantities of compressed air to refill SCBA cylinders for all emergencies. A written plan to assure sufficient quantities of compressed air for all emergencies was not available for review. All components of an acceptable respiratory program had not been implemented.
 3. N.J.A.C. 12:100-10.14(c): The charging station was not equipped with proper facilities to ensure the safety of the charging system operator and nearby personnel. The cascade system did not have a fragmentation container to prevent injury to personnel in the event of component failure while recharging. The cascade system did not have an adjustable pressure regulator to reduce the pressure of the cascade bottles to the allowable pressure of the SCBA bottle.

All violations have since been abated.

Metallurgical Evaluation of the Roxbury SCBA Cylinder

The U.S. DOT sent the Roxbury cylinder to Failure Analysis Associates, Inc. of Alexandria Virginia for metallurgical evaluation. The Neshanic cylinder was not evaluated and remains in the custody of the U.S. Department of Transportation.

The scope of the work that was performed by Failure Analysis Associates, Inc. was a detailed evaluation of the cylinder remains, including photodocumentation and non-destructive examinations, chemical and mechanical property determination, metallographic sectioning, and fractography. The metallurgical evaluation report is contained in Appendix A of this report.

Related Information Provided by the U.S. Department of Transportation

The following information was published in the Federal Register⁵ on July 26, 1994 by the U.S. Department of Transportation, Research and Special Programs Administration referred to as Notice No. 94-7; Safety Advisory; High Pressure Aluminum Seamless and

⁵ Federal Register, United States Printing Office, Washington, DC.

Aluminum Composite Hoop-Wrapped Cylinders

Summary: Research and Special Programs Administration is aware of ruptures involving two DOT-3AL cylinders made of aluminum alloy 6351-T6. Cylinder ruptures pose a risk of death, serious personal injury, and property damage. The purpose of this notice is to advise owners of certain cylinders made of aluminum alloy 6351-T6 to follow the precautionary measures outlined in this notice. Research and Special Programs Administration also seeks information on ruptures involving other cylinders made of aluminum alloy 6351-T6.

Supplementary Information: Research and Special Programs Administration has been notified of the rupture of two DOT-3AL aluminum cylinders made of aluminum alloy 6351-T6. The first cylinder rupture occurred in Deer Park, Texas. This cylinder was manufactured in 1977 and was part of a self-contained breathing apparatus (SCBA) unit. It ruptured while being filled to its marked service pressure of 2216 pounds per square inch gauge (psig). The second cylinder rupture occurred in North Miami, Florida. This cylinder was manufactured in 1982 and was part of a self-contained underwater breathing apparatus (SCUBA) unit. It ruptured while being filled to its marked service pressure of 3000 psig. The person filling the SCUBA cylinder sustained serious injury. In both ruptures, a piece of the cylinder neck separated from the cylinder.

Research and Special Programs Administration estimates that approximately seven million cylinders have been manufactured using aluminum alloy 6351-T6. Research and Special Programs Administration presently does not know which cylinders among this population have the potential for similar failure. Cylinders made of aluminum alloy 6351-T6 are known to be susceptible to sustained load cracking (SLC) in the neck and shoulder area of the cylinder. Extensive research, testing and analysis have been performed on cylinders made of aluminum alloy 6351-T6 to determine any correlation between SLC and the probability of rupture. Findings indicated that cylinders with a marked service pressure below 4000 psig failing due to SLC would leak and not rupture. Present data are inconclusive as to why the two cylinders noted here ruptured instead of leaked. Research and Special Programs Administration is continuing to investigate the incidents.

Aluminum cylinders are widely used in industrial, medical, SCUBA and SCBA services. Aluminum alloy 6351-T6 has been used in the manufacture of the following DOT high-pressure cylinders:

1. Cylinders (seamless aluminum) marked "DOT 3AL", including those marked with "DOT 3AL" above or near one of the following exemption or special permit numbers: 6498 7042 8107 8364 8422
2. Composite cylinders (aluminum-lined with hoop-wrapped, fiber-reinforced plastic) marked with one of the following exemption numbers: 7235 8023 8115

To Research and Special Programs Administration's knowledge, no cylinders have been manufactured under the exemption or special permit numbers listed above, except DOT-E

7235, since 1984. Any cylinder marked with one of these exemptions or special permit numbers most likely is made of aluminum alloy 6351-T6 (DOT-E 7235 cylinders are discussed more fully below). If in doubt, contact the cylinder manufacturer or distributor to identify the material of construction.

The primary domestic manufacturers of DOT-3AL cylinders currently in service are Luxfer USA; Walter Kidde Co.; Cliff Impact Division of Parker Hannifer Corporation; and Catalina Cylinders, a Division of Aluminum Precision Products Inc. Luxfer USA is the only manufacturer of DOT-E 7235 cylinders. Between 1987 and 1989, Luxfer USA discontinued using alloy 6351-T6 and changed to alloy 6061-T6 for DOT-3AL cylinders and DOT-E 7235 cylinder liners. Cylinders manufactured from alloy 6061-T6 are not believed to be susceptible to SLC; therefore, they are not subject to this advisory notice. According to Luxfer USA data, the following types of cylinders stamped as manufactured by Luxfer USA before the dates indicated in the following table are likely to be made from alloy 6351-T6.

