NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

Hazardous Materials Factual Report
February 27, 2006
HWY-05-MH-035

A. Incident Identification

Location:	Wilmer, Texas
Date and Time:	September 23, 2005; 6:07 a.m.
Hazardous Materials:	Oxygen, Compressed gas
Injuries:	23 Fatalities
Shipper:	Brighten Gardens, Houston, TX
Transportation Mode:	Highway

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C. Accident Summary

On September 23, 2005 at about 6:07 a.m. CDT, a 1998 MCI 54-passenger motorcoach was traveling northbound on Interstate Highway 45 (I-45) with 44 passengers and the driver, evacuating in anticipation of Hurricane Rita. The passengers were from an assisted living facility in Bellaire, Texas, and most needed to be carried or assisted onto the motorcoach by firefighters. The trip began about 2:30 p.m. on September 22, 2005. The motorcoach had been traveling over 13 hours in heavy traffic when the right rear (#3 axle) tire went flat and needed to be changed near the FM 1126 overpass in Rice, Texas. The tire left approximately 6,800 ft. of tire marks before the motorcoach came to a stop. A service mechanic was summoned to assist and he changed the tire. The motorcoach continued north on I-45 for about 26 miles.

At approximately 6:00 a.m. a motorist noticed the right rear (#3 axle) hub was glowing red/white hot. He was able to stop the motorcoach in the traffic lane and tried to tell the driver (who did not speak English) of the danger. The motorcoach driver waited for traffic to clear and proceeded to pull the vehicle to the right shoulder. The motorcoach driver exited along with a nursing staff-passenger (the trip coordinator) and two other nurse-passengers and saw flames coming from the right rear wheel well. The passengers, with help from the nursing staff on-board and other motorist, began to disembark. At 6:07 the first call was made to 911. Fourteen intact oxygen cylinders were recovered from the motorcoach along with parts of 4 others for a total of eighteen. One of those cylinders shows evidence of failure. Six nursing staff-passengers on the vehicle, a parent of one of the nursing staff, and 14 patient-passengers were able to exit the burning vehicle. Twenty-three patient-passengers, many of those who needed assistance in walking or needed to be carried off the vehicle were unable to escape.

D. Events Preceding the Accident

According to the Director of Risk Management Finance for Sunrise Senior Living, the owners of the Brighten Gardens assisted living facility, Brighten Gardens employees placed the cylinders on the bus for use by two of their residents. Initially, two cylinders were hooked up to nasal canulas and used to provide medical oxygen to those two people. According to a representative of the nursing home, fifteen cylinders were placed in metal racks (9 in one rack and 6 in another) to keep them from tipping over, and put into the luggage bay under the bus with wheelchairs, bottled water and other necessities. The director was unable to explain the discovery of eighteen cylinders, or parts thereof, on the bus after the accident.

As a cylinder was emptied it was replaced by a full cylinder from the luggage bay. During the trip, the head attendant was concerned that they may not have sufficient oxygen cylinders to complete the trip and considered a diversion Bryant College Station, TX, to get additional oxygen cylinders, however, they determined that this was unnecessary. As the trip continued several extra cylinders were transferred from the luggage bay to the passenger compartment to reduce the time spent stopping in the evacuation traffic to exchange depleted oxygen cylinders with full cylinders.

The risk management director said that the attendants told her that at the time of the fire all the oxygen cylinders in the luggage bay were empty, and that all of the remaining full cylinders had been placed in the passenger compartment. Then, when the cylinders in the passenger compartment were emptied, they were left in the passenger compartment. Therefore, at the time of the fire some of the cylinders in the passenger compartment were empty and some were full. The attendants did not know the totals of each. (See Appendix A and B.)

E. Hazardous Materials Information

Oxygen is an atmospheric gas. It is transported as a compressed or liquefied gas. It is not flammable but will support and enhance combustion. An oxygen-enriched atmosphere will lower the ignition temperatures of certain combustible materials, and increase the intensity of a fire. Oxygen is also reactive with combustible materials and can cause a fire. (See Appendix C.)

