Nitrous oxide – N₂O
(3 CE Hours)

Learning objectives

- Review the history of nitrous oxide.
- Describe the production of nitrous oxide.
- List the uses of nitrous oxide.
- Explain the use of nitrous oxide in dental operatories.
- Describe the hazards in the workplace.
- Review the methods of engineering control and training.

Introduction

Sedation dentistry, sometimes called relaxation dentistry, refers to the way dentists manage pain and anxiety during dental appointments.

Conscious sedation is defined as a minimally depressed level of consciousness that retains the patient’s ability to independently and continuously maintain an airway and respond appropriately to physical stimulation and verbal command that is produced by pharmacological or nonpharmacologic method or a combination of both. Nitrous oxide is only one of the 14 different ways that sedation drugs can be administered. There are three primary ways that sedation is administered in the dental office: IV sedation, enteral internal? External? conscious sedation and inhalation conscious sedation or nitrous oxide.

N₂O

Inhalation conscious sedation or the use of nitrous oxide, commonly known as laughing gas, is a chemical compound with the formula N₂O. It is an oxide of nitrogen. At room temperature, it is a colorless non-flammable gas with a pleasant, slightly sweet odor and taste. It is used in surgery and dentistry for its anesthetic and analgesic effects. It is known as “laughing gas” because of the euphoric effects of inhaling it, a property that has led to its recreational use as a dissociative hallucinogen. It is also used as an oxidizer in rocketry and in motor racing to increase the power output of engine. At elevated temperatures, nitrous oxide is a powerful oxidizer similar to molecular oxygen. For example, nitrous oxide in a test tube will reignite a smoldering splint.

Nitrous oxide reacts with ozone and is the main naturally occurring regulator of stratospheric ozone. It is also a major greenhouse gas and air pollutant. Considered over a 100-year period, it has 298 times more impact per unit weight than carbon dioxide.

History

The gas was first synthesized by English chemist and Unitarian minister Joseph Priestley in 1772, who called it phlogisticated nitrous air. Priestley published his discovery in the book “Experiments and Observations on Different Kinds of Air” (1775), where he described how to produce the preparation of “nitrous air diminished” by heating iron filings dampened with nitric acid.

Early use (1794-1843)

The first important use of nitrous oxide was made possible by Thomas Beddoes and the renowned engineer James Watt, who worked together to publish the book “Considerations on the Medical Use and on the Production of Factitious Airs” (1794). This book was important for two reasons. First, James Watt had invented a novel machine to produce “factitious airs” (i.e. nitrous oxide) and a novel “breathing apparatus” to inhale the gas. Second, the book also presented the new medical theories by Thomas Beddoes, that tuberculosis and other lung diseases could be treated by inhalation of factitious airs.

The machine to produce factitious airs was comprised three parts: a furnace to burn the needed material, a vessel with water where the produced gas passed through in a spiral pipe (in order for impurities to be “washed off”), and finally the gas cylinder with a gasometer where the produced air could be tapped into portable air bags (made of airtight oily silk). The breathing apparatus was one of the portable air bags connected with a tube to a mouthpiece. With this new equipment engineered and produced already in 1794, the way was now paves for clinical trials, which began when Thomas Beddoes in 1798 established the Pneumatic Institution for Relieving Diseases by Medical Airs in Clifton (Bristol). In the basement of the building, a large-scale machine was producing the gases under the supervision of a young Humphry Davy, who was encouraged to experiment with new gases for patients to inhale. The first important work of Davy was to examine the nitrous oxide, with the results being published in his book: “Researches, Chemical and Philosophical” (1800).

Despite the valuable finding made by Davy, that inhalation of nitrous oxide could relieve a conscious person from pain, another 44 years would elapse before doctors attempted to use it for anesthesia.

Anesthetic use

At a “popular science” exhibition in Hartford, Connecticut, where volunteers inhaled nitrous oxide, local dentist Horace Wells noted one of them, a man who had injured his leg, seemed unaware of any pain from the injury. Thus was the born the first use of nitrous oxide as anesthetic drug. Wells himself, with assistance by Gardner Quincy Colton and John Mankey Riggs, demonstrated insensitivity to pain from a dental extraction in December 1844. In the following weeks, Wells treated the first 12-15 patients with nitrous oxide in Hartford, and according to his own record, only failed in two cases. In spite of these convincing results reported by Wells to the medical society in Boston in December 1844, this new method was not immediately adopted by other dentists. This probably was because in January 1845, Wells had been partly unsuccessful at his first public demonstration of the use of nitrous oxide for the medical faculty in Boston, leaving his colleagues doubtful regarding its efficacy and safety.

The method did not come into general use until 1863, when Colton successfully started to use it in all his Colton Dental Association clinics, which he just had established in New Haven and New York City. Over the following three years, Colton and his associates successfully administered nitrous oxide to more than 25,000 patients. With its efficacy and safety now demonstrated by large numbers, the usage of nitrous oxide rapidly became the preferred anesthetic method in dentistry. Because the gas is mild enough to keep a patient in a conscious and conversational state but in most cases is strong enough to suppress the pain caused by dental work, it remains the preferred agent in dentistry today.

In hospitals, however, nitrous oxide was found not to be a strong enough for use in large operations. A stronger and more potent anesthetic, sulfuric ether, was instead demonstrated and accepted for use in October 1846, along with chloroform in 1847. When Joseph Thomas Clover invented the “gas-ether inhaler” in 1876, it became a common practice at hospitals to initiate all anesthetic treatments.
with a mild flow of nitrous oxide, and then gradually increase the anesthesia with the stronger ether/chloroform. Clover’s gas-ether inhaler was designed to supply the patient with nitrous oxide and ether at the same time, with the exact mixture controlled by the operator of the device. It remained in use by many hospitals until the 1930s. Although hospitals today are using a more advanced anesthetic machine, these machines still use the same principle launched with Clover’s gas-ether inhaler, to initiate the anesthesia with nitrous oxide before the administration of a more powerful anesthetic.

Production
Nitrous oxide is most commonly prepared by careful heating of ammonium nitrate, which decomposes into nitrous oxide and water vapor. The addition of various phosphates favors formation of a purer gas at slightly lower temperatures. One of the earliest commercial producers was George Poe in Trenton, New Jersey.

- \( \text{NH}_4\text{NO}_3(s) \rightarrow 2 \text{H}_2\text{O}(g) + \text{N}_2\text{O}(g) \)
  - This reaction occurs between 170-240 degrees C, temperatures where ammonium nitrate is a moderately sensitive explosive and a very powerful oxidizer. Above 240 degrees C, the exothermic reaction may accelerate to the point of detonation, so the mixture must be cooled to avoid such a disaster. Superheated steam is used to reach reaction temperature in some turnkey production plants.

Downstream, the hot, corrosive mixture of gases must be cooled to condense the steam, and filtered to remove higher oxides of nitrogen. Ammonium nitrate smoke, as an extremely persistent colloid, will also have to be removed. The cleanup is often done in a train of gas washes, base, acid, base again. However, significant amounts of nitric oxide (NO) may not necessarily be absorbed directly by the base (sodium hydroxide) washes.

The nitric oxide impurity is sometimes chelated out with ferrous sulfate, reduced with iron metal or oxidized and absorbed in base as a higher oxide. The first base wash may (or may not) react out much of the ammonium nitrate smoke. However, this reaction generates ammonia gas, which may have to be absorbed in the acid wash.

Other routes
The direct oxidation of ammonia may someday rival the ammonium nitrate pyrolysis synthesis of nitrous oxide mentioned above. This capital-intensive process, which originates in Japan, uses a manganese dioxide-bismuth oxide catalyst:

- \( 2 \text{NH}_3 + 2 \text{O}_2 \rightarrow \text{N}_2\text{O} + 3 \text{H}_2\text{O} \)
  - Higher oxides of nitrogen are formed as impurities. In comparison, uncatalyzed ammonia oxidation (i.e. combustion or explosion) goes primarily to \( \text{N}_2 \) and \( \text{H}_2\text{O} \).

Nitrous oxide can be made by heating a solution of sulfamic acid and nitric acid. Many gases are made this way in Bulgaria.

- \( \text{HNO}_3 + \text{NH}_2\text{SO}_3\text{H} \rightarrow \text{N}_2\text{O} + \text{H}_2\text{SO}_4 + \text{H}_2\text{O} \)
  - There is no explosive hazard in this reaction if the mixing rate is controlled. However, as usual, toxic higher oxides of nitrogen are formed.

Nitrous oxide is produced in large volumes as a byproduct in the synthesis of adipic acid, one of the two reactants used in nylon manufacture. This might become a major commercial source, but will require the removal of higher oxides of nitrogen and organic impurities. Currently, much of the gas is decomposed before release for environmental protection. Greener processes may prevail that substitute hydrogen peroxide for nitric acid oxidation; hence no generation of oxide of nitrogen by-products.

Hydroxylammonium chloride can react with sodium nitrite to produce \( \text{N}_2\text{O} \) as well:

- \( \text{NH}_3\text{OH}^+ + \text{NaNO}_2 \rightarrow \text{N}_2\text{O} + \text{NaCl} + 2 \text{H}_2\text{O} \)
  - If the nitrite is added to the hydroxylamine solution, the only remaining byproduct is salt water. However, if the hydroxylamine solution is added to the nitrite solution (nitrite is in excess), then toxic higher oxides of nitrogen are also formed.

Applications
Rocket motors
Nitrous oxide can be used as an oxidizer in a rocket motor. This has the advantages over other oxidizers that it is non-toxic, and because of its stability at room temperature, easy to store and relatively safe to carry on a flight. As a secondary benefit, it can be readily decomposed to form breathing air. Its high density and low storage pressure enable it to be highly competitive with stored high-pressure gas systems.

In a 1914 patent, American rocket pioneer Robert Goddard suggested nitrous oxide and gasoline as possible propellants for a liquid-fueled rocket. Nitrous oxide has been the oxidizer of choice in several hybrid rocket designs (using solid fuel with a liquid or gaseous oxidizer). The combination of nitrous oxide with hydroxylterminated polybutadiene fuel has been used by SpaceShipOne and others. It is also notably used in amateur and high power rocketry with various plastics as the fuel.

Nitrous oxide can also be used in a monopropellant rocket. In the presence of a heated catalyst, \( \text{N}_2\text{O} \) will decompose exothermically into nitrogen and oxygen, at a temperature of approximately 1,300 degrees C. Because of the large heat release, the catalytic action rapidly becomes secondary as thermal autodecomposition becomes dominant. In a vacuum thruster, this can provide a monopropellant specific impulse (\( \text{I}_\text{s} \)) of as much as 180s. While noticeably less than the \( \text{I}_\text{s} \) available from hydrazine thrusters (monopropellant or bipropellant with nitrogen tetroxide), the decreased toxicity makes nitrous oxide an option worth investigating.

Specific impulse (\( \text{I}_\text{s} \)) can be improved by blending a hydrocarbon fuel with the nitrous oxide inside the same storage tank, becoming a nitrous oxide fuel blend (NOFB) monopropellant. This storage mixture does not incur the danger of spontaneous ignition because \( \text{N}_2\text{O} \) is chemically stable. When the nitrous oxide decomposes by a heated catalyst, high-temperature oxygen is released and rapidly ignites the hydrocarbon fuel blend. NOFB monopropellants are capable of \( \text{I}_\text{s} \) greater than 300 seconds, while avoiding the toxicity associated with hypergolic propulsion systems. The low freezing point of NOFB eases thermal management compared to hydrazine and dinitrogen tetroxide – a valuable property for space storable propellants.

Internal combustion engine
In vehicle racing, nitrous oxide (often referred to as just “nitrous” or as NOS after the name of the brand Nitrous Oxide Systems) allows the engine to burn more fuel and air, resulting in a more powerful combustion. The gas itself is not flammable, but it delivers more oxygen than atmospheric air by breaking down at elevated temperatures.

Nitrous oxide is stored as a compressed liquid; the evaporation and expansion of liquid nitrous oxide in the intake manifold causes a large drop in intake charge temperature, resulting in a denser charge, further allowing more air/fuel mixture to enter the cylinder. Nitrous oxide is sometimes injected into (or prior to) the intake manifold,
whereas other systems directly inject right before the cylinder (direct port injection) to increase power.

The technique was used during World War II by Luftwaffe aircraft with the GM-1 system to boost the power output of aircraft engines. Originally meant to provide the Luftwaffe standard aircraft with superior high-altitude performance, technological considerations limited its use to extremely high altitudes. Accordingly, it was only used by specialized planes like high-altitude reconnaissance aircraft, high-speed bombers and high-altitude interceptor aircraft.

One of the major problems of using nitrous oxide in a reciprocating engine is that it can produce enough power to damage or destroy the engine. Very large power increases are possible, and if the mechanical structure of the engine is not properly reinforced, the engine may be severely damaged or destroyed during this kind of operation. It is very important with nitrous oxide augmentation of internal combustion engines to maintain proper operating temperatures and fuel levels to prevent “pre-ignition” or “detonation” (sometimes referred to as “knocking” or “pinging”). Most problems that are associated with nitrous do not come from mechanical failure due to the power increases. Since nitrous allows a much denser charge into the cylinder, it dramatically increases cylinder pressures. The increased pressure and temperature can cause problems, such as melting the piston or valves. It may also crack or warp the piston or head and cause pre-ignition due to uneven heating.

**Aerosol propellant**

The gas is approved for use as a food additive (also known as E942), specifically as an aerosol spray propellant. Its most common uses in this context are in aerosol whipped cream canisters, cooking sprays and as an inert gas used to displace oxygen and inhibit bacterial growth when filling packages of potato chips and other similar snack foods.

