# OCCUPATIONAL SAFETY AND HEALTH GUIDELINE FOR AMMONIA

## INTRODUCTION

This guideline summarizes pertinent information about ammonia for workers and employers as well as for physicians, industrial hygienists, and other occupational safety and health professionals who may need such information to conduct effective occupational safety and health programs. Recommendations may be superseded by new developments; readers are therefore advised to regard these recommendations as general guidelines and to determine periodically whether new information is available.

## SUBSTANCE IDENTIFICATION

- **Formula**

$NH_3$

- **Structure**

$NH_3$

- **Synonyms**

Anhydrous ammonia, ammonia gas, Am-fol, Nitro-sil, aqua ammonia, spirit of hartshorn

- **Identifiers**

1. CAS No.: 7664-41-7

2. RTECS No.: BO0875000

3. DOT UN: 1005 15 (anhydrous); 2073 15 (solutions containing more than 44% ammonia); 2672 60 (solutions containing 12% to 44% ammonia)

4. DOT labels: Poison Gas, Nonflammable Gas

- **Appearance and odor**

At room temperature, ammonia is a colorless, flammable gas; it is shipped as a liquid under its own vapor pressure. This substance has a penetrating and pungent odor. The odor threshold is reported to be 5 parts per million (ppm) parts of air.

## CHEMICAL AND PHYSICAL PROPERTIES

- **Physical data**

1. Molecular weight: 17.0

2. Boiling point (at 760 mm Hg): -33.4°C (-28°F)

3. Specific gravity: 0.77 at 0°C (32°F)

4. Vapor density (air = 1 at boiling point of ammonia): 0.6

5. Melting point: -77.7°C (-107.8°F)

6. Vapor pressure at 20°C (68°F): 8,500 mm Hg

7. Solubility: Very soluble in water, alcohol, ether, and chloroform

8. Evaporation rate: Data not available

- **Reactivity**

1. Conditions contributing to instability: Under certain conditions, mixtures of ammonia and air will explode when ignited.

2. Incompatibilities: Fires and explosions may result from contact of ammonia with trimethylammonium amide, 1-chloro-2,4-dinitrobenzene, o-chloronitrobenzene, platinum, trioxygen difluoride, selenium difluoride dioxide, boron halides, acids, mercury, chlorine, iodine, bromine, hypochlorites, or chlorine bleach.

3. Hazardous decomposition products: Toxic gases (such as hydrogen gas, nitrogen gas, and nitrous oxides) may be released when ammonia decomposes.

4. Special precautions: Liquid ammonia attacks some coatings and some forms of plastic and rubber; this substance should not be allowed to contact copper, brass, bronze, or galvanized steel.

- **Flammability**

The National Fire Protection Association has assigned a flammability rating of 1 (slight fire hazard) to ammonia.

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service Centers for Disease Control
National Institute for Occupational Safety and Health
Division of Standards Development and Technology Transfer

U.S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration

1. Flash point: Not applicable (ammonia is a gas at room temperature).

2. Autoignition temperature: 651°C (1,204°F)

3. Flammable limits in air (% by volume): Lower, 16; upper, 25.

4. Extinguishant: Use water spray or fog.

Fires involving ammonia should be fought upwind and from the maximum distance possible. Isolate the hazard area and deny access to unnecessary personnel. Emergency personnel should stay out of low areas and should ventilate closed spaces before entering. Containers of ammonia may explode in the heat of the fire and should be moved from the fire area if it is possible to do so safely. If this is not possible, cool containers from the sides with water until well after the fire is out. Stay away from the ends of containers. Do not get water inside the container. Personnel should withdraw immediately if they hear a rising sound from a venting safety device or if a container becomes discolored as a result of fire. Because ammonia is highly soluble in water, dikes should be used to contain fire-control water for later disposal. If a tank car or truck is involved in a fire, personnel should isolate an area of a half mile in all directions. Firefighters should wear a full set of protective clothing (including a self-contained breathing apparatus) when fighting fires involving ammonia. Firefighters' protective clothing may not provide protection against permeation by ammonia.

## EXPOSURE LIMITS

- **OSHA PEL**

The current Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for ammonia is 35 ppm (27 mg/m$^3$) as a 15-min short-term exposure limit (STEL) [29 CFR 1910.1000, Table Z-1-A]. A STEL is a 15-min time-weighted average (TWA) exposure which should not be exceeded at any time during the workday.