F. Cylinder Information

Eighteen cylinders or partial cylinders were found in the bus after the fire (fifteen aluminum and three steel). All the cylinders found in the bus after the fire appeared to be medical E cylinders. Medical E cylinders are about 26 inches in length by 4 3/8 inches in diameter, have a volumetric capacity of about 283 cubic inches, and hold about 5 lbs of oxygen. The estimated total weight of eighteen cylinders and valves, each filled with 5 lbs of oxygen, is about 247.5 lbs. (full aluminum cylinder $\simeq$ 13.5 lbs.; full steel cylinder $\simeq$ 15 lbs.) The aluminum cylinders were DOT 3AL specification cylinders manufactured of 6061 aluminum. The steel cylinders were DOT 3AA specification cylinders manufactured of carbon steel. Of the eighteen cylinders, seventeen were still stamped with the marked service pressure of 2015 psig. The one exception to the pressure stamping was what remained of a cylinder base attached to a deposit of melted and resolidified aluminum. All DOT specification markings, including the service pressure, were obliterated with the exception of a material lot number stamped into the base. Catalina Cylinders traced this material lot number and base design back to a lot of aluminum medical E cylinders manufactured in 2002. These cylinders were also manufactured to the DOT 3AL specification and had a service pressure of 2015 psig.

Valves were found mounted in sixteen of the eighteen cylinders recovered. The sixteen valves examined by the investigators were standard plated brass medical post valves. According to one valve manufacturer, the typical pressure relief device installed on these valves include a burst disk[1] set to actuate and relieve the internal pressure of the cylinder at between 3025 and 3360 psig, in accordance with the Hazardous Materials Regulations (Title 49 CFR Subchapter C) and the referenced Compressed Gas Association (CGA) S-1.1 standard.[2] They also stated that the valves

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[1] A burst disk is a pressure-actuated device used to prevent the pressure in a normally charged cylinder from rising above a predetermined maximum, thereby preventing rupture of the cylinder when subjected to high temperatures.

[2] The Compressed Gas Association is an industrial gas industry association dedicated to the development and promotion of safety standards and safe practices in the industry. CGA S-1.1 standard, *Pressure Relief Device Standards Part 1 – Cylinders for Compressed Gases*, provides the minimum requirements for pressure relief devices

should have a fusible material applied in the pressure relief opening outside the burst disk. The fusible material typically melts around 160° F, also in accordance with the CGA S-1.1 standard.

The details of the eighteen cylinders, their damage and the condition of their pressure relief devices are found in Table 1. In summary, eleven cylinders were retrieved from the passenger compartment (ten aluminum and one steel), and seven from the luggage bay (five aluminum and two steel). Of the eleven cylinders found in the passenger compartment four aluminum cylinders had evidence of melting. One additional aluminum cylinder burst and fractured about a foot below the cylinder neck. These five cylinders will be discussed in detail below. The remaining six cylinders in the passenger compartment had evidence of extensive fire damage, including discoloration or complete obliteration of the exterior paint and coatings, and oxidation, but were intact.

Visual observation and depth measurement of the pressure relief device openings in the nine valves installed in cylinders found in the passenger compartment revealed that six had actuated burst disks; a seventh was nearly occluded by resolidified pieces of its fusible element. Probing with a wire into the opening of this pressure relief device located an obstruction at the proximate location of the burst disk although the disk could not be observed to visually determine its condition. The two remaining cylinders had valves with intact burst disks. These two valves were found installed in two of the five burst and fractured, or melted cylinders discussed in detail below.

The seven cylinders found in the luggage bay had sooting and limited fire damage; no permanent discoloration of coatings. Many had labels still intact and legible. Also several of the aluminum cylinders found in the luggage bay had a temperature sensitive clear coating. This coating is formulated to change from clear to yellow, then brown and finally black when exposed to temperatures of 350° F or higher over a set time period. (At 350° F, the coating changes from clear to yellow after 3 to 4 hours. At higher temperatures the change occurs more rapidly.) A postaccident pressure check performed by a compressed gas distributor, not involved in the accident, revealed that the maximum pressure in the seven cylinders found in the luggage bay was 200 psi. Prior to the checking the pressure on the cylinders, the valve and cylinder valve opening were tested for leakage. This test revealed that a couple cylinders had minor leakage through the regulator opening. Visual observation and depth measurement of the seven cylinders' pressure relief devices installed in their valves revealed little evidence of fusible elements, but the burst disks appeared to be intact.

