Safety Bulletin

U.S. Chemical Safety and Hazard Investigation Board

Hazards of Nitrogen Asphyxiation

No. 2003-10-B | June 2003

Introduction

Every year people are killed by breathing "air" that contains too little oxygen. Because 78 percent of the air we breathe is nitrogen gas, many people assume that nitrogen is not harmful. However, *nitrogen is safe to breathe only when mixed with the appropriate amount of oxygen.*

These two gases cannot be detected by the sense of smell. A nitrogen-enriched environment, which depletes oxygen, can be detected only with special instruments. If the concentration of nitrogen is too high (and oxygen too low), the body becomes oxygen deprived and asphyxiation occurs.

This Safety Bulletin is published to bring additional attention to the continuing hazards of nitrogen asphyxiation.[1]

- Nitrogen is widely used commercially. It is often used to keep material free of contaminants (such as oxygen) that may corrode equipment, present a fire hazard, or be toxic.
- Nitrogen asphyxiation hazards in industry resulted in 80 deaths from 1992 to 2002. These incidents occurred in a variety of facilities, including industrial plants, laboratories, and medical facilities; almost half involved contractors.
- Good practices and awareness of hazards minimize the risk of nitrogen asphyxiation (Figure 1).

Many incidents reviewed by CSB were caused by inadequate knowledge of the hazard or inadvertent use of nitrogen rather than breathing-air delivery systems.

➡ Figure 1. Sign warning of nitrogen hazard.

This bulletin focuses only on the hazard of asphyxiation, though nitrogen also presents cryogenic and high-pressure hazards.

Commercial Uses of Nitrogen

One of the most important commercial uses of nitrogen is as an inerting agent to improve safety. Nitrogen is inert under most conditions (i.e., it does not react with or affect other material).

It is often used to keep material free of contaminants, including oxygen—which can corrode equipment or present a fire and explosion hazard when in contact with flammable liquids or combustible solids. In such cases, a flow of nitrogen is maintained in a vessel to keep oxygen out. Nitrogen is also used to purge air from equipment prior to introducing material, or to purge flammable or toxic material prior to opening equipment for maintenance.

In industrial and commercial settings where a nitrogen-enriched environment may present a hazard, such as when using supplied air or working in or around spaces that are confined,

[1] In 1998, the U.S. Chemical Safety Board (CSB) investigated a nitrogen asphyxiation incident that occurred in Hahnville, Louisiana. As part of that investigation, CSB reviewed the prevalence of asphyxiation incidents.

precautions must be taken to ensure that sufficient oxygen is provided to personnel.

➡ Nitrogen is safe to breathe only when mixed with the appropriate amount of oxygen.

Effects of Oxygen-Deficient Atmosphere

Nitrogen is not a "poison" in the traditional sense. It presents a hazard when it displaces oxygen, making the atmosphere hazardous to humans. Breathing an oxygen-deficient atmosphere can have serious and immediate effects, including unconsciousness after only one or two breaths. The exposed person has no warning and cannot sense that the oxygen level is too low.

The Occupational Safety and Health Administration (OSHA) requires employers to maintain workplace oxygen at levels between 19.5 and 23.5 percent. As shown in the table on page 3, the human body is adversely affected by lower concentrations.

As the oxygen concentration falls below 16 percent, the brain sends commands to the breathing control center, causing the victim to breathe faster and deeper. As the oxygen level continues to decrease, full recovery is less certain. An atmosphere of only 4 to 6 percent oxygen causes the victim to fall into a coma in less than 40 seconds. Oxygen must be administered within minutes to offer a chance of survival. Even when a victim is rescued and resuscitated, he or she risks cardiac arrest.

➡ In industrial and commercial settings where a nitrogen-enriched environment may present a hazard, . . . precautions must be taken to ensure that there is sufficient oxygen in the atmosphere.

➡ Nitrogen . . . presents a hazard when it displaces oxygen.