- **NIOSH REL**

The National Institute for Occupational Safety and Health (NIOSH) has established a recommended exposure limit (REL) for ammonia of 25 ppm (17 mg/m$^3$) as an 8-hr TWA and 35 ppm as a STEL [NIOSH 1992a].

- **ACGIH TLV®**

The American Conference of Governmental Industrial Hygienists (ACGIH) has assigned ammonia a threshold limit value (TLV) of 25 ppm (17 mg/m$^3$) as a TWA for a normal 8-hr workday and a 40-hr workweek; a STEL of 35 ppm (24 mg/m$^3$) has been established for periods not to exceed 15 min [ACGIH 1991b].

- **Rationale for limits**

The limits are based on the risk of eye irritation and respiratory effects associated with exposure to ammonia. OSHA did not find it necessary to establish a TWA to protect against chronic effects. OSHA concluded that a STEL would protect against the substance's irritant effects.

## HEALTH HAZARD INFORMATION

- **Routes of exposure**

Exposure to ammonia can occur through inhalation and eye or skin contact.

- **Summary of toxicology**

1. *Effects on Animals*: Ammonia is a severe irritant of the eyes, respiratory tract, and skin. Liquified ammonia can induce freezing, burns, and corrosion of tissues. Exposure of guinea pigs to 5,000 to 6,000 ppm for 30 to 120 min induced blindness [AIHA 1988]. The approximate 1-hr $LC_{50}$ for cats and rabbits was 9,900 ppm. This concentration induced severe bronchiolar damage, alveolar congestion, edema atelectasis, hemorrhage, and emphysema in the animals that died [NLM 1991]. The 4-hr $LC_{50}$ in rats is 2,000 ppm, and the oral $LD_{50}$ is 350 mg/kg [NIOSH 1992b]. In mice, the $RD_{50}$ (the concentration capable of reducing respiratory rate by 50%) was approximately 300 ppm. Continued exposure for 6 hr/day for 5 days produced nasal lesions including hypertrophy, hyperplasia, epithelial erosion, ulceration, and necrosis [NLM 1991]. Continuous exposure to ammonia for several weeks at 658 ppm produced marked eye irritation in dogs and rabbits and corneal opacity in rabbits [Grant 1986]. Rats similarly exposed developed interstitial pneumonitis with calcification of the bronchi and renal tubules, epithelial proliferation of the renal tubules, myocardial fibrosis, and fatty liver [NLM 1991]. Rats, guinea pigs, dogs, rabbits, and monkeys exposed to 1,100 ppm for 8 hr/day, 5 days/week for 6 weeks showed signs of moderate eye and nasal irritation but no signs of systemic poisoning [AIHA 1988]. Although all monkeys, dogs, and rabbits survived a continuous 90-day exposure to 680 ppm, this exposure was fatal to 13 of 15 rats and 4 of 15 guinea pigs [AIHA 1988]. No clinically significant findings were detected at autopsy in rats continuously exposed to 180 ppm for 90 days [AIHA 1988; Clayton and Clayton 1981].

2. *Effects on Humans*: Ammonia gas is severely irritating to the eyes and to the moist skin and mucous membranes of humans. In contact with the eyes, liquid anhydrous ammonia causes severe damage that may lead to blindness [Proctor et al. 1988]. When in contact with the skin, liquified ammonia can cause freezing and third-degree burns [NLM 1991; Proctor et al. 1988]. Two volunteers exposed to ammonia at approximately 24 ppm showed signs of mild nasal irritation

