Waste anesthetic gases (WAGs) can be defined as all halogenated organic compounds (including methoxyflurane, halothane, isoflurane, sevoflurane, desflurane, and enflurane) and nitrous oxide that escape from the anesthetic circuit, or are exhaled by the patient. Management of WAGs intuitively seems prudent, but because excessive exposure is often difficult to detect without special monitoring devices, there seems to be a feeling of “out of sight, out of mind.” WAGs can be likened to a stealth bomber -- often silently present, but still potentially dangerous.

Historically, patients receiving methoxyflurane (MOF), one of the oldest halogenated gases, retained 50%-80% of metabolites in body fat, which were then metabolized by the liver and excreted by the kidneys. Halothane recipients metabolized 20%-40%, after being mobilized from fat and subsequently excreted by the kidneys. However, both halothane and MOF are no longer commercially available.

Comparatively, modern inhalants such as isoflurane and result desflurane require metabolism of a mere 0.2%-0.02% respectively. Metabolism of isoflurane and desflurane do not in a significant increase in serum fluoride ions. Approximately 2.5%-3% of enflurane and sevoflurane will be metabolized. Metabolism of enflurane and sevoflurane do result in increased fluoride ion concentrations, however they rarely caused nephrotoxicity. Furthermore, free radical formation is common secondary to the biodegradation of inhalant anesthetics.

Nitrous oxide has also been implicated as a health hazard. It is not metabolized in vivo (0.0004%), but undergoes a physiochemical reaction with vitamin B₁₂ that results in bone marrow changes and neurologic disease. It also indirectly inhibits deoxyribonucleic acid synthesis, which can result in reproductive disorders.

HEALTH IMPLICATIONS IN HUMANS
There are two categories for health implications related to WAGs in humans. Symptoms associated with short-term exposure usually occur immediately or shortly after the contact and can include fatigue, headaches, drowsiness, nausea, depression, and irritability. Long-term or chronic implications become evident days, weeks, or even years after the exposure. Examples of conditions seen as a result of long-term exposure include reproductive disorders, liver and kidney damage, neoplasia, hematopoietic changes, pruritus, and chronic nervous system dysfunction. Organ toxicity caused by long-term exposure to inhalants is most likely due to biodegradation of metabolic by-products. Individuals who are immuno-compromised, have pre-existing liver or kidney damage, or in the first trimester of pregnancy are most prone to the adverse effects of WAGs.
Obviously the health implications can vary drastically depending upon the agent used. Unfortunately, much of the following information is riddled with contradictions. Some reports indicate no definitive cause-and-effect relationship between exposure to WAGs and disease, while other reports seem irrefutable. Complicating matters is a lack of new research, as well as many various factors that made interpretation of research data muddy and inconclusive. Nevertheless, most authorities agree that exposure to excessive levels of WAGs should be avoided, and controls to reduce exposure should be implemented.

**Reproductive Effects** - In a survey undertaken by the American Society of Anesthesiologists, it was discovered that the risk of spontaneous abortions was 1.3-2 times the general population among female physician anesthesiologists and nurse anesthetists. Other studies demonstrated that working hospital anesthetists had spontaneous abortion rates that were 18.2%, versus 14.7% in a control group, and 12% of working anesthetists were infertile, versus 6% of a control group. Another study confirmed that 16% of the children of practicing nurse anesthetists developed birth defects, versus a 6% incidence in a control group. However, other studies demonstrated a borderline statistical correlation between WAGs and birth defects. Studies are difficult to perform as human hospitals used various agents, control measures were inconsistent, and the amount of exposure to WAGs varied; nitrous oxide may have been partially responsible for some of the reproductive hazards.

**Liver and Kidney Effects** - Many halogenated organic compounds can cause depression of hepatic function and hepatocellular damage. An increased risk of developing liver disease in operating room personnel exposed to trace levels of WAGs was noted by 1.6 fold in men and by 1.5 fold in women, but it was difficult to determine with certainty whether WAGs or some other occupational hazard were causative. Halothane was known to cause “halothane hepatitis” which is defined as massive hepatic necrosis that is a result of the production of toxic by-products in certain anesthetized individuals. This condition is considered rare. MOF has also been implicated as potentially hepatotoxic. Enflurane, isoflurane, and nitrous oxide do not appear to be hepatotoxic.

In one study, a statistical significant increase in renal disease was reported in female operating room personnel (1.2-1.4-fold), and female dental assistants (1.2-1.7-fold) compared to the normal population. However, it was not determined whether the increase was the result of exposure to MOF, nitrous oxide, other anesthetic agent(s), or other occupational factor(s).