Statistics on Nitrogen Asphyxiation

From reported data for the United States, CSB identified 85 nitrogen asphyxiation incidents that occurred in the workplace between 1992 and 2002. In these incidents, 80 people were killed and 50 were injured.[2]

Profile of Affected Industries and Activities

Of the 85 incidents reported, 62 percent occurred in chemical plants and refineries, food processing and storage facilities, metal and manufacturing operations, and other industrial, maritime, and manufacturing sites, including nuclear plants.

Approximately 13 percent of the incidents involved maintenance

[2] Data sources for the CSB review include regulatory agencies, media reports, technical publications, and contacts with safety personnel; however, only those incidents that were reported and accessible are represented. Although the summary data reported above are not all-inclusive, the numbers clearly indicate that nitrogen asphyxiation presents a serious hazard in the workplace. Statistical analysis is based on available, limited information.

CSB Safety Bulletins offer advisory information on good practices for managing chemical process hazards. Case studies provide supporting information. Safety Bulletins differ from CSB Investigation Reports in that they do not comprehensively review all the causes of an incident.

U.S. Chemical Safety and Hazard Investigation Board
Office of Investigations and Safety Programs
2175 K Street NW, Suite 400
Washington, DC 20037-1848
202-261-7600
www.chemsafety.gov

Effects of Oxygen Deficiency on the Human Body

Atmospheric Oxygen Concentration (%)	Possible Results
20.9	Normal
19.0	Some unnoticeable adverse physiological effects
16.0	Increased pulse and breathing rate, impaired thinking and attention, reduced coordination
14.0	Abnormal fatigue upon exertion, emotional upset, faulty coordination, poor judgment
12.5	Very poor judgment and coordination, impaired respiration that may cause permanent heart damage, nausea, and vomiting
<10	Inability to move, loss of consciousness, convulsions, death

SOURCE: Compressed Gas Association, 2001.

➡ CSB identified 85 nitrogen asphyxiation incidents that occurred in the workplace between 1992 and 2002 . . . 80 people were killed and 50 were injured.

activities, such as railcar and tank truck cleaning, painting, maintenance, and repair. These incidents are categorized as "maintenance" because incident reports do not include enough information on the type of industrial setting; they could have occurred at manufacturing sites, which would increase the 62 percent estimate above.

Likewise, trenches and manholes—not specifically identified as being in manufacturing facilities—account for about 14 percent of the incidents. The remainder of the incidents occurred in laboratories and miscellaneous industries, such as medical and transportation.

The data show that employees and contractors alike are victims of asphyxiation. Of the 85 incidents reviewed, 42 involved contractors, including construction workers;

➡ Of the 85 incidents reviewed, 42 involved contractors, including construction workers; these 42 incidents account for over 60 percent of the fatalities.

➡ . . . 130 workplace fatalities and injuries occurred from breathing nitrogen-enriched air. Over 60 percent of these victims were working in or next to a confined space.

these 42 incidents account for over 60 percent of the fatalities.

Causal Information

From the CSB data, a combined total of 130 workplace fatalities and injuries occurred from breathing nitrogen-enriched air. Over 60 percent of these victims were working in or next to a confined space.[3,4]

One characteristic of a confined space is its capability to contain an atmosphere that may be totally different from outside air. Confined spaces in manufacturing sites typically include equipment such as reactors, vessels, tanks, and boilers. Other such spaces are railcars, trenches, and areas accessible by manholes.

[3] "Next to a confined space" means that a person's breathing zone is affected by the atmosphere emanating from the space. The person may be standing in the immediate area but not actually in the space.

[4] According to OSHA, a confined space can be entered to perform work, has limited means of egress, and is not designed for continuous employee occupancy. A "permit-required confined space" includes a space that contains or has the potential to contain a serious safety or health hazard, such as a hazardous atmosphere.

Failure to Detect Oxygen-Deficient Atmosphere

Failure to detect an oxygen-deficient (nitrogen-enriched) atmosphere was a significant factor in several incidents.

In the data evaluated for this study, 67 of the 85 incidents involved circumstances where personnel were in or around a confined area—such as a railcar, room, process vessel, or tank (Figure 2)—and nitrogen was initially present in high levels or later collected in the area. These incidents accounted for 62 fatalities and 33 injuries. In each of the 67 incidents, personnel failed to detect elevated levels of nitrogen and take appropriate precautions.