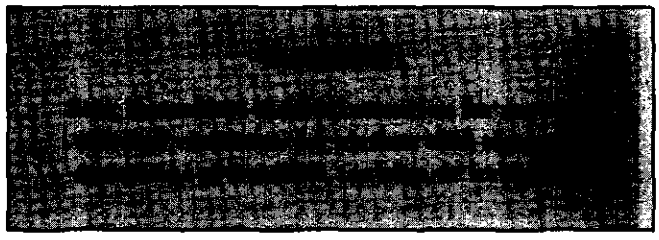
on clinical examination [Clayton and Clayton 1981]. Five of six volunteers exposed to 30 or 50 ppm for 10 min reported mild to moderate eye and upper respiratory tract irritation [Clayton and Clayton 1981]. At 130 ppm, however, volunteers experienced lacrimation and nose and throat irritation; one volunteer experienced pulmonary irritation [Clayton and Clayton 1981]. Exposure of humans to 500 ppm for 30 min caused changes in respiratory rate, and exposure to 1,720 ppm produced coughing in exposed individuals [AIHA 1988]. Accidental exposure to ammonia gas or the vapors of ammonia at high concentrations (approximately 2,500 to 6,500 ppm) for up to 2 hr induced chemical pneumonitis, burns (eyes, face, and mouth), severe local edema, dyspnea, progressive cyanosis, and death [Proctor et al. 1988; Clayton and Clayton 1981]. Death is normally caused by either suffocation or pulmonary edema [Clayton and Clayton 1981]. In near-lethal cases, residual effects may include visual impairment, decreased pulmonary function, and hoarseness [Clayton and Clayton 1981].

- **Signs and symptoms of exposure**

1. *Acute exposure*: Increasing ambient concentrations can cause contact irritation of the eyes and respiratory tract, tearing, hoarseness, violent coughing, painful breathing, impaired vision, severe eye damage, blindness, dyspnea, cyanosis, suffocation, and death. Direct contact with liquid anhydrous ammonia can cause frostbite and corrosion of the eyes and skin.

2. *Chronic exposure*: Exposure to ammonia can induce irritation of the eyes, nose, and upper respiratory tract, with coughing and difficult breathing.

- **Emergency procedures**



Keep unconscious victims warm and on their sides to avoid choking if vomiting occurs. Initiate the following emergency procedures:

1. *Eye exposure*: If tissue is frozen, seek medical attention ***immediately***; if tissue is not frozen, ***immediately and thoroughly*** flush the eyes with large amounts of water for at least 15 min, occasionally lifting the upper and lower eyelids. If irritation, pain, swelling, lacrimation, or photophobia persists, get medical attention as soon as possible.

2. *Skin exposure*: If frostbite has occurred, seek medical attention ***immediately***; do ***not*** rub the affected areas or flush them with water. If frostbite has ***not*** occurred, ***immediately and thoroughly*** wash contaminated skin with soap and water.

3. *Inhalation exposure*: Move the victim to fresh air ***immediately***.

If the victim is not breathing, clean any chemical contamination from the victim's lips and perform cardiopulmonary resuscitation (CPR); if breathing is difficult, give oxygen.

4. *Ingestion exposure*: Take the following steps if an ammonia solution is ingested:

—Have the victim rinse the contaminated mouth cavity several times with a fluid such as water.

—Have the victim drink a glass (8 oz) of fluid such as water.

—Induce vomiting by giving syrup of ipecac as directed on the package. If ipecac is unavailable, have the victim touch the back of the throat with a finger until productive vomiting ceases.

—Do ***not*** force an unconscious or convulsing person to drink fluid or to vomit.

5. *Rescue*: Remove an incapacitated worker from further exposure and implement appropriate emergency procedures (e.g., those listed on the material safety data sheet required by OSHA's hazard communication standard [29 CFR 1910.1200]). All workers should be familiar with emergency procedures and the location and proper use of emergency equipment.

## EXPOSURE SOURCES AND CONTROL METHODS

*The following uses of ammonia may result in worker exposures to this substance:*

—*Use as a soil fertilizer*

—Use in the manufacture of fertilizers; as a solvent in the manufacture of textiles, leather, and pulp and paper processing; and as a stabilizer in the manufacture of rubber

—*Use* in organic and inorganic synthesis of nitric acid, urea, plastics, fibers, synthetic resins, pharmaceuticals, pesticides, explosives, rocket fuels, cyanides, amides, dyestuffs, amines, flame retardants, household cleaners, sulfuric acid, and alkalies

—Use in mining and metallurgy, ore extraction and purification, treatment of scrap metal, annealing, atomic hydrogen welding, electronics, and nitriding of steel

—Use in petroleum refining as a neutralizing agent, in the manufacture and recovery of cracking catalysts, and in the dewaxing of lubrication oils

—Use as a commercial refrigerant in food processing, the production of ice, cold storage, and de-icing operations

—Use as a substitute for calcium in the bisulfite pulping of wood

—Use with chlorine to purify municipal and industrial water supplies

The following methods are effective in controlling worker exposures to ammonia, depending on the feasibility of implementation:

—Process enclosure

—Local exhaust ventilation

—General dilution ventilation

—Personal protective equipment

Good sources of information about control methods are as follows:

1. ACGIH [1992]. Industrial ventilation—a manual of recommended practice. 21st ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

2. Burton DJ [1986]. Industrial ventilation—a self study companion. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

3. Alden JL, Kane JM [1982]. Design of industrial ventilation systems. New York, NY: Industrial Press, Inc.

4. Wadden RA, Scheff PA [1987]. Engineering design for control of workplace hazards. New York, NY: McGraw-Hill.

5. Plog BA [1988]. Fundamentals of industrial hygiene. Chicago, IL: National Safety Council.

## MEDICAL MONITORING

Workers who may be exposed to chemical hazards should be monitored in a systematic program of medical surveillance that is intended to prevent occupational injury and disease. The program should include education of employers and workers about work-related hazards, placement of workers in jobs that do not jeopardize their safety or health, early detection of adverse health effects, and referral of workers for diagnosis and treatment. The occurrence of disease or other work-related adverse health effects should prompt immediate evaluation of primary preventive measures (e.g., industrial hygiene monitoring, engineering controls, and personal protective equipment). A medical monitoring program is intended to supplement, not replace, such measures. To place workers effectively and to detect and control work-related health effects, medical evaluations must be performed (1) before job placement, (2) periodically during the term of employment, and (3) at the time of job transfer or termination.

- **Preplacement medical evaluation**

Before a worker is placed in a job with a potential for exposure to ammonia, a licensed health care professional should evaluate and document the worker's baseline health status with thorough medical, environmental, and occupational histories, a physical examination, and physiologic and laboratory tests appropriate for the anticipated occupational risks. These should concentrate on the function and integrity of the eyes, skin, and respiratory system. Medical monitoring for respiratory disease should be conducted using the principles and methods recommended by the American Thoracic Society [ATS 1987].

A preplacement medical evaluation is recommended to assess an individual's suitability for employment at a specific job and to detect and assess medical conditions that may be aggravated or may result in increased risk when a worker is exposed to ammonia at or below the prescribed exposure limit. The licensed health care professional should consider the probable frequency, intensity, and duration of exposure as well as the nature and degree of any applicable medical condition. Such conditions (which should not be regarded as absolute contraindications to job placement) include a history and other findings consistent with eye, skin, or respiratory tract diseases.

- **Periodic medical examinations and biological monitoring**

Occupational health interviews and physical examinations should be performed at regular intervals during the employment period, as mandated by any applicable Federal, State, or local standard. Where no standard exists and the hazard is minimal, evaluations should be conducted every 3 to 5 years or as frequently as recommended by an experienced occupational health physician. Additional examinations may be necessary if a worker develops symptoms attributable to ammonia exposure. The interviews, examinations, and medical screening tests should focus on identifying the adverse effects of ammonia on the eyes, skin, and respiratory tract. Current health status should be compared with the baseline health status of the individual worker or with expected values for a suitable reference population.

Biological monitoring involves sampling and analyzing body tissues or fluids to provide an index of exposure to a toxic substance or metabolite. No biological monitoring test acceptable for routine use has yet been developed for ammonia.

- **Medical examinations recommended at the time of job transfer or termination**

The medical, environmental, and occupational history interviews, the physical examination, and selected physiologic or laboratory tests that were conducted at the time of job placement should be repeated at the time of job transfer or termina-

tion. Any changes in the worker's health status should be compared with those expected for a suitable reference population. Because occupational exposure to ammonia may cause diseases with prolonged latent periods, the need for medical monitoring may extend well beyond the termination of employment.

## WORKPLACE MONITORING AND MEASUREMENT

A worker's exposure to airborne ammonia is determined by using sulfuric-acid-impregnated carbon bead tubes (Supelco ORBO-77 tubes). Samples are collected at a maximum flow rate of 0.1 liter/min until a minimum air volume of 1.5 liters or a maximum air volume of 24 liters is collected. The samples are desorbed with deionized water and analyzed by ion chromatography. The limit of detection for this procedure is 1.5 ppm. This method is described in *OSHA Analytical Laboratory Method* ID-188 [OSHA 1988]. NIOSH has a similar method for analyzing ammonia using liquid sorbent badges and the same analytical procedure (Method 6701) in the *NIOSH Manual of Analytical Methods* [NIOSH 1984].