**Neurologic and Oncogenic Effects** - It is important to remember that all halogenated agents are classified as potent central nervous system depressants. Physician anesthesiologists and nurse anesthetists reported an increased incidence of headaches, nausea, fatigue and irritability when exposed to WAGs. Other short-term effects reported included depression, lethargy, and ataxia. Long-term effects reported myoneuropathies, muscle weakness, neuron destruction, and learning disabilities/cognitive disorders. Other studies have demonstrated that exposure to high levels of WAGs effect motor skill performance and short-term memory.

It is generally believed that none of the commonly used veterinary anesthetic agents or nitrous oxide is carcinogenic, but valid studies to support this hypothesis do not exist.
Nitrous Oxide- There is little doubt that unnecessary exposure to nitrous oxide (N₂O) be avoided, especially during pregnancy. Female dental assistants exposed to N₂O for > 9 hours per week had a 1.7-2.3 times increase in spontaneous abortions versus the general population. Even the female spouses of male dentists using N₂O noted an increased rate of spontaneous abortion. Rats exposed to high levels of N₂O demonstrated abnormalities in sperm morphology, reduced ovulation, and retarded fetal development.

Female dental assistants working with N₂O had a 1.7-2.8-fold increased risk of developing neurologic disease compared to the general population. Exposure to high levels of N₂O resulted in muscle weakness, tingling sensations, and numbness. Chronic exposure to N₂O has been associated with myeloneuropathies.

EXPOSURE LEVEL RECOMMENDATIONS AND REDUCING EXPOSURE
The American College of Veterinary Anesthesiologists recommends that veterinary hospitals institute and maintain protocols for controlling WAGs, based on the possibility that small amounts may adversely affect human health. The National Institute for Occupational Safety and Health (NIOSH) recommends that the workplace environmental concentration of inhalants alone should not exceed 2 parts per million (ppm). Workplace environmental exposure to inhalants combined with N₂O should not exceed 0.5 ppm, and the N₂O level should not exceed 25 ppm. These levels are time-weighted averages over the course of the surgical procedure(s). Although no research exists to support the selection of these criteria, they were chosen as realistically achievable levels based on the current technology. The U.S. Occupational Safety and Health Administration (OSHA), the government body that enforces safety and health in the workplace, has adopted the NIOSH recommendations. It has been widely accepted that these levels dictate a safe working environment for employees, including pregnant women. If additional protection against WAGs is desired, pregnant women can wear activated charcoal masks.

There are numerous things that can be done to reduce or eliminate exposure to WAGs. Scavenging is the single most important thing that can be done to eliminate WAG pollution. One survey of veterinary hospitals demonstrated that scavenging reduced the indoor environmental concentration of waste halothane by 64% to 94%.

Scavenger systems function to collect WAGs from the anesthetic machine and dispose of them outside of the building. The systems consist of a gas capturing system (pop-off valve or scavenger hosing attached to a non-rebreathing circuit), interface (gas capture mechanism joining the disposal system), and a disposal system to vent WAGs outdoors.

There are two types of scavenging systems available, active and passive. Active scavengers use mechanical means to eliminate the WAGs, by creating suction using a vacuum pump or fan to draw gases into the scavenger. Passive scavenging involves non-mechanical methods to discharge the waste gases outdoors (away from air intakes, windows and doors) by using the positive pressure of the gas in the machine to push the WAGs into the scavenger.
There are several ways to scavenge passively. One example would involve the use of one-way directional valves to facilitate movement of WAGs outdoors. Another method involves using a transfer hose (maximum length of 10 feet) placed adjacent to the room ventilation exhaust or non-re-circulating air conditioning system. Re-circulation of air within the building must be avoided when using this system. Additionally, since anesthetic molecules are heavier than room air, the hose should travel downwards toward the exit. Passive systems are ineffective for interior rooms, when the outlet exceeds a distance of twenty feet.

The last alternative involves the use of activated charcoal cartridges. Charcoal cartridges are the least desirable option, due to numerous limitations. Activated charcoal cartridges (ex. f/air, by A.M Bickford) are effective for scavenging halogenated vapors. They are not effective for nitrous oxide or at higher flow rates. They are good for only 12 hours of use, or when the cartridge weighs 50 grams heavier than when new. It is important to not occlude the holes located on the bottom of the cartridge, as this is where the filtered air escapes.