When fatalities and injuries occurred in "open areas" (including areas with ventilation, laboratories, buildings, and outside in the vicinity of equipment), the hazard of asphyxiation was not expected and personnel were typically caught off guard. In some cases, personnel unknowingly created a nitrogen-enriched atmosphere by mistakenly using nitrogen instead of air to flush equipment prior to entry. In either situation, inadequate knowledge of the hazard and failure to detect additional nitrogen resulted in a fatal concentration of gas.

➡ When fatalities and injuries occurred in "open areas" . . . the hazard of asphyxiation was not expected and personnel were typically caught off guard.

Mix-Up of Nitrogen and Breathing Air

Confusing nitrogen gas with air and problems with breathing-air delivery systems accounted for 12 of the 85 incidents, and approximately 20 percent of fatalities.

➡ Figure 2. Confined area.

The data provide examples of workers inadvertently using nitrogen instead of air because of interchangeable couplings on lines and poor or nonexistent labeling.

In one incident, a worker mistakenly used nitrogen instead of air to purge a confined space. An inert atmosphere was unexpected and undetected. One worker was killed, and a colleague also died while attempting rescue. In another case, workers inadvertently connected the hose for their breathing-air respirator to a pure nitrogen line.

➡ In one incident, a worker mistakenly used nitrogen instead of air to purge a confined space . . . In another case, workers inadvertently connected the hose for their breathing-air respirator to a pure nitrogen line.

Fatalities and Injuries During Attempted Rescue

One of the most difficult issues concerning hazardous atmosphere emergencies is the human instinct to aid someone in distress. Approximately 10 percent of fatalities from the CSB data were due to attempts to rescue injured persons in confined spaces.

➡ Approximately 10 percent of fatalities from the CSB data were due to attempts to rescue injured persons in confined spaces.

Asphyxiation Hazards Outside Industry and Effect on General Public

Asphyxiation hazards may also be present outside industry, especially among people who use breathing air, such as firefighters, divers, and medical patients. Statistics on these types of incidents are difficult to collect and are not included in this bulletin, though one such case is summarized below.

Selected Case Studies

Failure to Recognize Asphyxiation Hazards Near Confined Spaces

Employee Dies After Partially Entering a Nitrogen-Purged Tank

Two coworkers and the victim were cleaning filters in a hydrogen purifying tank. The tank was partly purged with nitrogen to remove internal dust particles. The victim used a lift to access the *external* area of the upper tank, which was fitted with a manway. As he leaned into the tank opening, his coworkers noticed that he was not responding to their communication. They found the victim unconscious, and he later died as a result of oxygen deficiency.

Employee Overcome While Testing Atmosphere

An operator was conducting a flammable gas test on a tower feedline that discharged into a low-pressure flare gas header. The test was required for a hot work permit to take flash photos.

The chief operator issued a work permit that required a supplied-air respirator. Two contractor pipefitters wore respirators and removed the safety valve. The operator, however, wore no respiratory protection. After climbing the scaffold, he was overcome by nitrogen gas from the open flare line before he could complete atmospheric sampling.

The operator backed away, turned, and slumped to his knees. He was disoriented and briefly lost consciousness. An investigation concluded that the incident was due to elevated levels of nitrogen gas that had inadvertently entered the flare system.

Inadequate Monitoring of Atmosphere

Contractor Asphyxiated Inside Tank Car

White mineral oil in a tank car at an oil refinery was offloaded by injecting nitrogen gas into the car. An employee of a railcar cleaning company was asphyxiated while cleaning the nitrogen-filled tank car.

Corrupt Breathing Air Supply

Two Laborers/Painting Contractors Asphyxiated

Two painting contractors were abrasive-blasting tubes inside a boiler at a chemical plant. They each wore supplied-air respirators connected to a 12-pack cluster of compressed air cylinders. Another subcontractor monitored the work outside the confined space.

Work proceeded normally throughout the night shift; however, at 3:00 am, the attendant got no response after repeatedly sounding the air horn. When another contractor employee was sent into the boiler to assess the situation, he found the two men lying on opposite ends of the scaffolding.