The gas is extremely soluble in fatty compounds. In aerosol whipped cream, it is dissolved in the fatty cream until it leaves the can, when it becomes gaseous and thus creates foam. Used in this way, it produces whipped cream four times the volume of the liquid, whereas whipping air into cream only produces twice the volume. If air were used as a propellant, oxygen would accelerate rancidification of the butterfat; nitrous oxide inhibits such degradation. Carbon dioxide cannot be used for whipped cream because it is acidic in water, which would curdle the cream and give it a seltzer-like “sparkling” sensation.

However, the whipped cream produced with nitrous oxide is unstable and will return to a liquid state within half an hour to one hour. Thus, the method is not suitable for decorating food that will not be immediately served.

Similarly, cooking spray, which is made from various types of oils combined with lecithin (an emulsifier), may use nitrous oxide as a propellant; other propellants used in cooking spray include food-grade alcohol and propane.

Users of nitrous oxide often obtain it from whipped cream dispensers that use nitrous oxide as a propellant for recreational use as a euphoria-inducing inhalant drug. It is not harmful in small doses, but risks due to lack of oxygen do exist (see Recreational use below).

**Recreational use**

Nitrous oxide (N₂O) is a dissociative drug that can cause analgesia, depersonalization, dizziness, euphoria and some sound distortion. Research has also found that it increases suggestibility and imagination. Inhalation of nitrous oxide for recreational use to cause euphoria and slight hallucinations began as a phenomenon for the British upper class in 1799 at “laughing gas parties.” When equipment became more widely available for dentistry and hospitals, most countries also restricted the legal access to buy pure nitrous oxide gas cylinders to those sectors. A low availability of equipment to produce the gas combined with a low usage of the gas for medical purposes meant recreational use was a relatively rare phenomenon that mainly took place among students at medical universities. That apparently continued into the 20th century. A poll taken in 1979 indicated that between 1 and 2 percent of medical and dental students used nitrous oxide for recreational purposes, according to Theodore J. Jastak in a 1991 article in the Journal of the American Dental Association.

In the 1960 and ’70s, the recreational use of inhalants became somewhat fashionable again, according to a Consumers Union report in 1972 based on reports of use in Maryland and Vancouver and a survey at the University of Michigan in 1970.

According to the Michigan survey: “It was not uncommon [in the interviews] to hear from individuals who had been to parties where a professional (doctor, nurse, scientist, inhalation therapist, researcher) had provided nitrous oxide. There also were those who work in restaurants who used the N₂O stored in tanks for the preparation of whip cream. Reports were received from individuals who used the gas contained in aerosol cans both of food and non-food products. At a … rock festival, nitrous oxide was widely sold for 25 cents a balloon. Contact was made with a ‘mystical-religious’ group that used the gas to accelerate arriving at their transcendental-meditative state of choice. Although a few more sophisticated users employed nitrous oxide-oxygen mixes with elaborate equipment, most users employed balloons or plastic bags. They either held a breath of N₂O or rebreathed the gas. There were no adverse effects reported in the more than 100 individuals surveyed.”

Although recreational use is believed to be somewhat limited today, government data on substance abuse of youths shows that inhalants, including nitrous oxide, are being used by young people.

The Substance Abuse and Mental Health Services Administration (SAMHSA) said in its 2007 report on trends in drug use that almost 1 million youth had used inhalants within the past year. The percentage of young people aged 12-17 who had used all inhalants within the past year was lower in 2007 (3.9 percent) than in 2003 (4.5 percent), in 2004 (4.6 percent), and in 2005 (4.5 percent). Among first-time users, the rate of use of nitrous oxide, or “whippets” – usually canisters of the propellants to create whipped cream – declined between 2002 and 2007 among males (40.3 percent to 20.2 percent) and females (22.3 percent to 21.2 percent).

However, an investigation in 2009 by the Bristol (Va.) Herald Courier reported that the records of 46 health care professionals in the area – including doctors, nurses, pharmacists and dentists – were “marred by substance abuse, and in some cases, criminal convictions.”

The Herald Courier told the story of a Big Stone Gap, Va., dentist who “huffed nitrous oxide in the mid-1970s and quit only after a temporary loss of feeling in his hands.” From there, the dentist descended into alcoholism and took Valium and Hydrocodone from his office, the newspaper said.

A grassroots drug-recovery group of Virginia dentists directed the man to a rehab program. The state board of dentistry got an anonymous call about his situation. Instead of disciplinary action, the board helped monitor his recovery. According to the newspaper, keeping addictions confidential is at the discretion of either a
Department of Health Professions investigator or a licensing board. A board of medicine official said the policy protected the public by “making sure the individual is identified and investigated, set for an evaluation and treatment, and continue with monitoring. They (the Virginia monitoring program) will not OK a doctor to go back into practice until he or she is believed to be safe.”

That is a common practice. The Federation of State Physician Health Programs Inc. (FSPHP) evolved in 1990 from an initiative of the American Medical Association and individual state physician health programs that focus upon rehabilitation and monitoring of physicians with psychoactive substance abuse disorders as well as mental and physical illness. The nonprofit organization includes members from 42 state programs.

FSPHP serves as a resource for state programs; helps to establish monitoring standards; serves as an informational source; advocates for physicians and their health issues at local state and national levels; and helps states in their quest to protect the public. The organization promotes confidentiality for health care professionals who chose to address their substance problems and submit to rigorous monitoring of their progress.

A 2003 report in the Journal of the California Dental Association [Malamed and Clark] cited concerns about abuse of nitrous oxide by health care professionals. The authors said nitrous oxide causes euphoria and can include “sexual phenomena,” including increased feelings of sexuality and arousal, and therefore has the potential for abuse. “This abuse is usually not as addictive as some drugs, but nonetheless can be a steppingstone to other drugs and can cause incapacitation of the affected person. Nitrous oxide should be given the same respect as all drugs.”

The typical abuser of nitrous oxide is older and middle- or upper class, they said. If the abuser has an inhalation sedation unit available, it may have been altered to deliver a higher concentrate of gas, they said.

The authors noted there have been reports of sexual abuse of patients under anesthetics, including nitrous oxide. They noted there are three elements that put a practitioner at risk: treating a patient without an assistant in the operatory, high concentrations of nitrous oxide, and failure to titrate the patient to avoid extension of therapeutic sedation.

“Nitrous oxide should be employed with confidence. Employing simple guidelines will ensure there are no difficulties with sexual issues and the administrator of nitrous oxide,” they said.

In medicine
Nitrous oxide has been used for anesthesia in dentistry since December 1844, when Horace Wells made the first dental operations with the gas in Hartford. Its debut as a generally accepted method came in 1863, when Gardner Quincy Colton introduced it more broadly at all the Colton Dental Association clinics. The first devices used in dentistry to administer the gas, known as nitrous oxide inhalers, were designed in a very simple way, with the gas stored and breathed through a breathing bag made of rubber cloth, without a scavenger system and flow meter, and with no addition of oxygen/air.

Today these simple and somewhat unreliable inhalers, of course, have been replaced by the more modern relative analgesia machine, which is an automated machine designed to deliver a precisely dosed and breath-actuated flow of nitrous oxide mixed with oxygen for the patient to inhale safely. The machine used in dentistry is designed as a more simplified version of the larger anesthetic machine used by hospitals, and it doesn’t feature the additional anesthetic vaporizer and medical ventilator. The machine allows for a more simple design, because it only delivers a mixture of nitrous oxide and oxygen for the patient to inhale to depress the feeling of pain while keeping the patient in a conscious state.

The relative analgesia machine typically features a constant-supply flow meter, which allows the proportion of nitrous oxide and the combined gas flow rate to be individually adjusted. The gas is administered by dentists through a demand-valve inhaler over the nose, which will only release gas when the patient inhales through the nose. Because nitrous oxide is minimally metabolized in humans (with a rate of 0.004 percent), it retains its potency when exhaled into the room by the patient and can pose an intoxicating and prolonged exposure hazard to the clinic staff if the room is poorly ventilated. Where nitrous oxide is administered, a continuous-flow fresh-air ventilation system or nitrous scavenger system is used to prevent a waste-gas buildup.

Hospitals are administering nitrous oxide as one of the anesthetic drugs delivered by anesthetic machines. Nitrous oxide is a weak general anesthetic, and so is generally not used alone in general anesthesia. In general, anesthesia it is used as a carrier gas in a 2:1 ratio with oxygen for more powerful general anesthetic drugs such as sevoflurane or desflurane. It has a MAC (minimum alveolar concentration) of 105 percent and a blood gas partition coefficient of 0.46.

When nitrous oxide is inhaled as the only anesthetic drug, it is normally administered as a mixture with 30 percent gas and 70 percent oxygen.

Neuropharmacology
The pharmacological mechanism of action of N₂O in medicine is not fully known. However, it has been shown to directly modulate a broad range of ligand-gated ion channels, and this likely plays a major role in many of its effects. It moderately blocks NMDA and β₂-subunit-containing nACh channels; weakly inhibits AMPA, kainate, GABAβ, and 5-HT₃ receptors; and slightly potentiates GABAα and glycine receptors. It has also been shown to activate two-pore-domain K⁺ channels. While N₂O affects quite a few ion channels, its anesthetic, hallucinogenic and euphoriant effects are likely caused predominantly or fully via inhibition of NMDAR-mediated currents. In addition to its effects on ion channels, N₂O may act to imitate nitric oxide (NO) in the central nervous system as well, and this may relate to its analgesic and anxiolytic properties.

Anxiolytic effect
In behavioral tests of anxiety, a low dose of N₂O is an effective anxiolytic, and this anti-anxiety effect is associated with enhanced activity of GABAα receptors as it is partially reversed by benzodiazepine receptor antagonists. Mirroring this, animals that have developed tolerance to the anxiolytic effects of benzodiazepines are partially tolerant to N₂O. Indeed, in humans given 30 percent N₂O, benzodiazepine receptor antagonists reduced the subjective reports of feeling “high,” but did not alter psychomotor performance in human clinical studies.

Analgesic and anti-nociceptive effect
The analgesic effects of N₂O are linked to the interaction between the endogenous opioid system and the descending noradrenergic system. When animals are given morphine chronically, they develop tolerance to its pain-killing effects, and this also renders the animals tolerant to the analgesic effects of N₂O. Administration of antibodies that bind and block the activity of some endogenous opioids (not β-endorphin) also block the anti-nociceptive effects of N₂O. Drugs
that inhibit the breakdown of endogenous opioids also potentiate the anti-nociceptive effects of N\textsubscript{2}O. Several experiments have shown that opioid receptor antagonists applied directly to the brain block the anti-nociceptive effects of N\textsubscript{2}O, but these drugs have no effect when injected into the spinal cord.

Conversely, \(\alpha\)-adrenoceptor antagonists block the anti-nociceptive effects of N\textsubscript{2}O when given directly to the spinal cord, but not when applied directly to the brain. Indeed, \(\alpha\)-adrenoceptor knockout mice or animals depleted in norepinephrine are nearly completely resistant to the anti-nociceptive effects of N\textsubscript{2}O. It seems N\textsubscript{2}O-induced release of endogenous opioids causes disinhibition of brain stem noradrenergic neurons, which release norepinephrine into the spinal cord and inhibit pain signaling. Exactly how N\textsubscript{2}O causes the release of endogenous opioid peptides is still uncertain.

**Euphoric effect**

In rats, N\textsubscript{2}O stimulates the mesolimbic reward pathway via inducing dopamine release and activating dopaminergic neurons in the ventral tegmental area and nucleus accumbens, presumably through antagonization of NMDA receptors localized in the system. This action has been implicated in its euphoric effects, and notably, appears to augment its analgesic properties as well.

However, it is remarkable that in mice, N\textsubscript{2}O blocks amphetamine-induced and dopamine release in the nucleus accumbens and behavioral sensitization, abolishes the conditioned place preference (CPP) of cocaine and morphine, and does not produce reinforcing (or aversive) effects of its own. Studies on CPP of N\textsubscript{2}O in rats is mixed, consisting of reinforcement, aversion and no change. In contrast, it is a positive reinforcer in squirrel monkeys, and is well known as a drug of abuse in humans. These discrepancies in response to N\textsubscript{2}O may reflect specie variations or methodological differences.

It is noteworthy that in human clinical studies, N\textsubscript{2}O was found to produce mixed responses similarly to rats, reflecting high subjective individual variability.

**Neurotoxicity**

Similarly to other NMDA antagonists like ketamine, N\textsubscript{2}O has been demonstrated to produce neurotoxicity in the form of Olney’s lesions (damage to the posterior cingulate and retrosplenial cortices) in rodents upon prolonged (e.g., several hours) exposure. However, it also simultaneously exerts widespread neuroprotective effects via inhibiting glutamate-induced and it has been argued that on account of its very short duration under normal circumstances, N\textsubscript{2}O may not share the neurotoxicity of other NMDA antagonists. Indeed, in rodents, short-term exposure results in only mild injury that is rapidly reversible, and permanent neuronal death only occurs after constant and sustained exposure.

**Safety**

The major safety hazards of nitrous oxide come from the fact that it is a compressed liquefied gas, an asphyxiation risk and a dissociative anesthetic. Exposure to nitrous oxide causes short-term decreases in mental performance, audiovisual ability and manual dexterity. Long-term exposure can cause vitamin B\textsubscript{12} deficiency, numbness, reproductive side effects and other problems.

The National Institute for Occupational Safety and Health recommends that workers’ exposure to nitrous oxide should be controlled during the administration of anesthetic gas in medical, dental and veterinary operators.

**Chemical/physical**

At room temperature (20 degrees C), the saturated vapor pressure is 58.5 bar, rising up to 72.45 bar at 36.4 degrees C – the critical temperature. The pressure curve is thus unusually sensitive to temperature. Liquid nitrous oxide acts as a good solvent for many organic compounds; liquid mixtures may form shock-sensitive explosives.