## PERSONAL HYGIENE

If ammonia contacts the skin, workers should immediately wash the affected areas with large quantities of water. Clothing contaminated with liquid ammonia should be removed immediately and should then be thoroughly flushed with cold water. Persons laundering contaminated clothing should be informed of the hazardous properties of ammonia, particularly its potential for skin irritation.

A worker who handles ammonia should thoroughly wash hands, forearms, and face with soap and water before eating, using tobacco products, or using toilet facilities.

Workers should not eat, drink, or use tobacco products in areas where ammonia or a solution containing ammonia is handled, processed, or stored.

## STORAGE

Ammonia should be stored in a cool, well-ventilated, fire-resistant area in tightly sealed containers that are labeled in accordance with OSHA's hazard communication standard [29 CFR 1910.1200]. Outside or detached storage is preferred. Containers of ammonia should be protected from physical damage and should be separated from oxidizers, combustible materials, heat, sparks, and open flame. Explosion proof electrical service must be installed in storage areas. Because containers that formerly contained ammonia may still hold product residues, they should be handled appropriately.

## SPILLS AND LEAKS

In the event of a spill or leak involving ammonia, persons not wearing protective equipment and clothing should be restricted from contaminated areas until cleanup is complete. The following steps should be undertaken following a spill or leak:

1. Do not touch the spilled material; stop the leak if it is possible to do so without risk.
2. Notify safety personnel.
3. Remove all sources of heat and ignition.
4. Ventilate potentially explosive atmospheres.
5. Use water spray to reduce vapors; do not put water directly on the leak or spill area.
6. For small leaks, flood the area with cool water.
7. For large liquid spills, build dikes far ahead of the spill to contain the ammonia for later reclamation or disposal.

## SPECIAL REQUIREMENTS

U.S. Environmental Protection Agency (EPA) requirements for emergency planning, reportable quantities of hazardous releases, community right-to-know, and hazardous waste management may change over time. Users are therefore advised to determine periodically whether new information is available.

- **Emergency planning requirements**

Employers owning or operating a facility with 500 lb or more of ammonia onsite must comply with EPA's emergency planning requirements [40 CFR 355.30].

- **Reportable quantity requirements for hazardous releases**

A hazardous substance release is defined by EPA as any spilling, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing of a hazardous substance into the environment (including the abandonment or discarding of contaminated containers) of hazardous substances. In the event of a release that is equal or greater than the reportable quantity for that chemical, employers are required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) [40 CFR 355.40] to notify the proper Federal, State, and local authorities.

The reportable quantity for ammonia is 100 lb. If an amount equal to or greater than this quantity is released within a 24-hr period in a manner that will expose persons outside the facility, employers are required to do the following:

—Notify the National Response Center ***immediately*** at (800) 424-8802 or at (202) 426-2675 in Washington, D.C. [40 CFR 302.6].

—Notify the emergency response commission of the State likely to be affected by the release [40 CFR 355.40].

—Notify the community emergency coordinator of the local emergency planning committee (or relevant local emergency response personnel) of any area likely to be affected by the release [40 CFR 355.40].

- **Community right-to-know requirements**

Employers who own or operate facilities in SIC codes 20 to 39, who employ 10 or more workers, and who manufacture 25,000 lb or more or otherwise use 10,000 lb or more of ammonia per calendar year are required by EPA [49 CFR 372.30] to submit a Toxic Chemical Release Inventory Form (Form R) to EPA reporting the amount of ammonia emitted or released from their facility annually.

- **Hazardous waste management requirements**

EPA considers a waste to be hazardous if it exhibits any of the following characteristics: ignitability, corrosivity, reactivity, or toxicity as defined in 40 CFR 261.21-261.24. Although ammonia is not specifically listed as a hazardous waste under the Resource Conservation and Recovery Act (RCRA) [40 USC 6901 et seq.], EPA requires employers to treat waste as hazardous if it exhibits any of the characteristics discussed above.

Providing detailed information about the removal and disposal of specific chemicals is beyond the scope of this guideline. The U.S. Department of Transportation, EPA, and State and local regulations should be followed to ensure that removal, transport, and disposal of this substance are conducted in accordance with existing regulations. To be certain that chemical waste disposal meets EPA regulatory requirements, employers should address any questions to the RCRA hotline at (800) 424-9346 or (202) 382-3000 in Washington, D.C. In addition, relevant State and local authorities should be contacted for information about their requirements for waste removal and disposal.