Examination of the one burst and fractured, and four melted aluminum cylinders revealed the following:

1. The burst and fractured cylinder was stamped with the manufacturer symbol "Cliff Div" which is a symbol used by Catalina Cylinders. It was stamped as being manufactured in July 2005. The serial number was ASO605416. The cylinder had fractured about 1 foot

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considered to be appropriate for use on cylinders having capacities of 1000 lbs (454 kg) of water or less. The CGA standards are available through the Compressed Gas Association, Chantilly, VA. 20151-2923. (www.cganet.com)

Table 1. DOT Cylinder Information and Damage

Serial Nos [Matl Heat Nos]*	Manufacturer	Date of Mfg	Aluminum or Steel	PRD Condition	Cylinder Damage
Cylinders in Passenger Cmpt					
ASO605416	Catalina	07/05	Aluminum	Intact burst disk	Cylinder burst
BX272790	Luxfer	06/05	Aluminum	Intact burst disk	Base melted and no longer attached
ASO33432	Catalina	07/01	Aluminum	Actuated	Base melted and no longer attached
[E422]	Luxfer	06/05	Aluminum	Valve not recovered	Shoulder and neck melted
[4422]	Catalina	06/02	Aluminum	Valve not recovered	Cylinder melted only a few inches of the base remained
PO4283	PST	10/81	Steel	Actuated	Fire exposure
ASO203202	Catalina	09/02	Aluminum	Actuated	Fire exposure
MM1157745	Catalina	02/02	Aluminum	Actuated	Fire exposure
KP61964	Catalina	01/01	Aluminum	Actuated	Fire exposure
ASO605801	Catalina	07/05	Aluminum	Actuated	Fire exposure
E768853	Luxfer	07/98	Aluminum	Undetermined	Fire exposure
Cylinders in Baggage Bay					
E866121	Luxfer	11/98	Aluminum	Intact burst disk	Sooting
265766	Coyne	12/92	Steel	Intact burst disk	Sooting
BX211769	Luxfer	09/99	Aluminum	Intact burst disk	Sooting
E410908	Luxfer	09/96	Aluminum	Intact burst disk	Sooting
485778	M8004	02/92	Steel	Intact burst disk	Sooting
BX272760	Luxfer	06/06	Aluminum	Intact burst disk	Sooting
BX330772	Luxfer	05/05	Aluminum	Intact burst disk	Sooting

* -Material lot numbers are used when the serial numbers were destroyed in the fire.

below the top opening. No evidence of the bottom portion of the cylinder was identified in the wreckage. The weight of the partial cylinder without its valve was about 4 lbs. whereas, the typical weight of an aluminum medical E cylinder is about 7.5 lbs. The valve mounted in the cylinder opening was marked as having been manufactured by Sherwood HARSCO. Markings also indicated that the valve was manufactured on 14th day of 2005 and that it was intended for use with oxygen. Examination of the burst disk revealed that it was intact. There was no evidence of fusible material in the disk opening.

2. The first melted cylinder was stamped with the manufacturer symbol "Luxfer" which is a symbol used by Luxfer Gas Cylinders. It was stamped as being manufactured in June 2005. The serial number was BX272790. The cylinder maintained its cylindrical shape until about 1 foot below the top opening. Several inches of molten aluminum were attached below that point. The remaining melted aluminum did not appear to represent a complete cylinder. Other than molten and resolidified aluminum, no evidence of a bottom portion of this cylinder was identified in the wreckage. The weight of the partial cylinder without its valve was about 5 lbs. The valve mounted in the cylinder opening was marked as having been manufactured by Sherwood HARSCO. Markings also indicated that the valve was manufactured on 7th day of 2005 and that it was intended for use with oxygen. Examination of the burst disk revealed that it was intact. There were remnants of a polymer cap in the disk opening. According to the valve manufacturer a polymer cap was installed during manufacture.

3. The second melted cylinder was stamped with the manufacturer symbol "Cliff Div" which is a symbol used by Catalina Cylinders. It was stamped as being manufactured in July 2001. The serial number was ASO33432. The cylinder maintained its cylindrical shape until about 1 foot below the top opening. Several inches of molten aluminum were attached below that point. The remaining melted aluminum did not appear to represent a complete cylinder. No evidence of a bottom portion of this cylinder was identified in the wreckage. . The weight of the partial cylinder without its valve was about 4.5 lbs. A Youngdo Ind. Co., Ltd. valve was mounted in the cylinder opening. Markings also indicated that the valve was manufactured in June of 2001 and that it was intended for use with oxygen. Examination of the burst disk revealed that it had actuated. There was no evidence of fusible material in the disk opening.