When the plant health, safety, and environmental department tested the compressed air 12-pack, they found that it contained less than 5 percent oxygen. The "air" had been manufactured with too low a

concentration of oxygen. (Note: This fatal incident prompted OSHA to issue a safety alert on the batch of breathing air.)

Mix-Ups Between Nitrogen and Air

Three Employees Asphyxiated in Coating Tank

The atmosphere inside a coating tank was tested and ventilated the day before work was to be performed. On the following day, a contractor entered the tank to clean it and collapsed. Two plant employees entered to attempt rescue, but they were also overcome.

The tank had been ventilated with what was thought to be compressed air but was actually nitrogen. The atmosphere was not tested prior to beginning work. All three men were asphyxiated.

Employee Killed by Overexposure to Pure Nitrogen

A contractor planned to use an air-powered hammer to chip residue from a furnace in an aluminum foundry. He wore an airline respirator. Of two compressed gas lines with fittings, one was labeled "natural gas" and the other had an old paper tag attached with "air" handwritten on it. However, this line actually contained pure nitrogen.

A splitter diverted one part of the gas stream to the air hammer and the other part to the airline respirator. Once the respirator was in place, the worker breathed pure nitrogen and was asphyxiated.

Four Killed and Six Injured in Nursing Home

A nursing home routinely ordered large pure oxygen compressed gas cylinders for residents with respiratory system diseases. The supplier mistakenly delivered one cylinder of pure nitrogen with three cylinders of oxygen; a nursing home maintenance employee mistakenly accepted the nitrogen tank.

Another maintenance employee took this cylinder, which had a nitrogen label partially covering an oxygen label, to connect it to the oxygen supply system. The tank was fitted with nitrogen-compatible couplings. The employee removed a fitting from an empty oxygen cylinder and used it as an adapter to connect the nitrogen tank to the oxygen system. Four deaths and six injuries occurred as a result of pure nitrogen being delivered to the patients.

Good Practices for Safe Handling of Nitrogen

Implement Warning Systems and Continuous Atmospheric Monitoring of Enclosures

The atmosphere in a confined space or small enclosed area may be unfit for breathing prior to entry, or it may change over time, depending on the type of equipment or work being performed. Recognizing this hazard, good practice calls for continuous monitoring of a confined space to detect oxygen-deficient, toxic, or explosive atmospheres. The entire confined space should be monitored—not just the entry portal.

➡ The atmosphere in a confined space or small enclosed area may be unfit for breathing prior to entry, or it may change over time . . .

Warning and protection systems include flashing lights, audible alarms, and auto-locking entryways to prevent access. Such devices, if properly installed and

maintained, warn workers of hazardous atmospheres. Personal monitors can measure oxygen concentration and give an audible or vibration alarm for low oxygen concentrations.

➡ Good practice calls for continuous monitoring of a confined space to detect oxygen-deficient, toxic, or explosive atmospheres.

Ensure Ventilation With Fresh Air

Because the atmosphere of a confined space or small/enclosed area often changes during the course of work, it is essential to maintain continuous forced draft fresh-air ventilation before the job begins through to completion. Areas with the potential to contain elevated levels of nitrogen gas should be continuously ventilated prior to and during the course of the job.

Ventilation is also required in rooms and chambers into which nitrogen may leak or vent. In a few of the study cases, people who were simply working close to the nitrogen-containing confined space, room, or enclosure were asphyxiated.

Systems must be in place to properly design, evaluate, and maintain ventilation systems. A warning system will alert workers of a dangerous atmosphere. Personnel should be trained on how to properly respond and evacuate in the event of failure of the system.

Implement System for Safe Rescue of Workers

Rescue may be necessary in the event of continuous monitoring, ventilation failure, or another emergency condition. The ability to immediately retrieve immobilized workers is a critical component of confined space entry preplanning.

➡ It is essential to maintain continuous forced draft fresh-air ventilation before the job begins through to completion.