As with many strong oxidizers, contamination of parts with fuels have been implicated in rocketry accidents, where small quantities of nitrous/fuel mixtures explode due to “water hammer-like” effects (sometimes called “dieseling” – heating caused by adiabatic compression of gases that can reach decomposition temperatures). Some common building materials, such as stainless steel and aluminum, can act as fuels with strong oxidizers such as nitrous oxide, as can contaminants, which can ignite due to adiabatic compression.

There have also been accidents where nitrous oxide decomposition in plumbing has led to the explosion of large tanks.

**Biological**

Nitrous oxide inactivates the cobalamin form of vitamin B\textsubscript{12} by oxidation. Symptoms of vitamin B\textsubscript{12} deficiency, including sensory neuropathy and encephalopathy, can occur within days or weeks of exposure to nitrous oxide anesthesia in people with subclinical vitamin B\textsubscript{12} deficiency. Symptoms are treated with high doses of vitamin B\textsubscript{12}, but recovery can be slow and incomplete. People with normal vitamin B\textsubscript{12} levels have stores to make the effects of nitrous oxide insignificant, unless exposure is repeated and prolonged (nitrous oxide abuse). Vitamin B\textsubscript{12} levels should be checked in people with risk factors for vitamin B\textsubscript{12} deficiency prior to using nitrous oxide anesthesia.

A study of workers and several experimental animal studies indicate that adverse reproductive effects for pregnant females may also result from chronic exposure to nitrous oxide.

**Flammability**

Nitrous oxide is a non-flammable gas at room temperature. The National Fire Protection Association has not assigned a flammability rating to nitrous oxide:

- Flash point: Not applicable.
- Autoignition temperature: Not applicable.
- Flammable limits in air: Not applicable.
- Extinguishing: For small fires, use dry chemical or carbon dioxide. Use water spray, fog or standard foam to fight large fires involving nitrous oxide.

Fires involving nitrous oxide should be fought upwind from the maximum distance possible. Keep unnecessary people away; isolate the hazard area and deny entry. Isolate the area for ½-mile in all directions if a tank, rail car or tank truck is involved in the fire. For a massive fire in a cargo area, use unmanned hose holders or monitor nozzles; if this is impossible, withdraw from the area and let the fire burn. Emergency personnel should stay out of low areas and ventilate closed spaces before entering. Vapors are an explosion hazard indoors, outdoors or in sewers. Containers of nitrous oxide 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 fire-exposed containers from the sides with water until well after the fire is out. Stay away from the ends of containers. Firefighters should wear a full set of protective clothing and self-contained breathing apparatus when fighting fires involving nitrous oxide.
Environmental

Nitrous oxide is a greenhouse gas, accounting for about 6 percent of the heating effect of greenhouse gases in the atmosphere. According to 2006 data from the United States Environmental Protection Agency, industrial sources make up only about 20 percent of all anthropogenic sources, and include the production of nylon and the burning of fossil fuel in internal combustion engines. Human activity is thought to account for 30 percent; tropical soils and oceanic release account for 70 percent. However, a 2008 study by Nobel Laureate Paul Crutzen suggests that the amount of nitrous oxide release attributable to agricultural nitrate fertilizers has been seriously underestimated, most of which would presumably come under soil and oceanic release in the Environmental Protection Agency data. Nitrous oxide also causes ozone depletion. A recent study suggests that N$_2$O emission currently is the single most important ozone-depleting substance (ODS) emission and is expected to remain the largest throughout the 21st century.

Legality

In the United States, possession of nitrous oxide is legal under federal law and is not subject to DEA purview. It is, however, regulated by the Food and Drug Administration under the Food Drug and Cosmetics Act; prosecution is possible under its “misbranding” clauses, prohibiting the sale or distribution of nitrous oxide for the purpose of human consumption.

Many states have laws regulating the possession, sale and distribution of nitrous oxide. Such laws usually ban distribution to minors or limit the amount of nitrous oxide that may be sold without special license.

In the state of California, possession for recreational use is prohibited and qualifies as a misdemeanor.

In some countries, it is illegal to have nitrous oxide systems plumbed into an engine’s intake manifold. These laws are ostensibly used to prevent street racing and to meet emission standards. Nitrous oxide is entirely legal to possess and inhale in the United Kingdom, although supplying it to others to inhale, especially minors, is more likely to end up with a prosecution under the Medicines Act.

In New Zealand, the Ministry of Health has warned that nitrous oxide is a prescription medicine, and its sale or possession without a prescription is an offense under the Medicines Act. This statement would seemingly prohibit all non-medical uses of the chemical, though it is implied that only recreational use will be legally targeted.

In India, for general anesthesia purposes, nitrous oxide is available as nitrous oxide IP. India’s gas cylinder rules (1985) permit the transfer of gas from one cylinder to another for breathing purposes. This law benefits remote hospitals, which would otherwise suffer because of India’s geographic immensity. Nitrous oxide IP is transferred from bulk cylinders (17,000 liters capacity gas) to smaller pin-indexed valve cylinders (1,800 liters of gas), which are then connected to the yoke assembly of Boyle’s machines. Because India’s Food and Drug Authority (FDA-India) rules state that transferring a drug from one container to another (refilling) is equivalent to manufacturing, anyone found doing so must possess a drug-manufacturing license.

Nitrous oxide in dental operatories

The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering studies the aspects of health hazard prevention and control in the workplace. Nitrous oxide (N$_2$O) mixed with oxygen has been used in dentistry as an analgesic and as a sedative for more than 100 years. Today, more than 424,000 workers who practice dentistry (such as dentists, dental assistants and dental hygienists) in the United States are potentially exposed to N$_2$O.

In a technical report published in 1977, the National Institute for Occupational Safety and Health recommended controlling exposure limits of nitrous oxide waste to 25 parts per million parts (ppm) of air during dental surgery. The report presented methods for limiting the waste during administration, based on the technical feasibility of existing controls. Since publication of this technical report, data collected by NIOSH have shown occupational exposures as high as 300 ppm in hospital operating rooms and exposures higher than 1,000 ppm in dental operatories equipped with scavenging systems (properly operating scavenging systems have been shown to reduce N$_2$O concentrations by more than 70 percent). The scavenging systems use local exhaust ventilation to collect waste gases from anesthetic breathing systems and remove them from the workplace.

Effects of exposure to high concentrations

Animal studies have shown adverse reproductive effects in female rats exposed to airborne concentrations of N$_2$O. Data from these studies indicate that exposure to N$_2$O during gestation can produce adverse health effects in the offspring.

Several studies of workers have shown that occupational exposure to N$_2$O causes adverse effects such as reduced fertility, spontaneous abortions and neurologic, renal and liver disease. A recent study reported that female dental assistants exposed to unscaened N$_2$O for five or more hours per week had a significant risk of reduced fertility compared with unexposed female dental assistants. The exposed assistants had a 59 percent decrease in probability of conception for any given menstrual cycle compared with the unexposed assistants. For dental assistants who used scavenging systems during N$_2$O administration, the probability of conception was not significantly different from that of the unexposed assistants. Because environmental exposures were not measured during these epidemiologic studies, no dose-effect relationship could be established.

Exposure to high concentrations of waste anesthetic gases – even for a short time – may cause the following health effects:
- Headache.
- Irritability.
- Fatigue.
- Nausea.
- Drowsiness.
- Difficulties with judgment and coordination.
- Liver and kidney disease.

Workers exposed

In 1983, the American Dental Association (ADA) reported that 35 percent of all dentists used N$_2$O to control pain and anxiety in their patients [ADA 1983]. The ADA 1991 Survey of Dental Practice indicated that 58 percent of dentists reported having N$_2$O anesthetic equipment, and 64 percent of those practitioners also reported having a scavenging system. The percentage of pediatric dentists using N$_2$O increased from 65 percent in 1980 to 88 percent in 1988.

Occupational exposure limits

The Occupational Safety and Health Administration (OSHA) does not currently have a standard for N$_2$O.

The NIOSH recommended exposure limit (REL) for N$_2$O is 25 ppm as a time-weighted average (TWA) during the period of anesthetic administration [NIOSH 1977b]. This REL is intended to prevent decreases in mental performance, audiovisual ability and manual dexterity during exposures to N$_2$O. A recommended exposure limit
to prevent adverse reproductive effects cannot be established until more data are available.

The American Conference of Governmental Industrial Hygienists’ (ACGIH) threshold limit value (TLV) for N₂O is 50 ppm as an eight-hour time-weighted average [ACGIH 1993]. The 1991 Documentation of the Threshold Limit Values and Biological Exposure Indices states that “control to this level should prevent embryo-fetal toxicity in humans and significant decrements in human psychomotor and cognitive functions or other adverse health effects in exposed personnel” [ACGIH 1991].

Medical surveillance
OSHA is currently developing requirements for medical surveillance. When these requirements are promulgated, readers should refer to them for additional information and to determine whether employers whose employees are exposed to nitrous oxide are required to implement medical surveillance procedures.

Medical screening:
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, 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 surveillance program is intended to supplement, not replace, such measures. To detect and control work-related health effects, medical evaluations should 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 nitrous oxide, 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 respiratory, reproductive, central nervous and hematological systems. Medical surveillance for respiratory disease should be conducted using the principles and methods recommended by the American Thoracic Society. A preplacement medical evaluation is recommended to assess medical conditions that may be aggravated or may result in increased risk when a worker is exposed to nitrous oxide at or below the prescribed exposure limit. The 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 diseases of the respiratory, reproductive, central nervous or hematological systems.

Periodic medical evaluations
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 three to five years or as frequently as recommended by an experienced occupational health physician. Additional examinations may be necessary if a worker develops symptoms attributable to nitrous oxide exposure. The interviews, examinations and medical screening tests should focus on identifying the adverse effects of nitrous oxide on the respiratory, reproductive, central nervous or hematological systems. Current health status should be compared with the baseline health status of the individual worker or with expected values for a suitable reference population.

Termination medical evaluations
The medical, environmental and occupational history interviews; the physical examination; and selected physiologic or laboratory tests that were conducted at the time of placement should be repeated at the time of job transfer or termination to determine the worker’s medical status at the end of his or her employment. Any changes in the worker’s health status should be compared with those expected for a suitable reference population.

Biological monitoring
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 nitrous oxide.

Workplace monitoring and measurement
Determination of a worker’s exposure to airborne nitrous oxide can be made using one of the following techniques:

- A Landauer Passive Dosimeter badge, which can be used for a minimum sampling duration of one hour (maximum duration 40 hours). Analysis is performed by the manufacturer of the badge as described in the OSHA Computerized Information System.
- An ambient air or bag sample with a minimum collection volume of two spectrophotometer cell volumes. Analysis is conducted using a long-path-length portable infrared spectrophotometer as described in NIOSH Method No. 6600.

Personal hygiene procedures
If liquid nitrous oxide contacts the skin, workers should flush the affected areas immediately with tepid water to reduce the likelihood of frostbite. A large population of health care workers is potentially exposed to N₂O, and NIOSH has documented cases in which exposures substantially exceed existing recommended exposure limits. NIOSH has concluded that exposure to N₂O causes decreases in mental performance, audiovisual ability and manual dexterity. Data from animal studies demonstrate that exposure to N₂O may cause adverse reproductive effects. Studies of workers exposed to N₂O have reported adverse health effects such as reduced fertility, spontaneous abortion, and neurological, renal, and liver disease. The recommendations in a 1994 NIOSH alert should therefore be followed to minimize worker exposures.

Recommendations
Engineering controls, work practices and respirators (when necessary) should be used to minimize the exposure of workers to N₂O. Employers should ensure that their workers are adequately protected from N₂O exposure by taking the following steps:

- Monitor airborne concentrations of N₂O.
- Implement appropriate engineering controls, work practices and maintenance procedures.
- Institute a worker education program that:
  - Describes standard operating procedures for all tasks that may expose workers to N₂O.
  - Informs workers about proper work practices, controls, equipment and protective gear that should be used when working with N₂O.
Use the guidelines in the following section to minimize worker exposures to N\textsubscript{2}O.

Guidelines for minimizing worker exposures

Exposure monitoring

Exposure monitoring should be the first step in developing work practices and worker education programs, because measurements of N\textsubscript{2}O are needed to determine the type and extent of controls that are necessary. Follow the guidelines below to minimize worker exposures:
- Monitor for N\textsubscript{2}O when the anesthetic equipment is installed and every three months thereafter. Include the following types of monitoring:
  - Leak testing of equipment.
  - Monitoring of air in the worker’s personal breathing zone.
  - Environmental (room air) monitoring.
- Prepare a written monitoring and maintenance plan for each facility that uses N\textsubscript{2}O. This plan should be developed by knowledgeable persons who consider the equipment manufacturers’ recommendations, frequency of use and other circumstances that might affect the equipment.
- Perform air monitoring by gasbag sampling or real-time sampling.
- When real-time sampling is conducted to obtain personal exposure data, attach the sampling train to the lapel of the worker on the side closest to the patient; N\textsubscript{2}O concentrations in this location are most representative of those in the worker’s breathing zone. Diffusive samplers (referred to as passive dosimeters) are commercially available and may be useful as initial indicators of exposures.

Engineering controls and maintenance procedures

The following engineering controls and maintenance procedures have been shown to be feasible and effective in reducing exposure to N\textsubscript{2}O during anesthetic administration.

Anesthetic delivery. Excessive exposure to N\textsubscript{2}O may occur as a result of leaks from the anesthetic delivery system during administration. The rubber and plastic components of the anesthetic equipment are potential sources of N\textsubscript{2}O leakage because they may be degraded by the N\textsubscript{2}O and the oxygen as well as by repeated sterilization.