4. The third melted cylinder was stamped with the manufacturer symbol ***M4141***; a symbol used by Luxfer Gas Cylinders. It was stamped as being manufactured in June 2005. The serial number was not identifiable. The cylinder base was stamped with a material heat stamp "E422." This material heat was used by Luxfer to manufacture a lot of 98 cylinders, including BX272790, (S/Ns BX272781– BX272879) in June 2005. The cylinder maintained its cylindrical shape, however, the top shoulder where the cylinder stamping was placed had melted through in several locations destroying some markings. There was also severe distortion to the valve opening and threads. Much of the thread material was present but was distorted by heat. The weight of this cylinder was about 7.5 lbs. When found, there was no valve mounted in the cylinder. None was located in the wreckage.

5. The remains of the fourth melted cylinder were limited to about 4 inches of the sidewall and a cylinder base attached to a deposit of resolidified aluminum. This base was stamped with a material heat stamp "4422," which was used by Catalina Cylinders to manufacture a lot of 195 cylinders (S/Ns AS161180 – AS161374) in June 2002. However, the weight of this "cylinder" was 15 lbs. When found, there was no valve mounted in the cylinder. None was located in the wreckage.

According to a representative of Luxfer, the manufacturer of two of the melted aluminum cylinders, the aluminum used in these cylinders has a melting range between 1,020° and 1,206° F. However, He stated that aluminum will loose its strength at temperatures well below that. Exposing a fully-pressurized aluminum cylinder to temperatures as low as 350° F over several days will cause a cylinder to loose its strength and fail. The Luxfer representative further stated that a fully-pressurized aluminum cylinder would only maintain its integrity for minutes at temperatures above 600° F. (See Appendices A, B, E, F, G, H, K and the Fire and Metallurgy Factual Reports.)

G. Owner Information

The cylinders that had undestroyed ownership labels or markings after the fire (most of the seven cylinders found in the luggage bay) were identified as being owned by Tallwood Medical Equipment & Service Company (Tallwood). Tallwood distributes medical oxygen in the greater Houston, Texas area. Their standard procedures involved replacing empty medical oxygen cylinders with full ones in a storage area at Brighten Gardens. They do not fill the cylinders. They contract with two companies to fill and check the cylinders for inspection and retest date compliance. These companies are Airgas Puritan Medical and LifeGas, LLC, both in Houston, Texas. Interviews with managers of Tallwood, and both filling companies indicate that the cylinders are not controlled by the serial numbers that are steel stamped on the cylinders. Since all the labels and marks, aside from the DOT-required steel stamp markings, were burned off the five melted and burst cylinders examined by the Board, the investigators were not able to get a complete history of those cylinders. (See Appendix B.)

H. Regulations and Standards

Federal Regulations--Regarding the transportation of the medical oxygen on the bus for the passenger's health, the Hazardous Materials Regulations (Title 49 CFR Subchapter C) section 171.8 defines *materials of trade,* in part, as a hazardous material that is carried on a motor vehicle for the purpose of protecting the health and safety of the motor vehicle operator or passengers. Section 173.6 states that when materials of trade are transported by a motor vehicle, they are not subject to DOT shipping requirements provided, in part, that division 2.2 materials (nonflammable gases, including oxygen) are carried in a cylinder with a gross weight not over 220 lbs. The cylinder must conform to packaging, qualification, maintenance, and use requirements of the Hazardous Materials Regulations, except that outer packagings are not required. A DOT specification cylinder must be marked and labeled as prescribed in the subchapter. Also the operator of a motor vehicle must be informed of the presence of the hazardous materials. The

aggregate gross weight of all materials of trade on a motor vehicle may not exceed 440 lbs.

Part 177 provides additional requirements for the highway transportation of hazardous materials. Section 177.870(e) only permits a maximum gross weight of 99 lbs of any given class of hazardous material, including Class 2 compressed gases, on passenger-carrying vehicles, with the exception that a single cylinder weighing not more than 250 lbs may be transported provided it is secured against movement while in transit.