## RESPIRATORY PROTECTION

- **Conditions for respirator use**

Good industrial hygiene practice requires that engineering controls be used where feasible to reduce workplace concentrations of hazardous materials to the prescribed exposure limits. However, some situations may require the use of respirators to control exposure. Respirators must be worn if the ambient concentration of ammonia exceeds prescribed exposure limits. Respirators may be used (1) before engineering controls have been installed, (2) during work operations such as maintenance or repair activities that involve unknown exposures, (3) during operations that require entry into tanks or closed vessels, and (4) during emergencies. If the use of respirators is necessary, the only respirators permitted are those that have been approved by NIOSH and the Mine Safety and Health Administration (MSHA).

- **Respiratory protection program**

Employers should institute a complete respiratory protection program that, at a minimum, complies with the requirements of OSHA's respiratory protection standard [29 CFR 1910.134]. Such a program must include respirator selection, an evaluation of the worker's ability to perform the work while wearing a respirator, the regular training of personnel, fit testing, periodic workplace monitoring, and regular respirator maintenance, inspection, and cleaning. The implementation of an adequate respiratory protection program (including selection of the correct respirator) requires that a knowledgeable person be in charge of the program and that the program be evaluated regularly. For additional information on the selection and use of respirators and on the medical screening of respirator users, consult the *NIOSH Respirator Decision Logic* [NIOSH 1987b] and the *NIOSH Guide to Industrial Respiratory Protection* [NIOSH 1987a].

## PERSONAL PROTECTIVE EQUIPMENT

Gloves, boots, aprons, full-body suits, etc. should be worn as necessary. Chemical protective clothing should be selected on the basis of available performance data, manufacturers' recommendations, and evaluation of the clothing under actual conditions of use. The following materials have been tested against ammonia and have demonstrated good to excellent resistance: butyl rubber and Teflon®. Butyl rubber may provide more than 8 hr of resistance to permeation. Saranex® has demonstrated poor resistance to permeation by ammonia.

If ammonia is dissolved in water or an organic solvent, the permeation properties of both the solvent and the mixture must be considered when selecting personal protective equipment and clothing.

Safety glasses, goggles, or face shields should be worn during operations in which ammonia might contact the eyes. Eyewash fountains and emergency showers should be available within the immediate work area whenever the potential exists for eye or skin contact with ammonia.

## REFERENCES CITED

ACGIH [1991a]. Documentation of the threshold limit values and biological exposure indices. 6th ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

ACGIH [1991b]. 1991-1992 Threshold limit values for chemical substances and physical agents and biological ex-

posure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

AIHA [1988]. Emergency response planning guidelines. Akron, OH: American Industrial Hygiene Association, Emergency Response Planning Guidelines Committee.

ATS [1987]. Standardization of spirometry—1987 update. American Thoracic Society. Am Rev Respir Dis *136*:1285-1296.

Clayton G, Clayton F, eds. [1981]. Patty's industrial hygiene and toxicology. 3rd rev. ed. New York, NY: John Wiley & Sons.

CFR. Code of Federal regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Grant WM [1986]. Toxicology of the eye. 3rd ed. Springfield, IL: Charles C. Thomas.

NIOSH [1984]. Ammonia: Method 6701 (supplement issued 5/15/85). In: Eller PM, ed. NIOSH manual of analytical methods. 3rd ed. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 84-100.

NIOSH [1987a]. NIOSH guide to industrial respiratory protection. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 87-116.

NIOSH [1987b]. Respirator decision logic. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 87-108.

NIOSH [1992a]. Recommendations for occupational safety and health: compendium of policy documents and statements. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 92-100.

NIOSH [1992b]. Registry of toxic effects of chemical substances database: ammonia. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Standards Development and Technology Transfer, Technical Information Branch.

NLM [1991]. The hazardous substances data bank: ammonia. Bethesda, MD: National Library of Medicine.

OSHA [1988]. OSHA analytical laboratory methods. Salt Lake City, UT: U.S. Department of Labor, Occupational Safety and Health Administration, OSHA Analytical Laboratory.

Proctor NH, Hughes JP, Fischman ML [1988]. Chemical hazards of the workplace. Philadelphia, PA: J.B. Lippincott Company.