Take the following steps to control N\textsubscript{2}O exposure from anesthetic delivery systems:
- Use connection ports with different-diameter hoses for N\textsubscript{2}O and O\textsubscript{2} to reduce the possibility of incorrectly connecting the gas delivery and scavenging hoses.
- Check all rubber hoses, connections, tubing and breathing bags daily and replace them when damaged or when recommended by the manufacturer.
- Following visual inspection, perform leak testing of the equipment and connections by using a soap solution to check for bubbles at high-pressure connections. For a more thorough inspection of all connectors, use a portable infrared spectrophotometer (such as a Miran 1A or 1B) calibrated for N\textsubscript{2}O detection.
- Check both high- and low-pressure connections (such as O-rings) regularly, as they may become worn; replace them periodically, according to the manufacturer’s recommendations.
- Evaluate the N\textsubscript{2}O and oxygen mixing system for leaks when it is first installed and periodically thereafter, according to the manufacturer’s recommendations.
- Ensure that gas cylinders are safely handled, used and stored as specified by the National Research Council and as required by OSHA Federal Code Rule Title 29, 1910.101.
- Sec. 1910.101 Compressed gases (general requirements).
- (a) Inspection of compressed gas cylinders. Each employer shall determine that compressed gas cylinders under his control are in a safe condition to the extent that this can be determined by visual inspection. Visual and other inspections shall be conducted as prescribed in the Hazardous Materials Regulations of the Department of Transportation (49 CFR parts 171-179 and 14 CFR part 103). Where those regulations are not applicable, visual and other inspections shall be conducted in accordance with Compressed Gas Association Pamphlets C-6-1968 and C-8-1962, which is incorporated by reference as specified in Sec. 1910.6.

Scavenging systems. Control of N\textsubscript{2}O at the scavenging mask is the next priority after control of N\textsubscript{2}O leakage from the anesthetic equipment. Leakage from the scavenging mask can be one of the most significant sources of N\textsubscript{2}O exposure because the breathing zone of a dentist or dental assistant is within inches of the mask. NIOSH research has reported breathing-zone concentrations of N\textsubscript{2}O above 1,000 ppm.

Take the following steps to control N\textsubscript{2}O exposure from anesthetic scavenging systems:
- Supply scavenging masks in a variety of sizes so that the mask always fits comfortably and securely over the patient’s nose or face.
- Use an automatic interlock system to assure that the N\textsubscript{2}O cannot be turned on unless the scavenging system is also activated. N\textsubscript{2}O should never be used without a properly operating scavenging system.
- Make sure that the scavenging system exhaust rates (flow rates) are approximately 45 liters per minute (L/min) to minimize leakage of N\textsubscript{2}O. Flow rates of less than 40 L/min may result in significant leakage around the mask. Monitor the flow rate with a flow meter that is:
  - Validated to measure airflow within 5 percent of actual airflow.
  - Positioned so that it is always visible to the operator.
- Maintain the flow meter by cleaning and recalibrating it according to the manufacturer’s recommendations.
- Use scavenging vacuum pumps that are powerful enough to maintain a scavenging flow rate of at least 45 L/min at each nasal mask, regardless of the number of scavenging units in use at one time.
- Vent N\textsubscript{2}O from all scavenging vacuum pumps to the outside of the building away from fresh air intakes, windows or walkways. Scavenging system exhaust should not be vented into a recirculating ventilation system.

Room ventilation. Take the following steps to assure that the ventilation system effectively removes waste N\textsubscript{2}O:
- If concentrations of N\textsubscript{2}O are above 25 ppm in work areas, increase the airflow into the room or increase the percentage of outside air to allow for more air mixing and further dilution of the anesthetic gas. Maintain a balanced air supply and exhaust system so that N\textsubscript{2}O does not contaminate adjacent areas.
- If concentrations of N\textsubscript{2}O are still above 25 ppm, use supplementary local ventilation in conjunction with a scavenging system to reduce N\textsubscript{2}O exposure in the operatory. The effectiveness of this ventilation depends on its location with respect to the patient and the airflow rates. Do not work between
the patient and the exhaust duct, where contaminated air would be drawn through the worker’s breathing zone.

- Dilute N₂O and remove contaminated air from the work area by placing fresh-air vents in the ceiling; direct the supply of fresh air toward the floor and the operating area. Place exhaust-air vents at or near the floor.

**Work practices**
Use the following work practices to control N₂O exposures:

- Inspect the anesthetic delivery systems and all connections before starting anesthetic gas administration. Make sure that breathing bags, hoses and clamps are in place before turning on the anesthetic machine.
- Connect the scavenging mask properly to the gas delivery hose and the vacuum system.
- Do not turn on the machine delivering N₂O until:
  - The vacuum system scavenging unit is operating at the recommended flow rate of 45 L/min.
  - The scavenging mask is secured over the patient’s nose or face.
- Fasten the mask according to the manufacturer’s instructions to prevent leaks around the mask during gas delivery.
- Do not fill the breathing bag to capacity with N₂O; an overinflated bag can cause excessive leakage from the scavenging mask. The breathing bag should collapse and expand as the patient breathes. This bag activity shows that the proper amounts of N₂O and air are being delivered to the patient.
- Flush the system of N₂O after surgery by administering oxygen to the patient through the anesthetic equipment for at least five minutes before disconnecting the gas delivery system.
- Encourage patients to minimize talking and mouth-breathing during dental surgery. When mouth-breathing is apparent, avoid the patient’s breathing zone to the extent possible.

**Respiratory protection**
Workers should wear respiratory protection when N₂O concentrations are not consistently below 25 ppm; however, practical considerations may prevent them from wearing such protection. Therefore, it is essential that employers use the engineering controls and work practices described in a 1994 NIOSH alert to reduce N₂O exposures:

- Use the following work practices to control N₂O; an overinflated bag can cause excessive leakage from the scavenging mask. The breathing bag should collapse and expand as the patient breathes. This bag activity shows that the proper amounts of N₂O and air are being delivered to the patient.
- When N₂O concentrations are not consistently below 25 ppm, workers should take the following steps to protect themselves:
  - Wear air-supplied respirators. Air-purifying respirators (that is, respirators that remove N₂O from the air rather than supply air from a clean source) should not be used because respirator filters do not efficiently remove N₂O.
  - As specified by the NIOSH respirator standards, the minimum level of protection for an air-supplied respirator is provided by a half-mask respirator operated in the demand or continuous-flow mode. More protective air-supplied respirators are described in the NIOSH respirator decision logic.
  - When respirators are used, the employer must establish a comprehensive respiratory protection program as outlined in the NIOSH Guide to Industrial Respiratory Protection [NIOSH 1987a] and as required by the OSHA respiratory protection standard [29 CFR 1910.134]. Important elements of this standard are:
    - An evaluation of the worker’s ability to perform the work while wearing a respirator.
    - Regular training of personnel.
    - Periodic environmental monitoring.
    - Respirator fit testing.

- Maintenance, inspection, cleaning and storage.
- Selection of proper NIOSH-approved respirators.
- The respiratory protection program should be evaluated regularly by the employer.

**Signs and symptoms of exposure**

- **Acute exposure:** The signs and symptoms of acute exposure to nitrous oxide include dizziness, difficult breathing, headache, nausea, fatigue and irritability. Acute exposure to nitrous oxide concentrations of 400,000 to 800,000 ppm may cause loss of consciousness.
- **Chronic exposure:** The signs or symptoms of chronic overexposure to nitrous oxide may include tingling, numbness, difficulty in concentrating, interference with gait, and reproductive effects.

**Storage**
Nitrous oxide should be stored in a cool, dry, well-ventilated area in tightly sealed containers that are labeled in accordance with OSHA’s Hazard Communication Standard [29 Code of Federal Regulations (CFR)1910.1200]. Containers of nitrous oxide should be protected from physical damage and should be stored separately from cylinders containing oxygen. Nitrous oxide should also be stored separately from aluminum, boron, hydrazine, lithium hydride, phenyllithium, phosphine, sodium, tungsten carbide, hydrogen, hydrogen sulfide, organic peroxides, ammonia and carbon monoxide.

**Spills and leaks**
In the event of a spill or leak involving nitrous oxide (liquid or gas), persons not wearing protective equipment and clothing should be restricted from contaminated areas until cleanup has been completed. The following steps should be undertaken following a spill or leak:

- Do not touch the spilled material; stop the leak if it is possible to do so without risk.
- Use water spray to protect persons attempting to stop the leak.
- Notify safety personnel of large spills or leaks.
- Minimize all sources of ignition because a fire may cause nitrous oxide to accelerate the burning of other combustibles; keep combustible materials (wood, paper, oil, etc.) away from the spilled material.
- Isolate the area until the gas has dispersed.

**Special requirements**
United States 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**
Nitrous oxide is not subject to EPA emergency planning requirements under the Superfund Amendments and Reauthorization Act (SARA) (Title III) in 42 CFR 11022.

**Reportable quantity requirements for hazardous releases**
Employers are not required by the emergency release notification provisions in 40 CFR Part 355.40 to notify the National Response Center of an accidental release of nitrous oxide; there is no reportable quantity for this substance.

**Community right-to-know requirements**
Employers are not required by EPA in 40 CFR Part 372.30 to submit a Toxic Chemical Release Inventory form (Form R) to EPA reporting the amount of nitrous oxide 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. Under the Resource Conservation and Recovery Act (RCRA) [40 USC 6901 et seq.], EPA has specifically listed many chemical wastes as hazardous. Although nitrous oxide is not specifically listed as a hazardous waste under RCRA, 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 (703) 412-9810 (in the Washington, D.C. area) or toll-free at 800-424-9346 (outside Washington, D.C.). In addition, relevant state and local authorities should be contacted for information on any requirements they may have for the waste removal and disposal of this substance.

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 limit. However, some situations may require the use of respirators to control exposure. Respirators must be worn if the ambient concentration of nitrous oxide 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. Workers should only use respirators 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, respirator 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 latest edition of the NIOSH Respirator Decision Logic [NIOSH 1987b] and the NIOSH Guide to Industrial Respiratory Protection [NIOSH 1987a].

Personal protective equipment
Workers should use appropriate personal protective clothing and equipment that must be carefully selected, used and maintained to be effective in preventing skin contact with liquid nitrous oxide. The selection of the appropriate personal protective equipment (PPE) (e.g., gloves, sleeves, encapsulating suits) should be based on the extent of the worker’s potential exposure to liquid nitrous oxide and the PPE material’s ability to protect workers from frostbite. There are no published reports on the resistance of various materials to permeation by liquid nitrous oxide.

To evaluate the use of PPE materials with liquid nitrous oxide, users should consult the best available performance data and manufacturers’ recommendations. Significant differences have been demonstrated in the chemical resistance of generically similar PPE materials (e.g., butyl) produced by different manufacturers. In addition, the chemical resistance of a mixture may be significantly different from that of any of its neat components.

Any chemical-resistant clothing that is used should be periodically evaluated to determine its effectiveness in preventing dermal contact. Safety showers and eye wash stations should be located close to operations that involve nitrous oxide.

Splash-proof chemical safety goggles or face shields (20 to 30 cm long, minimum) should be worn during any operation in which a solvent, caustic or other toxic substance may be splashed into the eyes.

In addition to the possible need for wearing protective outer apparel (e.g., aprons, encapsulating suits), workers should wear work uniforms, coveralls or similar full-body coverings that are laundered each day. Employers should provide lockers or other closed areas to store work and street clothing separately. Employers should collect work clothing at the end of each work shift and provide for its laundering. Laundry personnel should be informed about the potential hazards of handling contaminated clothing and instructed about measures to minimize their health risk.

Protective clothing should be kept free of oil and grease and should be inspected and maintained regularly to preserve its effectiveness.

Protective clothing may interfere with the body’s heat dissipation, especially during hot weather or during work in hot or poorly ventilated work environments.

More on personal protective equipment
◦ Personal protective equipment should not be used as a substitute for engineering, work practice and/or administrative controls in anesthetizing locations and post anesthesia care units (PACUs). In fact, exposure to waste gases is not effectively reduced by gloves, goggles and surgical masks. A negative-pressure, high-efficiency particulate air (HEPA) filter used for infection control is also not appropriate to protect workers from waste gases. Air-supplied respirators with self-contained air source are ideal for eliminating exposure but are not a practical alternative.
◦ During cleanup and containment of spills of liquid anesthetic agents, personal protective equipment should be used in conjunction with engineering, work practice and/or administrative controls to provide for employee safety and health. Gloves, goggles, face shields and chemical protective clothing (CPC) are recommended to ensure worker protection. Respirators, where needed, should be selected based on the anticipated contamination level.
◦ When selecting gloves and CPC, some of the factors to be considered include material chemical resistance, physical strength and durability, and overall product integrity. Permeation, penetration and degradation data should be consulted if available. Among the most effective types of gloves and body protection are those made from Viton®, neoprene and nitrile. Polyvinyl alcohol (PVA) is also effective, but it should not be exposed to water or aqueous solutions.
◦ When the gloves and the CPC being used have not been tested under the expected conditions, they may fail to provide adequate protection. In this situation, the wearer should observe the gloves and the chemical protective clothing during use and treat any noticeable change (e.g., color, stiffness, chemical odor
The basic anesthesia machine

OSHA has no permissible exposure limits regulating these agents. In use include halothane (Fluothane®), nitrous oxide and halogenated agents. Halogenated agents currently used in processing. Professional judgment must be used in determining the type of respiratory protection to be worn. For example, where spills of volatile anesthetic agents are small, exposure time brief and sufficient ventilation present, NIOSH-approved chemical cartridge respirators for organic vapors should provide adequate protection during cleanup activities. Where large spills occur and there is insufficient ventilation to adequately reduce airborne levels of the halogenated agent, respirators designed for increased respiratory protection should be used. The following respirators, to be selected for large spills, are ranked in order from minimum to maximum respiratory protection:

- Any type C supplied-air respirator with a full facepiece, helmet or hood operated in continuous-flow mode.
- Any type C supplied-air respirator with a full facepiece operated in pressure-demand or other positive-pressure mode.
- Any self-contained breathing apparatus with a full facepiece operated in pressure-demand or other positive-pressure mode.