On September 26, 2005, three days after this accident, the DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) issued *Guidance for the Safe Transportation of Medical Oxygen for Personal Use on Buses and Trains*. This guidance suggested that, if possible, no more that one cylinder per person be placed in the passenger compartment. The guidance also stated, "the total weight of oxygen cylinders permitted in a bus cargo compartment is 99 lbs." (Appendix D)

On September 23, 2005, PHMSA issued an exemption (DOT-E 14248) to Texas State, local, and Federal government officials, and persons conducting operations under the direction of those government officials that exempted operations concerning Hurricane Rita response efforts from the Hazardous Materials Regulations. However, according to PHMSA officials, the exemption would not have applied to the accident trip because the trip started and the fire occurred before the exemption was in force. No enforcement action has been initiated by PHMSA concerning the transportation of oxygen on the accident bus. (Appendix B & D)

Oxygen is classified by section 172.101 as a division 2.2 (nonflammable compressed gas) with a secondary hazard of a division 5.1 (oxidizer). Given the dual hazards, the regulations require both labels (2.2 and 5.1), however, an exception to the regulations allows oxygen to be labeled with a single Oxidizer label that has the word "Oxidizer" replaced with the word "Oxygen." (172.405(b))

Section 173.301(a) requires oxygen to be shipped in DOT specification cylinders. This includes DOT 3AL and DOT 3AA cylinders among other specifications. Subsection 173.301(f) requires that pressure relief device for these cylinders to be sized, selected and tested in accordance with the CGA S-1.1 standard. Also that the pressure relief device must be capable of preventing the rupture of a normally filled cylinder when subjected to a fire test conducted in accordance with the CGA C-14 standard.

CGA Standards—The S-1.1 standard only requires the performance of a fire test in accordance with C-14, when the flow capacity of a pressure relief device is sized less than that required by the standard. The C- 14 standard provides the procedures for performing a fire test but has no requirements for preparation and retention of records. The cylinder manufacturers were asked to provide the results of any fire testing performed on their cylinders; no test records were found.

The CGA S-1.1 standards for sizing, actuation pressure, and etc., were based on a series of

fire tests performed by Luxfer and other cylinder manufacturers in the late 1970s. In 1978, Luxfer performed fire tests on DOT E6498 exemption cylinders. At this time, the DOT 3AL aluminum cylinder specification did not exist. Aluminum cylinders were manufactured, tested, inspected, marked, and marketed as DOT exemption cylinders. In 1981, after several years in service, the DOT regulations were changed creating the current DOT 3AL specification, and the former aluminum exemption cylinders were converted into this specification.

One series of fire tests were performed on significantly larger sized, therefore greater capacity, aluminum cylinders (8 inch diameter by about 4 feet long) with medical post valves equipped with burst disks designed to actuate between 2600 and 3000 psig. In both tests the burst disks actuated at 2600 psig relieving the pressure and preventing the rupture of the cylinders. The first test was done on a thicker wall cylinder with a 2350 psig service pressure. In this test, a gas fire temperature of 771° F raised the cylinder base temperature to about 372° F and the mid-wall temperature to about 177° F in two minutes when the internal pressure of the gas in the cylinder caused the burst disk to actuate. The second test was done on a 2100 psig service pressure cylinder, a similar pressure cylinder to the 2015 psig involved in the fire. In this test, a gas fire temperature of 938° F raised the cylinder base temperature to about 271° F and the mid-wall temperature to about 176° F in two minutes and 44 seconds when the internal pressure of the gas in the cylinder caused the burst disk to actuate. After actuation of the burst disks it took approximately 2 minutes to vent the gas from each test cylinder. (Appendix I)

In June 1999, the FAA tested several steel oxygen cylinders and cylinders mounted in two different type of overpacks (one designed only for impact protection and one thermally insulated) in a furnace. The cylinders and cylinders in overpacks were placed in a furnace and subjected to 400° F. While the results of furnace testing steel cylinders may not parallel that of aluminum cylinders, the impact resistant overpack maintained the cylinder external temperature below 300° F for over an hour, and the thermally insulated overpack limited the cylinder temperature rise from ambient to less than 30 degrees Fahrenheit in about an hour. (See Appendix J.)

James E. Henderson

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Approved 03-16-06
Bob Spencer

LIST OF APPENDICES

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