DOT	Service and type cylinder	Part no.	Date mfd.
CO₂			
Spec. 3AL	1.2 and 1.5 lb.	C1.2, C1.5	1-89
Do	2.18 lb.	C2-18	11-88
Do	10 lb.	C10	8-88
Do	5 lb.	C5	6-88
Do	15 lb.	C15	11-87
Do	20 and 35 lb.	C20, C35	4-88
Do	50 lb.	C50	2-88
SCBA			
Do	7, 8 and 13 cu. ft.	L7, L8, L13	9-87
Do	13.3 cu. ft.	L13-30	5-88
Do	15 cu. ft.	L15	1-89
Do	26 cu. ft.	L26	2-88
Do	45 cu. ft.	L45	11-87
SCUBA			
Do	30 and 63 cu. ft.	S30, S63	5-88
Do	40 cu. ft.	S40	6-88
Do	50 and 92 cu. ft.	S50, S92	4-88
Do	72 and 100 cu. ft.	S72, S100	8-87
Do	80 cu. ft.	S80	1-88
Do	80.8 cu. ft.	S80.8	5-87
Medical O1			
Do	C	M9	1-88
Do	D and E	MD, ME	12-87

Industrial

Do	22 and 150 cu. ft.	N22, N150	5-88
Do	33 cu. ft.	N33	11-88
Do	60 and 122 cu. ft.	N60, N122	12-87
Do	88 cu. ft.	N88	12-88
Do	Service Pressures 2016 and 3000 psig		8-89
E-7235	Service Pressure 4500 psig		See below

All Walter Kidde DOT-3AL cylinders, of which production ceased in January 1990, are made of alloy 6351-T6. Cliff Impact DOT-3AL cylinders were made from alloy 6351-T6 before July 1990, at which time Cliff Impact changed to alloy 6061-T6. Catalina Cylinders did not produce any DOT-3AL cylinders from alloy 6351-T6; therefore, cylinders manufactured by Catalina are not subject to this notice.

Until determined otherwise, any DOT-3AL or DOT-E 7235 cylinder should be assumed to be made of alloy 6351-T6, if it was:

1. Manufactured by Luxfer USA before the applicable date listed in the chart above;
2. Manufactured by Cliff Impact before July 1990;
3. Manufactured by any other company in the United States, excluding Catalina, before February 1990, or
4. Manufactured outside the United States.

For aid in determining whether a cylinder is constructed with alloy 6351-T6, contact the cylinder manufacturer or distributor. Research and Special Programs Administration will provide further information as it becomes available.

Any person who owns, uses, fills or retests an affected cylinder should take the following precautions:

1. Do not fill the cylinder to greater than the marked service pressure, except during a hydrostatic test.
2. Do not fill a cylinder that is beyond its required retest date.
3. Do not use a SCUBA or SCBA cylinder that is beyond its required retest date.
4. Whenever you remove the cylinder valve, visually inspect the interior of the cylinder neck and shoulder area for cracks.

Any evidence of a crack or crack-like defect may require further evaluation. Contact the cylinder retester, distributor or manufacturer for the procedure to be used in performing the visual inspection and for rejection criteria. For guidance on inspecting Luxfer USA cylinders, contact Luxfer USA Limited, Customer Service Department, PO Box 5300, Riverside CA 92517, telephone (909) 684-5110.

Research and Special Programs Administration wishes to reiterate two previous advisories

it has issued regarding DOT-E 7235 cylinders. On August 15, 1985, Research and Special Programs Administration published an exemption-related notice [Notice 85-4, 50 FR 32944] to alert users that any cylinder marked DOT-E 7235, with a service pressure of 4500 psig and not equipped with a neckring was required to be removed from service by October 1, 1985. On March 24, 1993, Research and Special Programs Administration published a safety advisory notice [Notice 93-8, 58 FR 15895] after being notified of the rupture of a cylinder authorized under DOT-E 7235 that had not been fitted with a neckring. Cylinders properly fitted with the required neckring are not susceptible to rupture. That notice stated in part:

Persons finding cylinders without the required neckring should immediately take the following precautions.

1. If a cylinder has been filled, its entire contents should be vented in order to relieve internal pressure.
2. The vented cylinders should be segregated from all other cylinders by being placed in a secured area and marked conspicuously with a tag bearing the notation "Do Not Use" or similar warning.
3. Under no circumstances should any of the cylinders in question be sold or otherwise transferred, filled, refilled or used for any purpose.

Once the above procedures have been taken, persons finding cylinders without neckrings should contact the company, or distributor from whom they were purchased, for their disposition.