One method is to attach a body harness and lifeline to personnel entering confined areas. This procedure also benefits potential rescuers because they do not have to enter the confined area to retrieve the victim. However, when a worker enters a pipeline, some furnaces, ducts, or other narrow-diameter confined spaces, pulling on a line attached to a body harness may cause the person to bunch up and become stuck inside.

Depending on the situation, wristlets or anklets attached to a lifeline and a retrieval mechanism allow the confined space attendant to pull the person out by the arms or legs. The attendant and rescue personnel should be available at all times. Rescuers must have an effective system to communicate with personnel inside enclosures. No one should enter a dangerous atmosphere without proper personal protective equipment.

The last measure of defense requires personnel to actually enter the confined area to retrieve the victim. This approach should be used only when personnel are appropriately trained, have donned rescue equipment, and have dependable breathing air.

Approximately 10 percent of fatalities from the survey data occurred to personnel attempting rescue. These deaths could have been prevented if a reliable retrieval system was in place. Such a system would also prevent many entry worker fatalities because it provides for quickly removing the worker from a dangerous atmosphere to a safe one.

Ensure Uninterrupted Flow and Integrity of Breathing Air

Breathing air must be supplied when workers enter environments where oxygen is or may become deficient. Workers may use either a self-contained breathing apparatus (SCBA) or an airline respirator, which consists of a long hose connecting a breathing air supply to the respirator or hood.

Because a worker using an airline respirator does not control the

➡ Breathing air must be supplied when workers enter environments where oxygen is or may become deficient.

source of supply, air may suddenly or inadvertently be interrupted. For example, a power failure may stop an air compressor, the air supply may simply run out, or the supply hose may become twisted or obstructed (e.g., by a vehicle). When supplied air is used, facility management systems must protect against interruption of airflow and provide alternate sources of power for the compressors.

A comprehensive management system includes the following:

- Continuous monitoring of air supply.
- Routine inspection and replacement of supplied-air hoses.
- Restriction of vehicular traffic in the area of supply hoses.

When using supplied air, a worker should carry a small backup cylinder (escape pack)—attached to a different supplied-air system—with enough breathing air to last 5 to 10 minutes.

Breathing air is manufactured either by purifying and compressing air or by mixing nitrogen and oxygen to the appropriate ratio. A breathing-air compressor and its hoses should be specifically manufactured for and dedicated to breathing-air systems. The compressor should have a moisture trap, an oil trap, and a carbon monoxide sensor and alarm. When breathing air is manufactured by mixing nitrogen and oxygen, the pressure of the cylinders during filling must be known to ensure that the correct amounts are mixed. The final product must be tested to ensure its integrity.

Prevent Inadvertent Mix-Up of Nitrogen and Breathing Air

To prevent interchanging compressed nitrogen with compressed industrial grade air or compressed breathing-quality air, specific fittings should be used for each cylinder. Cylinders for nitrogen, industrial grade air, and breathing-quality air have distinct, incompatible fittings that cannot be cross-connected.

➡ Personnel should understand that the fittings are *intended* to be incompatible to ensure safety.

Personnel should understand that the fittings are *intended* to be incompatible to ensure safety. Cylinders should be clearly labeled; typical cylinders are shown in Figure 3. Labels on piping systems, compressors, and

➡ Figure 3. Compressed gas cylinders.

fittings are additional reminders of which gas is contained inside. Color coding also helps to identify systems.

Develop and Implement Comprehensive Training Programs

The good practices for safe handling of nitrogen, described above, are effective only if personnel are trained on the importance of the following:

- Use of ventilation systems, retrieval systems, and atmospheric monitoring equipment—both how to use them and how to determine when they are not working properly.
- Dangers of nitrogen-enriched atmospheres and the systems to

prevent interchanging breathing air and nitrogen.

- Implementing good hazard communication, which includes safe handling of air and nitrogen delivery systems.
- Mandatory safety practices and procedures for entry into confined spaces, such as permits, providing an attendant, monitoring, ventilating, rescue, and contractor oversight.
- Precautions when working around equipment that may contain elevated levels of nitrogen.
- The reason for special fittings on compressed gas cylinders.
- Proper use of air supply equipment.