Workplace exposures

Workplace exposures to anesthetic gases occur in hospital-based and stand-alone operating rooms, recovery rooms, dental operatories and veterinary facilities. Engineering, work practice and administrative controls that help reduce these exposures in all anesthetizing locations are identified and discussed. Sources of leaks in anesthesia equipment systems, components, and accessories are identified and appropriate methods are described that limit excessive leaks.

Inhaled anesthetic agents include two different classes of chemicals: nitrous oxide and halogenated agents. Halogenated agents currently in use include halothane (Fluothane®), enflurane (Ethrane®), isoflurane (Forane®), desflurane (Suprane®), and sevoflurane (Ultane®). Methoxyflurane (Penthrane®), once in general use, is now only infrequently used primarily in veterinary procedures. At present, OSHA has no permissible exposure limits regulating these agents.

The basic anesthesia machine

An anesthesia machine is an assembly of various components and devices that include medical gas cylinders in machine hanger yokes, pressure regulating and measuring devices, valves, flow controllers, flow meters, vaporizers, CO₂ absorber canisters, and breathing circuit assembly. The basic two-gas anesthesia machine has more than 700 individual components.

The anesthesia machine is a basic tool of the anesthesiologist/anesthetist and serves as the primary work station. It allows the anesthesia provider to select and mix measured flows of gases, to vaporize controlled amounts of liquid anesthetic agents, and thereby to administer safely controlled concentrations of oxygen and anesthetic gases and vapors to the patient via a breathing circuit. The anesthesia machine also provides a working surface for placement of drugs and devices for immediate access and drawers for storage of small equipment, drugs, supplies and equipment instruction manuals. Finally, the machine serves as a frame and source of pneumatic and electric power for various accessories such as a ventilator, and monitors that observe or record vital patient functions or that are critical to the safe administration of anesthesia.

Gas flow in the anesthesia machine and breathing system

The internal piping of a basic two-gas anesthesia machine is shown in Figure 1. The machine has many connections and potential sites for leaks. Both oxygen and N₂O may be supplied from two sources (Figure 2): a pipeline supply source (central piping system from bulk storage) and a compressed gas cylinder supply source. In hospitals, the pipeline supply source is the primary gas source for the anesthesia machine. Pipeline-supplied gases are delivered through wall outlets at a pressure of 50-55 psig through diameter indexed safety system (DISS) fittings or through quick-connect couplings that are gas-specific within each manufacturer’s patented system.

Because pipeline systems can fail and because the machines may be used in locations where piped gases are not available, anesthesia machines are fitted with reserve cylinders of oxygen and N₂O. The oxygen cylinder source is regulated from approximately 2,200 psig in the tanks to approximately 45 psig in the machine high-pressure system, and the N₂O cylinder source is regulated from 745 psig in the tanks to approximately 45 psig in the machine high-pressure system.

Figure 1
The flow arrangement of a basic two-gas anesthesia machine. A, The fail-safe valve in Ohmeda machines is termed a pressure sensor shut-off valve; in Dräger machines it is the oxygen failure protection device (OFPD). B, Second-stage oxygen pressure regulator is used in Ohmeda (but not Dräger Narkomed) machines. C, Second-stage nitrous oxide pressure regulator is used in Ohmeda Modulus machines having the Link 25 Proportion Limiting System; not used in Dräger machines. D, Pressure relief valve used in certain Ohmeda machines; not used in Dräger machines. E, Outlet check valve used in Ohmeda machines except Modulus II Plus and Modulus CD models; not used in Dräger machines. The oxygen take-off for the anesthesia ventilator driving gas circuit is downstream of the main on/off switch in Dräger machines, as shown here. In Ohmeda machines, the take-off is upstream of the main on/off switch. (Adapted from Check-out: a guide for preoperative inspection of an anesthesia machine, ASA, 1987. Reproduced by permission of the American Society of Anesthesiologists, 520 N. Northwest Highway, Park Ridge, Ill.) (See Figure 1 on previous page.)

Figure 2
The supply of nitrous oxide and oxygen may come from two sources: the wall (pipeline) supply and the reserve cylinder supply. (Reproduced by permission of Datex-Ohmeda, Madison, Wisconsin). Compressed gas cylinders of oxygen, N₂O, and other medical gases are attached to the anesthesia machine through the hanger yoke assembly. Each hanger yoke is equipped with the pin index safety system, a safeguard introduced to eliminate cylinder interchanging and the possibility of accidentally placing the incorrect gas tank in a yoke designed for another gas tank. (Reproduced by permission of Datex-Ohmeda, Madison, Wisconsin). (See Figure 2 on previous page.)

Figure 3 shows the oxygen pathway through the flow meter, the agent vaporizer, and the machine piping, and into the breathing circuit. Oxygen from the wall outlet or cylinder pressurizes the anesthesia delivery system. Compressed oxygen provides the needed energy for a pneumatically powered ventilator, if used, and it supplies the oxygen flush valve used to supplement oxygen flow to the breathing circuit. Oxygen also “powers” an in-line pressure-
Figure 3

Figure 4
sensor shutoff valve (“fail-safe” valve) for other gases to prevent their administration if the O2 supply pressure in the O2 high-pressure system falls below a threshold value. Figure 3

Oxygen and N2O flow from their supply sources via their flow control valves, flow meters and common manifold to the concentration-calibrated vaporizer and then via the machine common gas outlet to the breathing system. The high pressure system of the anesthesia machine comprises those components from the compressed gas supply source to the gas (O2 and N2O) flow control valves. The low pressure system of the anesthesia machine comprises those components downstream of the gas flow control valves. (See Figure 3 on previous page.)

Once the flows of oxygen, N2O, and other medical gases (if used) are turned on at their flow control valves, the gas mixture flows into the common manifold and through a concentration-calibrated agent-specific vaporizer where a potent inhaled volatile anesthetic agent is added. The mixture of gases and vaporized anesthetic agent then exits the anesthesia machine low pressure system through the common gas outlet and flows to the breathing system.

The circle system shown in Figure 4 is the breathing system most commonly used in operating rooms (ORs). It is so named because its components are arranged in a circular manner. The essential components of a circle breathing system (Figure 5) include a site for inflow of fresh gas (common [fresh] gas inlet), a carbon dioxide absorber canister (containing soda lime or barium hydroxide lime) where exhaled carbon dioxide is absorbed; a reservoir bag; inspiratory and expiratory unidirectional valves; flexible corrugated breathing tubing; an adjustable pressure-limiting (APL) or “pop-off” valve for venting excess gas; and a Y piece that connects to a face mask, tracheal tube, laryngeal mask airway (LMA) or other airway management device. (See Figure 4 on previous page.)

Once inside the breathing system, the mixture of gases and vapors flows to the breathing system’s inspiratory unidirectional valve, then on toward the patient. Exhaled gases pass through the expiratory unidirectional valve and enter the reservoir bag. When the bag is full, excess gas flows through the APL (or pop-off) valve and into the scavenging system that removes the waste gases. On the next inspiration, gas from the reservoir bag passes through the carbon dioxide absorber prior to joining the fresh gas from the machine on its way to the patient. The general use of fresh gas flow rates into anesthetic systems in excess of those required to compensate for uptake, metabolism, leaks, or removal of exhaled carbon dioxide results in variable volumes of anesthetic gases and vapors exiting the breathing system through the APL valve.

When an anesthesia ventilator is used, the ventilator bellows functionally replaces the circle system reservoir bag and becomes a part of the breathing circuit. The APL valve in the breathing circuit is either closed or excluded from the circuit using a manual (“bag”)/automatic (ventilator) circuit selector switch. The ventilator incorporates a pressure-relief valve that permits release of excess anesthetic gases from the circuit at end-exhalation. These gases should also be scavenged.

Sources of leaks within the anesthesia machine and breathing system

No anesthesia machine system is totally leak-free (Emergency Care Research Institute 1991). Leakage may originate from both the high-pressure and low-pressure systems of the anesthesia or analgesia machine.

The high-pressure system consists of all piping and parts of the machine that receive gas at cylinder or pipeline supply pressure. It extends from the high-pressure gas supply (i.e., wall supply or gas cylinder) to the flow control valves. Leaks may occur from the high-pressure connections where the supply hose connects to the wall outlet or gas cylinder and where it connects to the machine inlet. Therefore, gas-supply hoses should be positioned to prevent strain on the fittings (ASTM Standard F1161-88; Dorsch and Dorsch 1994) and constructed from supply-hose materials designed for high-pressure gas flow and minimal kinking (Bowie and Huffman 1985).

High-pressure leakage may also occur within the anesthesia machine itself. Other potential sources of leaks include quick-connect fittings, cylinder valves, absent or worn gaskets, missing or worn yoke plugs in a dual yoke assembly, and worn hoses.

The low-pressure system of the anesthesia machine (in which the pressure is slightly above atmospheric) consists of components downstream of the flow-control valves. It therefore includes the flow meter tubes, vaporizers, common gas outlet and breathing circuit, (i.e., from the common gas outlet to the patient). Low-pressure system leaks may occur from the connections and components anywhere between the anesthesia gas flow control valves and the airway. This leakage may occur from loose-fitting connections, defective and worn seals and gaskets, worn or defective breathing bags, hoses, and tubing, loosely assembled or deformed slip joints and threaded connections, and the moisture drainage port of the CO2 absorber, which may be in the “open” position.

Low-pressure system leaks also may occur at the gas analysis sensor (i.e., circuit oxygen analyzer) and gas sampling site(s), face mask, the tracheal tube (especially in pediatric patients where a leak is required around the uncuffed tracheal tube), laryngeal mask airway (over the larynx), and connection points for accessory devices such as a humidifier, temperature probe, or positive end-expiratory pressure (PEEP) valve. Inappropriate installation of a calibrated vaporizer(s) or misalignment of a vaporizer on its manifold can also contribute to anesthetic gas leakage.

Minute absorbent particles that may have been spilled on the rubber seal around the absorber canister(s) may also prevent a gas-tight seal when the canister(s) in the carbon dioxide absorber is (are) reassembled. The exhaust from a sidestream sampling respiratory gas analyzer and/or capnograph should also be connected to the waste gas scavenging system because the analyzed gas sample may contain N2O or halogenated vapors.

Figure 5

Checking anesthesia machines

Prior to induction of anesthesia, the anesthesia machine and its components/accessories should be made ready for use. All parts of the machine should be in good working order with all accessory equipment and necessary supplies on hand. The waste gas disposal system should be connected, hoses visually inspected for obstructions or kinks, and proper operation determined. Similarly, the anesthesia breathing system should be tested to verify that it can maintain positive pressure. Leaks should be identified and corrected before the system is used. The ability of the anesthesia system to maintain constant pressure is tested not only for the safety of the patient dependent on a generated positive pressure ventilation but also to test for leaks and escape of anesthetic gases, which may expose health-care personnel to waste anesthetic gases.

General workplace controls

Occupational exposures can be controlled by the application of a number of well-known principles, including engineering and work practice controls, administrative controls, personal protective equipment and monitoring. These principles may be applied at or
Figure 5

near the hazard source, to the general workplace environment, or at
the point of occupational exposure to individuals. Controls applied
at the source of the hazard, including engineering and work practice
controls, are generally the preferred and most effective means of
control. In anesthetizing locations and PACUs, where employees
are at risk of exposure to waste anesthetic gases, exposure may be
controlled by some or all of the following: (1) effective anesthetic
gas scavenging systems that remove excess anesthetic gas at
the point of origin; (2) effective general or dilution ventilation;
(3) good work practices on the part of the health-care workers,
including the proper use of controls; (4) proper maintenance of
equipment to prevent leaks; and (5) periodic personnel exposure
and environmental monitoring to determine the effectiveness of the
overall waste anesthetic gas control program.

The following is a general discussion of engineering controls, work
practices, administrative controls, and personal protective equipment
that can reduce worker exposure to waste anesthetic gases. However,
not every control listed in this section may be feasible in all settings.

Engineering controls
The collection and disposal of waste anesthetic gases in operating
rooms and non-operating room settings is essential for reducing
occupational exposures. Engineering controls such as an appropriate
anesthetic gas scavenging system are the first line of defense and
the preferred method of control to protect employees from exposure
to anesthetic gases. An effective anesthetic gas scavenging system
traps waste gases at the site of emission, and
delivers it to the transfer tubing.

A transfer tubing, which conveys the excess anesthetic gases to
the interface.

The interface, which provides positive (and sometimes
negative) pressure relief and may provide reservoir capacity. It
is designed to protect the patient’s lungs from excessive positive
or negative scavenging system pressure.

A gas disposal assembly tubing, which conducts the excess
anesthetic gases from the interface to the gas disposal assembly.

The gas disposal assembly, which conveys the excess
gases to a point where they can be discharged safely into the
atmosphere. Several methods in use include a nonrecirculating
or recirculating ventilation system, a central vacuum system, a
dedicated (single-purpose) waste gas exhaust system, a passive
duct system and an adsorber.

In general, a machine-specific interface must be integrated with a
facility’s system for gas removal. The interface permits excess gas
to be collected in a reservoir (bag or canister) and limits the pressure
within the bag or canister. A facility’s gas disposal system receives
waste anesthetic gases from the interface and should vent the waste
gases outside the building and away from any return air ducts or
open windows, thus preventing the return of the waste gases back
into the facility.

Removal of excess anesthetic gases from the anesthesia circuit
can be accomplished by either active or passive scavenging.
When a vacuum or source of negative pressure is connected to the
scavenging interface, the system is described as an active system.
When a vacuum or negative pressure is not used, the system is
described as a passive system. With an active system, there will be a
negative pressure in the gas disposal tubing. With a passive system,
this pressure will be increased above atmospheric (positive) by the
patient exhaling passively, or manual compression of the breathing
system reservoir bag.