Any person who is aware of the rupture of any DOT-3AL cylinder or any other cylinder manufactured from aluminum alloy 6351-T6, whether the incident was domestic or foreign, is requested to contact Research and Special Programs Administration as soon as possible.

Issued in Washington, DC on July 20, 1994. Alan I. Roberts, Associate Administrator for Hazardous Materials Safety. [FR Doc. 94-18192 Filed 7-25-94; 8:45 am] BILLING CODE 4910-60-P

For Further Information Contact: Charles H. Hochman or Gopala K. Vinjamuri, telephone (202) 366-4545, Office of Hazardous Materials Technology, Research and Special Programs Administration, U.S. Department of Transportation, 400 Seventh Street SW, Washington, DC 20590-0001. Office hours are: 8:30 a.m. to 5 p.m., Monday through Friday, except holidays.

LESSONS LEARNED

Respiratory Protection Program and Filling of Air Cylinders

In the two incidents detailed in this report, neither fire department had implemented a respiratory protection program, nor did they employ proper facilities for the charging of SCBA cylinders that provided for the safety of the operator and nearby personnel.

N.J.A.C. 12:100-10.10(e)(3) *Standard for Firefighters; Respiratory Protection Devices* requires all fire departments to establish and maintain a respiratory protection program which conforms to the PEOSHA regulations. The scope of this program includes all aspects of respiratory protection.

N.J.A.C. 12:100-10.14 *Standard for Firefighters; Filling air cylinders* details requirements for the filling of air cylinders including training to be received by personnel filling SCBA cylinders and requirements for the charging station. Training must include:

- procedures for inspecting the SCBA cylinder for damage;
- information to ensure that the cylinder has the proper hydrostatic test date;
- information to ensure that composite cylinders older than 15 years are not refilled and removed from service;
- procedures to safely operate the charging station;
- the fill station manufacturer instructions for safe filling;
- information on the importance of using at least Grade D air; and
- information on the consequences of cylinder failure.

The charging station requirements include:

- an adjustable pressure regulator;
- a regulated pressure gauge;
- an inlet pressure gauge;
- a fill control valve;
- isolation valves (for cascade filling);
- fill hose with bleed valves; and
- a fragmentation shield that would contain the cylinder in the event of failure.

Additionally, the PEOSHA regulations require periodic testing and inspection of compressed air cylinders relative to their composition and construction by qualified individuals. Hydrostatic testing and inspection must be conducted on aluminum cylinders every five years. Hydrostatic testing and inspection must be conducted on composite cylinders every three years. Composite cylinders are those constructed of an aluminum core wrapped with fiberglass. It must be remembered that if any cylinder shows any signs of damage or is found empty for no apparent reason, it should be removed from service

and tested and inspected by your fire department's SCBA vendor.

Identification of Air Cylinders

A short time after the occurrences of these two incidents, the Division of Fire Safety in conjunction with the NJ Department of Health and Senior Services issued a safety alert to all fire departments detailing the incidents. Included in the alert was information supplied by the U.S. Department of Transportation regarding the identification of cylinders constructed of an aluminum alloy 6351-T6. This information has been included on page 9 of this report.

The two cylinders detailed in this report were constructed of alloy 6351-T6.

If you have not identified cylinders in your possession that are constructed of alloy 6351-T6 as you were instructed to do in the safety alert, you should do so now by using the table provided by USDOT in this report. For aid in determining whether a cylinder is constructed with alloy 6351-T6, contact the cylinder manufacturer or distributor.

Once identified, persons using and filling alloy 6351-T6 cylinders should take the following precautions:

- As with any cylinder, filling must be done by individuals that possess the proper training; and in charging stations that conform to N.J.A.C. 12:100-10.14 *Standard for Firefighters; Filling air cylinders*.
- Do not fill the cylinder to greater than the marked service pressure.
- Do not fill a cylinder that is beyond its required retest date.
- Do not fill a cylinder that shows any signs of damage or is found empty for no apparent reason.
- Do not use an SCBA cylinder that is beyond its required retest date.
- Ensure that whenever your SCBA vendor removes the cylinder valve, he/she visually inspects the interior of the cylinder neck and shoulder area for cracks. If any evidence of a crack or crack-like defect is found, the manufacturer must further evaluate the cylinder.

CONCLUSION

The testing that was conducted by Failure Analysis Associates, Inc. clearly indicated the presence of cracks located within the folds of the cylinder neck area of the Roxbury cylinder.

However, due to the limitations of the testing performed, no conclusive cause of the formation of the cracks was found. Mark Toughiry of the U.S. Department of Transportation, the individual who ordered the tests on the cylinder stated that in order to determine the cause of the cracks, more exhaustive testing would need to be conducted. He further stated that the U.S. Department of Transportation was not prepared to expend the estimated \$60,000 for the more complete testing to be conducted.

Without a definitive cause of the cracking identified, the proper filling, inspection and testing of cylinders assumes the most important role in the prevention of similar accidents in the future.

APPENDIX A
METALLURGICAL EVALUATION OF THE
ROXBURY CYLINDER