Training should cover new and revised procedures for confined space entry, and establish measurements for employee proficiency. Contractors as well as employees should be trained.

➡ Contractors as well as employees should be trained.

References and Additional Information

American National Standards Institute (ANSI)/American Society of Safety Engineers (ASSE), 2003. *Safety Requirements for Confined Spaces,* Z117.1-2003.

ANSI/ASSE, 2003. *Criteria for Accepted Practices in Safety, Health, and Environmental Training,* Z490.1-2001.

ANSI, 2002. *Standards on Signage and Labeling,* Z535 Series.

Compressed Gas Association, Inc., 2002. *Standard for Compressed Gas Cylinder Valve Outlet and Inlet Connections*, V-1, 10th edition.

Compressed Gas Association, Inc., 2001. *Safety Bulletin, Oxygen-Deficient Atmospheres*, SB-2, 4th edition.

Compressed Gas Association, Inc., 1999. *Handbook of Compressed Gases,* 4th edition, Kluwer Academic Publishers.

Federal Aviation Administration (FAA), 2003. *NASA Physiology Training*, www.faa.gov/avr/cmo/coa/PH-TR.html.

Finkel, Martin H., 2000. *Guidelines for Hot Work in Confined Spaces; Recommended Practices for Industrial Hygienists and Safety Professionals*, ASSE.

Harris, Michael K., Lindsay E. Booher, and Stephanie Carter, 1996. *Field Guidelines for Temporary Ventilation of Confined Spaces,* American Industrial Hygiene Association (AIHA).

Kletz, Trevor, 1995. *What Went Wrong? Case Histories of Process Plant Disasters*, Gulf Publishing Company.

Institution of Chemical Engineers (IChemE), 2003. *Accident Data Base*, she@ichme.org.uk.

Martin, Lawrence, 1997. "Effects of Gas Pressure at Depth: Nitrogen Narcosis, CO and CO_2 Toxicity, Oxygen Toxicity, and 'Shallow-Water' Blackout," *Scuba Diving Explained, Physiology and Medical Aspects of Scuba Diving*, Best Publishing Company.

McManus, Neil, 1999. *Safety and Health in Confined Spaces*, Lewis Publishers/CRC Press.

National Institute for Occupational Safety and Health (NIOSH), 2002. "State FACE Investigations of Fatal Confined-Space Incidents," *Traumatic Occupational Injury,* www.cdc.gov/niosh/face, Oct-Nov 2002.

Occupational Safety and Health Administration (OSHA), 2003. *Safety and Health Topics: Confined Spaces,* www.osha.gov/SLTC/confinedspaces/index.html.

OSHA, 2002. *Accident Investigation Summary Index Page*, www.osha.gov, Oct-Nov 2002.

OSHA, 1994. "Permit-Required Confined Spaces," *Federal Register*, 29 CFR 1910.146, May 1994.

Rekus, John F., 1994. *Complete Confined Spaces Handbook*, Lewis Publishers/CRC Press.

Safety Engineering, 2002. *Daily Incident Alert Archives,* www.safteng.net, Oct-Nov 2002.

The Bureau of National Affairs, Inc. (BNA), 1998. *Occupational Safety and Health Reporter*, Vol. 27, No. 46, April 22, 1998.

BNA, 1996. *Occupational Safety and Health Reporter,* Vol. 25, No. 47, May 1, 1996.

U.S. Air Force, 2003. *Hypoxia*, www.batnet.com/mfwright/hypoxia.html.

U.S. Chemical Safety and Hazard Investigation Board (USCSB), 2002. *Incident Data Base*, www.csb.gov, Oct-Nov 2002.

Information about available publications may be obtained by contacting:

U.S. Chemical Safety and Hazard Investigation Board
Office of Prevention, Outreach, and Policy
2175 K Street NW, Suite 400
Washington, DC 20037-1848
(202) 261-7600

CSB investigation reports may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(800) 553-NTIS or (703) 487-4600
Email: *info@ntis.fedworld.gov*
For international orders, see:
www.ntis.gov/support/cooperat.htm.

Salus Populi Est Lex Suprema
People's Safety is the Highest Law