Use of a central vacuum system is an example of an active system:
The waste anesthetic gases are moved along by negative pressure.
Venting waste anesthetic gas via the exhaust grille or exhaust duct
duct of a nonrecirculating ventilation system is an example of a passive
system: The anesthetic gas is initially moved along by the positive
pressure from the breathing circuit until it reaches the gas disposal
assembly.

A scavenging system consists of five basic components (ASTM, F
1343 - 91):

- A gas collection assembly, such as a collection manifold or a
distensible bag (i.e., Jackson-Rees pediatric circuit), which
captures excess anesthetic gases at the site of emission, and
delivers it to the transfer tubing.

- A gas disposal assembly tubing, which conducts the excess anesthetic gases from the interface to the gas disposal assembly.
Active systems
Excess anesthetic gases may be removed by a central vacuum system (servicing the ORs in general) or an exhaust system dedicated to the disposal of excess gases. When the waste anesthetic gas scavenging system is connected to the central vacuum system (which is shared by other users, e.g., surgical suction), exposure levels may be effectively controlled. The central vacuum system must be specifically designed to handle the large volumes of continuous suction from OR scavenging units. If a central vacuum system is used, a separate, dedicated gas disposal assembly tubing should be used for the scavenging system, distinct from the tubing used for patient suctioning (used for oral and nasal gastric sources as well as surgical suctioning).

Similarly, when a dedicated exhaust system (low velocity) is used, excess gases can also be collected from one or more ORs and discharged to the outdoors. The exhaust fan must provide sufficient negative pressure and air flow so that cross-contamination does not occur in the other ORs connected to this system. Active systems are thought to be more effective than passive systems at reducing excess waste anesthetic gas concentrations because leaks in the scavenging system do not result in an outward loss of gas.

Passive systems
HVAC systems used in health-care facilities are of two types: nonrecirculating and recirculating. Nonrecirculating systems, also termed “one-pass” or “single-pass” systems, take in fresh air from the outside and circulate filtered and conditioned air (i.e., controlled for temperature and humidity) through the room. Whatever volumes of fresh air are introduced into the room are ultimately exhausted to the outside. Waste anesthetic gases can be efficiently disposed of via this nonrecirculating system.

When a nonrecirculating ventilation system serves through large-diameter tubing and terminating the tubing at the room’s ventilation exhaust as the disposal route for excess anesthetic gases, disposal involves directing the waste gases grille. The sweeping effect of the air flowing into the grille carries the waste gases away. Because all of the exhausted air is vented to the external atmosphere in this type of system, the excess anesthetic gases can be deposited into the exhaust stream either at the exhaust grille or further downstream in the exhaust duct.

Concern for fuel economy has increased the use of systems that recirculate air. Recirculating HVAC/ventilation systems return part of the exhaust air back into the air intake and recirculate the mixture through the room. Thus, only a fraction of the exhaust air is disposed of to the outside. To maintain minimal levels of anesthetic exposure, air that is to be recirculated must not contain anesthetic gases. Consequently, recirculating systems employed as a disposal pathway for waste anesthetic gases must not be used for gas waste disposal.

The exception is an arrangement that transfers waste gases into the ventilation system at a safe distance downstream from the point of recirculation to ensure that the anesthetic gases will not be circulated elsewhere within the building.

Under certain circumstances, a separate duct for venting anesthetic gases directly outside the building without the use of a fan may be an acceptable alternative. By this technique, excess anesthetic gases may be vented through the wall, window, ceiling or floor, relying only on the slight positive pressure of the gases leaving the gas collection assembly to provide the flow. However, several limitations are apparent. A separate line would be required for each OR to prevent the cross-contamination with anesthetic gases among the ORs. A safe disposal site would be necessary. The possible effects of variations in wind velocity and direction would require a means for preventing a reverse flow in the disposal system. Occlusion of the outer portion of such a passive system by ice or by insect or bird nests is also possible. The outside opening of a through-wall, window, ceiling or floor disposal assembly should be directed downward, shielded and screened to prevent the entrance of foreign matter or ice buildup. Despite these limitations, the separate duct without the use of a fan may be ideal in older facilities constructed with windows that cannot be opened and in the absence of nonrecirculating air conditioning.

Adsorbers can also trap most excess anesthetic gases. Canisters of varying shapes and capacities filled with activated charcoal have been used as waste gas disposal assemblies by directing the gases from the gas disposal tubing through them. Activated charcoal canisters will effectively adsorb the vapors of halogenated anesthetics, but not N₂O. The effectiveness of individual canisters and various brands of charcoal vary widely. Different potent inhaled volatile agents are adsorbed with varying efficiencies. The efficiency of adsorption also depends on the rate of gas flow through the canister. The canister is used where portability is necessary. The disadvantages are that they are expensive and must be changed frequently. Canisters must be used and discarded in the appropriate manner, as recommended by the manufacturer.

General or dilution ventilation
An effective room HVAC system when used in combination with an anesthetic gas scavenging system should reduce, although not entirely eliminate, the contaminating anesthetic gases. If excessive concentrations of anesthetic gases are present, then airflow should be increased in the room to allow for more air mixing and further dilution of the anesthetic gases. Supply register louvers located in the ceiling should be designed to direct the fresh air toward the floor and toward the health care workers to provide dilution and removal of the contaminated air from the operatory or PACU. Exhaust register louvers should be properly located (usually low on the wall near the floor level) in the room to provide adequate air distribution. They should not be located near the supply air vents because this will short-circuit the airflow and prevent proper air mixing and flushing of the contaminants from the room.

Work practices
Work practices, as distinct from engineering controls, involve the way in which a task is performed. OSHA has found that appropriate work practices can be a vital aid in reducing the exposures of OR personnel to waste anesthetic agents. In contrast, improper anesthetizing techniques can contribute to increased waste gas levels. These techniques can include an improperly selected and fitted face mask, an insufficiently inflated tracheal tube cuff, an improperly positioned laryngeal mask, or other airway, and careless filling of vaporizers and spillage of liquid anesthetic agents.

General work practices recommended for anesthetizing locations include the following:

- A complete anesthesia apparatus checkout procedure should be performed each day before the first case. An abbreviated version should be performed before each subsequent case. The FDA Anesthesia Apparatus Checkout Recommendations should be considered in developing inspection and testing procedures for equipment checkout prior to administering an anesthetic.
- If a face mask is to be used for administration of inhaled anesthetics, it should be available in a variety of sizes to fit each patient properly. The mask should be pliable and provide as effective a seal as possible against leakage into the surrounding air.
Tracheal tubes, laryngeal masks, and other airway devices should be positioned precisely and the cuffs inflated adequately.

Vaporizers should be filled in a well-ventilated area and in a manner to minimize spillage of the liquid agent. This can be accomplished by using a specialized “key-fill” spout to pour the anesthetic into the vaporizer instead of pouring from a bottle into a funnel-fill vaporizer. When feasible, vaporizers should be filled at the location where the anesthetic will be administered and, when filled electively, with the fewest possible personnel present in the room. Vaporizers should be turned off when not in use.

Spills of liquid anesthetic agents should be cleaned up promptly.

Before extubating the patient’s trachea or removing the mask or other airway management device, one should administer non-anesthetic gases/agents so that the washed-out anesthetic gases can be removed by the scavenging system. The amount of time allowed for this should be based on clinical assessment and may vary from patient to patient. When possible, flushing of the breathing system should be achieved by exhausting into the scavenging system rather than into the room air.

Work practices performed by biomedical engineers and technicians also contribute significantly to the efficacy of managing waste gas exposure. It is, therefore, important for this group of workers to do the following:

- Monitor airborne concentrations of waste gases by sampling, measuring, and reporting data to the institution’s administration. Air monitoring for waste anesthetic gases should include both personal sampling (i.e., in a health-care worker’s breathing zone) and area sampling.
- Assist in identifying sources of waste/leaking gases and implementing corrective action.
- Determine whether the scavenging system is designed and functioning properly to remove the waste anesthetic gases from the breathing circuit, and ensure that the gases are vented from the workplace in such a manner that occupational re-exposure does not occur (e.g., smoke trail tests of exhaust grilles used with passive scavenging systems).
- Ensure that operatory and PACU ventilation systems provide sufficient room air exchange to reduce ambient waste gas levels.

Administrative controls

Administrative controls represent another approach for reducing worker exposure to waste gases other than through the use of engineering controls, work practices, or personal protective equipment. Administrative controls may be thought of as any administrative decision that results in decreased anesthetic-gas exposure. For workers potentially exposed to waste anesthetic gases, the program administrator should establish and implement policies and procedures to:

- Institute a program of routine inspection and regular maintenance of equipment in order to reduce anesthetic gas leaks and to have the best performance of scavenging equipment and room ventilation. Preventive maintenance should be performed by trained individuals according to the manufacturer’s recommendations and at intervals determined by equipment history and frequency of use. Preventive maintenance includes inspection, testing, cleaning, lubrication and adjustment of various components. Worn or damaged parts should be repaired or replaced. Such maintenance can result in detection of deterioration before an overt malfunction occurs. Documentation of the maintenance program should be kept indicating the nature and date of the work performed, as well as the name of the trained individual servicing the equipment.
- Implement a monitoring program to measure airborne levels of waste gases in the breathing zone or immediate work area of those most heavily exposed (e.g., anesthesiologist, nurse anesthetist, oral surgeon) in each anesthetizing location and PACU. Periodic monitoring (preferably at least semiannually) of waste gas concentrations is needed to ensure that the anesthesia delivery equipment and engineering/environmental controls work properly and that the maintenance program is effective. Monitoring may be performed effectively using conventional time-weighted average air sampling or real-time air sampling techniques.
- Encourage or promote the use of scavenging systems in all anesthetizing locations where inhaled agents are used, recognizing that a waste gas scavenging system is the most effective means of controlling waste anesthetic gases.
- Implement an information and training program for employees exposed to anesthetic agents that complies with OSHA’s Hazard Communication Standard (29 CFR 1910.1200) so that employees can meaningfully participate in, and support, the protective measures instituted in their workplace.
- Define and implement appropriate work practices to help reduce employee exposure. Training and educational programs covering appropriate work practices to minimize levels of anesthetic gases in the operating room should be conducted at least annually. Employers should emphasize the importance of implementing these practices and should ensure that employees are properly using the appropriate techniques on a regular basis.
- Implement a medical surveillance program for all workers exposed to waste gases.
- Ensure the proper use of personal protective equipment during cleanup and containment of major spills of liquid anesthetic agents.
- Manage disposal of liquid agents, spill containment, and air monitoring for waste gases following a spill.
- Comply with existing federal, state, and local regulations and guidelines developed to minimize personnel exposure to waste anesthetic gases, including the proper disposal of hazardous chemicals.

Location-specific workplace controls

This section describes engineering and work practice controls specific to hospital ORs, PACUs, dental operators and veterinary clinics and hospitals. Operational procedures relating to engineering controls are also discussed where appropriate.

Hospital operating rooms

For years, anesthesia providers tolerated exposure to waste anesthetic gases and regarded it as an inevitable consequence of their work. Since the 1970s, anesthesiologists have steadily worked to improve equipment and technique to reduce workplace exposures to waste anesthetic gases, and significant progress has been made. In early delivery equipment, waste gases were exhausted through the APL or “pop-off” valve into the face of the anesthesia provider and were distributed into the room air. Present practice, which utilizes an efficient scavenging system, avoids this type of contamination by collecting the excess gases immediately at the APL valve.

Engineering controls

Waste gas evacuation is required for every type of breathing circuit configuration with the possible exception of a closed circuit, because most anesthesia techniques typically use more fresh gas flow than is required. Appropriate waste gas evacuation involves collection and removal of waste gases, detection and correction of leaks,
If the circle absorber system (Figure 6) is used, the following scavenging in the OR. The tracheal tube connects the patient with essential for maintaining a gas-tight system that permits effective seals the tube within the trachea. The seal between the tracheal airways secured using a tracheal tube with an inflatable cuff that in ORs. Patients undergoing general anesthesia usually have their surgery require different work practices than those routinely used coupled with the patient’s immediate condition upon arrival from exposures to waste anesthetic gases. The unique PACU environment the PACU, it becomes more difficult to control health-care workers’ consideration of work practices, and effective room ventilation. To minimize waste anesthetic gas concentrations in the operating room, the recommended air exchange rate (room dilution ventilation) is a minimum total of 15 air changes per hour with a minimum of 3 air changes of outdoor air (fresh air) per hour. Operating room air containing waste anesthetic gases should not be recirculated to the operating room or other hospital locations.

**Work practices**

In most patients, a circle absorption system is used and can be easily connected to a waste gas scavenging system. In pediatric anesthesia, systems other than those with a circle absorber may be used. Choice of the breathing circuit that best meets the needs of pediatric patients may alter a clinician’s ability to scavenge waste gas effectively. Breathing circuits frequently chosen for neonates, infants and small children are usually valveless, have low resistance and limit rebreathing. The Mapleson D system and the Jackson-Rees modification of the Ayre’s T-piece are examples of limited rebreathing systems that require appropriate scavenging equipment.

The following work practices may be employed with any of the above breathing circuits:

- Empty the contents of the reservoir bag directly into the anesthetic gas scavenging system and turn off the flow of N₂O and any halogenated anesthetic agent prior to disconnecting the patient circuit.
- Turn off the flow of N₂O and the vaporizer, if appropriate, when the patient circuit is disconnected from the patient, for example, for oral or tracheal suctioning.
- Test daily for low-pressure leaks throughout the entire anesthesia system. All leaks should be minimized before the system is used. Starting anesthetic gas flow before the actual induction of anesthesia begins is not acceptable. For techniques to rapidly induce anesthesia using inhaled agents (single-breath mask induction), the patient connector should be occluded when filling the breathing circuit with nitrous oxide or halogenated agent prior to applying the mask to the patient’s face.

If the circle absorber system (Figure 6) is used, the following additional work practices can be employed:

- Adjust the vacuum needle valve as needed to regulate the flow of waste anesthetic gases into the vacuum source in an active scavenging system. Adjustments prevent the bag from overdistending by maintaining the volume in the scavenging system reservoir bag between empty and half-full. In machines that use an open reservoir to receive waste gas, a flow meter is used to adjust the rate of gas flow to the vacuum system.
- Cap any unused port in a passive waste gas scavenging configuration. (See Figure 6 on next page.)

**Postanesthesia care in hospitals and stand-alone facilities**

Because the patient is the main source of waste anesthetic gases in the PACU, it becomes more difficult to control health-care workers’ exposures to waste anesthetic gases. The unique PACU environment coupled with the patient’s immediate condition upon arrival from surgery require different work practices than those routinely used in ORs. Patients undergoing general anesthesia usually have their airways secured using a tracheal tube with an inflatable cuff that seals the tube within the trachea. The seal between the tracheal tube cuff and the trachea (or between the face mask and the face) is essential for maintaining a gas-tight system that permits effective scavenging in the OR. The tracheal tube connects the patient with the breathing circuit that is connected to the scavenging system in the OR. Once the patient reaches the PACU, scavenging systems such as those used in the OR are no longer effective, since the patient is no longer connected to the breathing circuit. Other less-effective methods of waste gas removal are thus relied upon.

**Engineering controls**

As a result of using appropriate anesthetic gas scavenging in ORs, the levels of contamination have been decreased. In the PACU, however, the principle of scavenging as practiced in the OR is not widely accepted due to medical considerations and consequently is infrequently employed as a source-control method for preventing the release of waste anesthetic gases into the PACU environment. Most PACUs provide care to multiple patients in beds without walls between them, and convective currents move the gases from their source to other areas. Therefore, in the PACU, a properly designed and operating dilution ventilation system should be relied upon to minimize waste anesthetic gas concentrations. This system should provide a recommended minimum total of 6 air changes per hour with a minimum of 2 air changes of outdoor air per hour to adequately dilute waste anesthetic gases. Room exhaust containing waste anesthetic gases should not be recirculated to other areas of the hospital.

**Work practices**

PACU managers should consider:

- Periodic exposure monitoring with particular emphasis on peak gas levels in the breathing zone of nursing personnel working in the immediate vicinity of the patient’s head. Methods using random room sampling to assess ambient concentrations of waste anesthetic gases in the PACU are not an accurate indicator of the level of exposure experienced by nurses providing bedside care. Because of the closeness of the PACU nurse to the patient, such methods would consistently underestimate the level of waste anesthetic gases in the breathing zone of the bedside nurse.
- Application of a routine ventilation system maintenance program to keep waste gas exposure levels to a minimum.

**Dental operatory**

Mixtures of N₂O and oxygen have been used in dentistry as general anesthetic agents, analgesics and sedatives for more than 100 years. The usual analgesia equipment used by dentists includes a N₂O and O₂ delivery system, a gas mixing bag and a nasal mask with a positive pressure relief valve. The analgesia machine is usually adjusted to deliver more of the analgesic gas mixture than the patient can use.

Analgesia machines for dentistry are designed to deliver up to 70 percent (700,000 ppm) N₂O to a patient during dental surgery. The machine restricts higher concentrations of N₂O from being administered to protect the patient from hypoxia. In most cases, patients receive between 30 and 50 percent N₂O during surgery. The amount of time N₂O is administered to a patient depends on the dentist’s judgment of patient needs and the complexity of the surgery. The most common route of N₂O delivery and exhaust is through a nasal scavenging mask applied to the patient.

Some dentists administer N₂O at higher concentrations at the beginning of the operation, then decrease the amount as the operation progresses. Others administer the same amount of N₂O throughout the operation. When the operation is completed, the N₂O is turned off. Some dentists turn the N₂O on only at the beginning of the operation, using N₂O as a sedative during the administration of local anesthesia, and turn it off before operating procedures. Based on variations in dental practices and other factors in room air, N₂O concentrations can vary considerably for each operation and also.
Figure 6

Figure 7
vary over the course of the operation.

Unless the procedure is performed under general anesthesia in an OR, halogenated anesthetics are not administered, nor does the patient undergo laryngoscopy and tracheal intubation. In the typical dental office procedure, the nasal mask is placed on the patient, fitted and adjusted prior to administration of the anesthetic agent. The mask is designed for the nose of the patient because access to the patient’s mouth is essential for dental procedures.

A local anesthetic, if needed, is typically administered after the N\(_2\)O takes effect. The patient’s mouth is opened and the local anesthetic is injected. The dental procedure begins after the local anesthetic takes effect. The patient opens his/her mouth but is instructed to breathe through the nose. Nonetheless, a certain amount of mouth breathing frequently occurs. The dentist may periodically stop the dental procedure for a moment to allow the patient to close the mouth and breathe deeply to re-establish an appropriate concentration of N\(_2\)O in the patient’s body before resuming the procedure. Depending on the nature of the procedure, high velocity suction is regularly used to remove intraoral debris and, when used, creates a negative air flow and captures some of the gas exhaled by the patient.

At the end of the procedure, the nosepiece is left on the patient while the N\(_2\)O is turned off and the oxygen flow is increased. The anesthetic mixture diffuses from the circulating blood into the lungs and is exhaled. Scavenging is continued while the patient is eliminating the N\(_2\)O.

The dental office or operatory should have a properly installed N\(_2\)O delivery system. This includes appropriate scavenging equipment with a readily visible and accurate flow meter (or equivalent measuring device), a vacuum pump with the capacity for up to 45 L/min of air per workstation, and a variety of sizes of masks to ensure proper fit for individual patients.

A common nasal mask, shown in Figure 7, consists of an inner and a slightly larger outer mask component. The inner mask has two hoses connected that supply anesthetic gas to the patient. A relief valve is attached to the inner mask to release excess N\(_2\)O into the outer mask. The outer mask has two smaller hoses connected to a vacuum system to capture waste gases from the patient and excess gas supplied to the patient by the analgesia machine. The nasal mask should fit over the patient’s nose as snugly as possible without impairing the vision or dexterity of the dentist. Gases exhaled orally are not captured by the nasal mask. A flow rate of approximately 45 L/min has been recommended as the optimum rate to prevent significant N\(_2\)O leakage into the room air. (See Figure 7 on previous page.)

A newer type of mask is a frequent choice in dental practice, a single-patient-use nasal hood. This mask does not require sterilization after surgery because it is used by only one patient and is disposable.

In a dental operatory, a scavenging system is part of a high-volume evacuation system used with a dental unit. The vacuum system may dispose of a combination of waste gases, oral fluid and debris, and is not limited to waste gas removal. The exhaust air of the evacuation system should be vented outside the building and away from fresh-air inlets and open windows to prevent re-entry of gas into the operatory.

The general ventilation should provide good room air mixing. In addition, auxiliary (local) exhaust ventilation used in conjunction with a scavenging system has been shown to be effective in reducing excess N\(_2\)O in the breathing zone of the dentist and dental assistant, from nasal mask leakage and patient mouth breathing. This type of ventilation captures the waste anesthetic gases at their source. However, there are practical limitations in using it in the dental operatory. These include proximity to the patient, interference with dental practices, noise, and installation and maintenance costs. It is most important that the dentist not work between the patient and a free-standing local exhaust hood. Doing so will cause the contaminated air to be drawn through the dentist’s breathing zone. These auxiliary ventilation systems are now not commercially available. The Academy of General Dentistry also emphasizes properly installed and maintained analgesia delivery systems.

**Work practices**

- Prior to first use each day of the N\(_2\)O machine and every time a gas cylinder is changed, the low-pressure connections should be tested for leaks. High-pressure line connections should be tested for leaks quarterly. A soap solution may be used to test for leaks at connections. Alternatively, a portable infrared spectrophotometer can be used to detect an insidious leak.
- Prior to first use each day, inspect all N\(_2\)O equipment (e.g., reservoir bag, tubing, mask, connectors) for worn parts, cracks, holes, or tears. Replace as necessary.
- Connect mask to the tubing and turn on vacuum pump. Verify appropriate flow rate (i.e., up to 45 L/min or manufacturer’s recommendations).
- A properly sized mask should be selected and placed on the patient. A good, comfortable fit should be ensured. The reservoir (breathing) bag should not be over- or underinflated while the patient is breathing oxygen (before administering N\(_2\)O).
- Encourage the patient to minimize talking, mouth breathing and facial movement while the mask is in place.
- During N\(_2\)O administration, the reservoir bag should be periodically inspected for changes in tidal volume, and the vacuum flow rate should be verified.
- On completing anesthetic administration and before removing the mask, non-anesthetic gases/agents should be delivered to the patient for a sufficient time based on clinical assessment that may vary from patient to patient. In this way, both the patient and the system will be purged of residual N\(_2\)O. Do not use an oxygen flush.

**Cleanup and disposal of liquid anesthetic agent spills**

Small volumes of liquid anesthetic agents such as halothane, enflurane, isoflurane, desflurane, and sevoflurane evaporate readily at normal room temperatures, and may dissipate before any attempts to clean up or collect the liquid are initiated. However, when large spills occur, such as when one or more bottles of a liquid agent break, specific cleaning and containment procedures are necessary and appropriate disposal is required. The recommendations of the chemical manufacturer’s material safety data sheet (MSDS) that identify exposure reduction techniques for spills and emergencies should be followed.

In addition, OSHA Standard for Hazardous Waste Operations and Emergency Response would apply if emergency response efforts are performed by employees. The employer must determine the potential for an emergency in a reasonably predictable worst-case scenario, and plan response procedures accordingly. Only adequately trained and equipped workers may respond to spills. When the situation is unclear or data are lacking on the exposure level, the response needs to be the same as for high levels of exposure. Responses to incidental releases of liquid anesthetic agents where the substance can be absorbed, neutralized or otherwise controlled at the time of release by employees in the immediate release area, or by maintenance personnel do not fall within the scope of this standard.
Because of the volatility of liquid anesthetics, rapid removal by suctioning in the OR is the preferred method for cleaning up spills. Spills of large volumes in poorly ventilated areas or in storage areas should be absorbed using an absorbent material, sometimes called a sorbent, that is designed for cleanup of organic chemicals. “Spill pillows” commonly used in hospital laboratories, vermiculite, and carbon-based sorbents are some of the materials commercially available and regularly used for this purpose. Caution should be exercised if broken glass bottles pose a hazard.

Both enflurane and desflurane are considered hazardous wastes under the EPA regulations because these chemicals contain trace amounts of chloroform (a hazardous substance), a byproduct of the manufacturing process. Consequently, sorbents that have been saturated with enflurane or desflurane should be managed as an EPA hazardous waste material due to the trace concentrations of chloroform present. Isoflurane and halothane do not contain trace amounts of chloroform or any other regulated substance and are therefore not considered hazardous wastes by EPA.

To minimize exposure to all liquid anesthetic agents during cleanup and to limit exposure during disposal procedures, the following general guidelines are recommended. The waste material should be placed in a container, tightly sealed, properly labeled, and disposed of with other chemical wastes sent to a facility’s incinerator or removed by a chemical waste contractor. After a large spill has occurred and the appropriate response action taken, airborne monitoring should be conducted to determine whether the spill was effectively contained and cleaned up.

Determination of appropriate disposal procedures for each facility is the sole responsibility of that facility. Empty anesthetic bottles are not considered regulated waste and may be discarded with ordinary trash or recycled. Furthermore, the facility as well as the waste handling contractor must comply with all applicable federal, state, and local regulations.

To minimize exposure to waste liquid anesthetic agents during cleanup and disposal, the following general guidelines are recommended by the manufacturers of liquid anesthetic agents:
- Wear appropriate personal protective equipment. Where possible, ventilate area of spill or leak. Appropriate respirators should be worn.
- Restrict persons not wearing protective equipment from areas of spills or leaks until cleanup is complete.
- Collect the liquid spilled and the absorbent materials used to contain a spill in a glass or plastic container. Tightly cap and seal the container and remove it from the anesthetizing location. Label the container clearly to indicate its contents.
- Transfer the sealed containers to the waste disposal company that handles and hauls waste materials.
- Health-care facilities that own or operate medical waste incinerators may dispose of waste anesthetics by using an appropriate incineration method after verifying that individual incineration operating permits allow burning of anesthetic agents at each site.

Air monitoring

Air monitoring is one of the fundamental tools used to evaluate workplace exposures. Accordingly, this section presents some of the appropriate methods that can be used to detect and measure the concentration of anesthetic gases that may be present in the health-care environment. The data provided by monitoring are necessary to establish proper engineering, work practice, and administrative controls to ensure the lowest reasonably achievable gas levels in the operating room and PACU room air.

OSHA recommends that air sampling for anesthetic gases be conducted every six months to measure worker exposures and to check the effectiveness of control measures. Furthermore, OSHA recommends that only the agent(s) most frequently used needs to be monitored, since proper engineering controls, work practices and control procedures should reduce all agents proportionately. However, the decision to monitor only selected agents could depend not only on the frequency of their use, but on the availability of an appropriate analytical method and the cost of instrumentation. ASA emphasizes regular maintenance of equipment and scavenging systems, daily check-out procedures for anesthesia equipment, and education to ensure use of appropriate work practices. It does not believe that a routine monitoring program is necessary when these actions are being carried out. ASA prefers to use monitoring when indicated such as in the event of known or suspected equipment malfunction.

Three fundamental types of air samples can be taken in order to evaluate the workplace: personal, area and source samples. Personal samples give the best estimate of a worker’s exposure level because they represent the actual airborne contaminant concentration in the worker’s breathing zone during the sampling period. This is the preferred method for determining a worker’s time-weighted average (TWA) exposure and should be used to assess personal exposures during anesthetizing administration and in the PACU. Where several health-care workers perform the same job, on the same shift, and in the same work area, and the length, duration, and level of waste gas exposures are similar, an employer may sample a representative fraction of the employees instead of all employees.

Area sampling is useful for evaluating overall air contaminant levels in a work area and for investigating cross-contamination with other areas in the health-care facility. Source sampling can be used to detect leaks in the anesthesia delivery and scavenging systems as well as ineffective capture by the scavenging system. Thus, how samples are taken is a critical point in any safety program.

The OSHA Chemical Information Manual contains current sampling technology for several of the anesthetic gases that may be present in anesthetizing locations and PACUs. Some of the sampling methods available are summarized below.

Time-integrated sampling
- **Nitrous oxide**
  Personal N₂O exposures can be determined by using the VAPOR-TRAK nitrous oxide passive monitor (sometimes called a “passive dosimeter” or “diffusive sampler”) as referenced in the 2000 OSHA Chemical Information Manual under IMIS:1953. The minimum sampling duration for the dosimeter is 15 minutes; however, it can be used for up to 16 hours of passive sampling. This sampler has not been validated by OSHA. Other dosimeters are commercially available and can be used. Although not validated by OSHA at this time, they may be validated in the future. Five liter, 5-layer aluminized gas sampling bags can also be used to collect a sample.

- **Halogenated agents**
  Three chlorofluorocarbon-based anesthetic agents (halothane, enflurane, and isoflurane) and one fluorocarbon-based agent (desflurane) are listed in the Chemical Information Manual. The OSHA sampling procedure for halothane is listed under IMIS:0395; for enflurane, under IMIS:1038; for isoflurane, under IMIS:F118; and for desflurane, under IMIS:R218.
The current recommended media sampling for halothane, enflurane and isoflurane requires an Anasorb 747 tube (140/70 mg sections) or an Anasorb CMS tube (150/75 mg sections). The sample can be taken at a flow rate of 0.5 L/min. Total sample volumes not exceeding 12 liters are recommended. The current recommended sampling media for desflurane requires an Anasorb 747 tube (140/70 mg sections). The sample can be taken at a flow rate of 0.05 L/min. Total sample volumes not exceeding 3 liters are recommended. All four sampling methodologies are fully validated analytical procedures.

Real-time sampling
Sampling that provides direct, immediate, and continuous (real-time) readout of anesthetic gas concentrations in ambient air utilizes a portable infrared spectrophotometer. Since this method provides continuous sampling and instantaneous feedback, sources of anesthetic gas leakage and effectiveness of control measures can be immediately determined.

Additional sampling guidelines
If it should ever be necessary to enter an operating room to conduct air sampling, the following guidelines provide the information needed. Individuals performing air sampling should be familiar with and follow all OR procedures for access into and out of the surgical suite with particular attention to sterile and nonsterile areas. The patient is the center of the sterile field, which includes the areas of the patient, operating table, and furniture covered with sterile drapes and the personnel wearing sterile attire. Sampling in the breathing zone of surgeons and other nursing or technical personnel who work in the sterile field must conform to the principles of sterile field access. Strict adherence to sound principles of sterile technique and recommended practices is mandatory for the safety of the patient.

Generally speaking, each hospital has its own guidelines for proper OR attire and other safety procedures. These rules should be strictly followed by anyone entering the OR. There are standard uniform guidelines that apply to all hospitals. Only clean and/or freshly laundered OR attire is worn in the OR. Proper attire consists of body covers such as a two-piece pantsuit (scrub suit), head cover (cap or hood), mask, and shoe covers. A sterile gown is worn over the scrub suit to permit the wearer to come within the sterile field. Other attire such as gloves and eyewear may be required. Some hospitals, but not all, may allow persons coming into the OR to wear a clean gown (in addition to the cap, the mask, and the shoe covers) over their street clothes if they are not going to remain in the OR for longer than 10-15 minutes.

In regard to decontaminating outside equipment, each hospital has its own policy. However, the common practice is to “wipe off” all surfaces with a chemical disinfectant. Most hospitals use Wescodyne or other phenolic solutions. Good physical cleaning before disinfection helps reduce the number of microorganisms present and enhances biocidal action.

Any person not familiar with the OR is usually instructed by a scrub nurse on all the safety procedures pertaining to the hospital. The scrub nurse will also provide instructions on hand scrubbing and other procedures that may be necessary. Persons entering the OR must follow these guidelines and instructions.

In addition, it should be recognized that the patient’s welfare, safety, and rights of privacy are paramount.

Hazard communication
In accordance with the Hazard Communication Standard (29 CFR 1910.1200), employers in health care facilities must develop, implement and maintain at the workplace a written, comprehensive hazard communication program that includes provisions for container labeling, collection and availability of material safety data sheets (MSDSs), and an employee training and information program. The standard also requires a list of hazardous chemicals in the workplace as part of the written hazard communication program.

Any chemicals subject to the labeling requirements of the FDA are exempt from the labeling requirements under the Hazard Communication Standard. This includes such chemicals as volatile liquid anesthetics and compressed medical gases. However, containers of other chemicals not under the jurisdiction of the FDA must be labeled, tagged or marked with the identity of the material and must show appropriate hazard warnings as well as the name and address of the chemical manufacturer, importer, or other responsible party. The hazard warning can be any type of message – words, pictures, or symbols – that conveys the hazards of the chemical(s) in the container. Labels must be legible, in English (plus other languages if desired), and prominently displayed.

Each MSDS must be in English, although the employer may maintain copies in other languages as well, and must include information regarding the specific chemical identity of the anesthetic gases or hazardous chemical and its common names. In addition, information must be provided on the physical and chemical characteristics of the hazardous chemical, known acute and chronic health effects and related health information, primary route(s) of entry, exposure limits, precautionary measures, emergency and first-aid procedures, and the identification of the organization responsible for preparing the sheet. As a source of detailed information on hazards, copies of the MSDS for each hazardous chemical must be readily accessible during each work shift to employees when they are in their work area(s).

Employers must prepare a list of all hazardous chemicals in the workplace, and the list should be checked to verify that MSDSs have been received for each chemical. If there are hazardous chemicals used for which no MSDS has been received, the employer must contact the supplier, manufacturer or importer to obtain the missing MSDS.

Health care employers must establish a training and information program for all personnel who are involved in the handling of, or who have potential exposure to, anesthetic gases and other hazardous chemicals to apprise them of the hazards associated with these chemicals in the workplace. Training relative to anesthetic gases should place an emphasis on reproductive risks. Training and information must take place at the time of initial assignment and whenever a new hazard is introduced into the work area. At a minimum, employees must be informed of the following:

- Any operations and equipment in the work area where anesthetic agents and hazardous chemicals are present.
- Location and availability of the written hazard communication program including the required lists of hazardous chemicals and the required MSDS forms.

The employee training program must consist of the following elements:

- How the hazard communication program is implemented in the workplace, how to read and interpret information on the MSDS and label of each hazardous chemical, and how employees can obtain and use the available hazard information.
The physical and health hazards of the chemicals in the work area.

Measures employees can take to protect themselves from these hazards, including specific procedures put into effect by the employer to provide protection such as engineering controls, appropriate work practices, emergency procedures for spill containment, and the use of personal protective equipment.

Methods and observations that may be used to detect the presence or release of anesthetic gases and other hazardous chemicals in the work area (such as monitoring conducted by the employer, continuous monitoring devices, and the appearance or odor of chemicals when released).

Personnel training records are not required to be maintained, but such records would assist employers in monitoring their programs to ensure that all employees are appropriately trained. Employers can provide employees information and training through whatever means are found appropriate and protective. Although there would always have to be some training on-site (such as informing employees of the location and availability of the written program and MSDSs), employee training may be satisfied in part by general training about the requirements of the hazard communication standard and about chemical hazards on the job which is provided by, for example, professional associations, colleges, universities, and training centers. In addition, previous training, education and experience of a worker may relieve the employer of some of the burdens of informing and training that worker. The employer, however, maintains the responsibility to ensure that employees are adequately trained and are equipped with the knowledge and information to do their jobs safely.

**STEP BY STEP APPROACH FOR CONTROLLING N₂O**

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Visually inspect all N₂O equipment (reservoir bag, hoses, mask, connectors) for worn parts, cracks, holes, or tears.</td>
<td>Replace defective equipment and/or parts.</td>
</tr>
<tr>
<td>2</td>
<td>Turn on the N₂O tank and check all high- to low-pressure connections for leaks. Use a non-oil-based soap worn solution to check for bubbles at high pressure connectors, or use a portable infrared gas analyzer.</td>
<td>Determine leak source and fix. If tank valve leaks, replace tank; if O-rings, gaskets, valves, hoses, or fittings, replace. Contact the manufacturer for parts replacement. For threaded pipe fittings, use Teflon tape. Do not use this tape on compression fittings.</td>
</tr>
<tr>
<td>3</td>
<td>Select scavenging system and mask. Mask should come in various sizes to patients. Scavenging systems should operate at air flow rate of 45 lpm.</td>
<td>Provide a range of mask sizes for patients. Check to see that noise levels at the mask are acceptable when the scavenging system exhaust rate is operated at 45 lpm.</td>
</tr>
<tr>
<td>4</td>
<td>Connect mask to hose and turn on vacuum pump before turning on N₂O. Scavenging system vacuum pump must have capacity to scavenge 45 lpm per dental operation.</td>
<td>Determine proper vacuum pump size for maintaining 45 lpm flow rates, especially when interconnected with other dental scavenging systems. If undersized, replace pump.</td>
</tr>
<tr>
<td>5</td>
<td>Place mask on patient and assure a good, comfortable fit. Make sure reservoir bag is not over- or under-inflated while the patient is breathing.</td>
<td>Secure mask with “slip” ring for “good activity” from patient breathing.</td>
</tr>
<tr>
<td>6</td>
<td>Check general ventilation for good room air mixing. Exhaust vents should not be close to air supply vents (use smoke tubes to observe air movement in room.)</td>
<td>If smoke from smoke tubes indicate room air mixing is poor, then increase the airflow or redesign. If exhaust vents are close to air supply vents, relocate (check with ventilation engineers to make adjustments).</td>
</tr>
<tr>
<td>7</td>
<td>Conduct personal sampling of dentist and dental assistant for N₂O exposure. Use diffusive sampler or infrared gas analyzer (see sampling methods).</td>
<td>If personal exposures exceed 150 ppm during administration, improve mask fit and make sure it is secure over the patient’s nose. Minimize patient talking while N₂O is administered.</td>
</tr>
<tr>
<td>8</td>
<td>Repeat procedure in step 7.</td>
<td>If personal exposures are less than 150 ppm but greater than 25 ppm, implement auxiliary exhaust ventilation near the patient’s mouth. Capture distance should no greater than 10 inches from the patient’s nose and mouth area and exhaust no less than 250 cfm at the hood opening. Avoid getting between the auxiliary exhaust hood and patient’s mouth and nose area.</td>
</tr>
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</table>

**Conclusion**

Nitrous oxide is used in many dental and medical offices and should be used with care. It is the most frequently used sedation method used in dentistry. All bodily functions remain normal, and the patient is able to breathe on his/her own. The patient will not fall asleep and will not have memory loss. It is best used for mildly anxious patients who wish only a small amount of sedation to “take the edge off” or to make them less nervous. The patient is able to respond appropriately to physical stimulation and verbal commands. It is a way for the dentist to manage pain and anxiety during dental
appointments, but they must also administer it wisely and with caution. Each dental or medical office should establish their own comprehensive training program on how to maintain the equipment and proper safety standards. This course should help you to review your office routines and make sure that you are setting the standards to achieve the best safety standards for your patients and for your employees.

Bibliography

“46 Health Care Professionals Linked to Substance Abuse,” Bristol Herald Courier, April 26, 2009.

NITROUS OXIDE – N₂O
FINAL EXAMINATION
3 CE HOURS

Choose True or False for questions 1 through 15 and then proceed to onlinedentalCE.com to process and complete your final examination online.

1. Nitrous oxide was first used as anesthetic treatment for dental use in 1844.
   a. True   b. False

2. Nitrous oxide vapors are not an explosion hazard outside in the open air.
   a. True       b. False

3. The scientific formula for nitrous oxide is NO₂.
   a. True       b. False

4. Long-term exposure can cause reproductive side effects.
   a. True       b. False

5. The National Institute for Occupational Safety and Health recommended, in a technical report published in 1977, controlling exposure limits of nitrous oxide waste to 35 parts per million (ppm) of air during dental surgery.
   a. True       b. False

6. The percentage of pediatric dentists using nitrous oxide in 1988 was 64 percent.
   a. True       b. False

7. Medical evaluations should be performed to detect and control work-related health effects upon the occurrence of a disease or work-related health problem, when a new employee is hired, transferred or terminated, and periodically during the term of employment.
   a. True       b. False

8. Inhaled anesthetic agents include two different classes of chemicals.
   a. True       b. False

9. Because leaks in the scavenging system do not result in an outward loss of gas, the more effective system is the central system.
   a. True       b. False

10. Good work practices with a nitrous oxide machine include using an oxygen flush for a sufficient time, based on clinical assessment, before removing the mask.
    a. True       b. False
11. A spill containing isoflurane and desflurane would be considered hazardous wastes under the EPA regulations because these chemicals contain trace amounts of chloroform (a hazardous substance).
   a. True  b. False

12. To minimize exposure to waste liquid anesthetic agents during cleanup and disposal, it is recommended by the manufacturers of liquid anesthetic agents to wear appropriate personal protective equipment, ventilate the area and wear appropriate respirators.
   a. True  b. False

13. Employers in health care facilities must develop, implement and maintain at the workplace a written hazard communication program. Personnel training records are required to be maintained.
   a. True  b. False

14. Three fundamental types of air samples can be taken to evaluate the workplace; they are personal, area and source samples.
   a. True  b. False

15. Venting waste anesthetic gas via the exhaust grille or exhaust duct of a non-recirculating ventilation system is an example of an active system.
   a. True  b. False