It is imperative to regularly inspect all anesthetic equipment, and service machines on an annual basis. Maintenance logs should be kept for each anesthetic machine, vaporizer, and ventilator. Leakage from anesthetic machines can be a significant source of WAGs. Leaks can occur from missing, worn, or damaged ‘O’ rings, washers or other seals, loose flutter valve caps, poorly sealed carbon dioxide canisters, loose hose connections, holes in hoses or reservoir bags, or vaporizer caps not completely tightened. Damaged hoses, reservoir bags, and endotracheal tubes should be discarded. Leak test anesthetic machines on a routine basis, or whenever the integrity of the anesthetic machine has been compromised (as when changing the carbon dioxide canister).

Checking anesthetic machines for low-pressure leaks is easy, and all anesthetists should know how to perform this simple task. Place a ‘Y’ hose and reservoir bag on the machine. Close the pop-off valve. Occlude the end of the ‘Y’ hose. Fill the reservoir bag to a pressure of 30 cm of water. Observe the needle on the pressure manometer. Pressure within the circuit should not decrease by > 5 cm of water in 30 seconds. Excessive leaks must be located and corrected.

Reserve the use of anesthetic chambers only for fractious patients. Anesthetic chambers allow large amounts of gas to escape into the room when opened. For best results use the smallest chamber possible, ensure the chamber has a good seal and is not damaged, and is equipped with two outlets, one for delivery of the inhalant and one for scavenging. Moreover, patients induced in chambers exit with fur that is contaminated with the inhalant agent. Once the patient is removed, quickly replace the lid of the chamber, and continue to run oxygen through the chamber for several minutes to help purge WAGs into the scavenger. Only use chambers in well-ventilated areas. Residual anesthetics can be removed from the chamber (as well as all anesthetic hoses and reservoir bags) after use by thoroughly cleaning with soap and water. As an alternative to chamber induction, many smaller patients will tolerate mask induction while wrapped ‘burrito’ style in a towel or placed in a cat bag.
Avoid masks for maintaining anesthesia. If masks must be used, ensure a snug diaphragm fit over the patient’s face with an appropriately sized mask. Start with oxygen first, and do not turn on the vaporizer until the mask is securely in place. When the procedure is finished, turn the vaporizer off first, and continue oxygen for several minutes to help purge WAGs from the circuit.

Use cuffed endotracheal tubes that are properly inflated. Properly inflated endotracheal tubes can significantly reduce WAGs. Check proper inflation by closing the pop-off valve and exerting gentle pressure on the reservoir bag. The cuff should be inflated to the “minimum no leak volume.” To protect the patients lungs, a leak should occur at slightly less than ~ 20 cm of water. Ensure the endotracheal tube and cuff are not damaged prior to use.

Do not turn the vaporizer on until the cuff has been inflated, and the endotracheal tube has been attached to the anesthetic circuit. There is no need to charge the circuit with the anesthetic agent prior to hook up to the patient. At the completion of the procedure, turn off the vaporizer first, and allow several minutes of oxygen flow to purge WAGs into the scavenging system.

Use appropriate oxygen flow rates (< 3 liters/minute) or low flow anesthesia. It has been suggested that the oxygen flow rate required for meeting the oxygen demands of the anesthetized patient, and for maintaining oxygen hemoglobin saturation (SpO2) and the partial pressure of arterial oxygen saturation (PaO2), is actually very low. Always run higher oxygen flow rates (2-3 L/minute) for the first 3-5 minutes of anesthesia to remove room air from the circuit (that develops after a period of disuse) and to avoid dilution of the inhalant. Then decrease the oxygen flow rate for maintenance of anesthesia to as low as ~500 mls for patients weighing up to 100 pounds. Since most vaporizers require a minimum flow rate of 350 mls, this lower flow rate should be sufficient for delivery of the inhalant while reducing costs (by reducing oxygen use and extending the life of charcoal cartridges) and WAGs, plus meeting the patient’s oxygen demands. If preferred, SpO2 and blood gases can be assessed to ensure adequate oxygenation during low flow anesthesia. While using low flow anesthesia, higher oxygen flow rates will also be indicated whenever rapid anesthetic plane changes are needed.

Maintain the machine connection for several minutes after the cessation of anesthesia, and allow the patient to breathe 100% oxygen at 2-3 times maintenance rates for a period of several minutes. Periodically refill the circuit with fresh oxygen and expel previous gases into the scavenger to assist in WAG removal. Before disconnecting the patient, turn off the oxygen and then gently expel the contents of the reservoir bag into the scavenging system. Never expel the contents of the reservoir bag into the room.

Levels of WAGs can vary greatly depending on the location in the hospital. Often the recovery room is one of the most contaminated areas in the hospital. Prevention is accomplished by ensuring that all rooms used for induction, maintenance and recovery of anesthetized patients have at least 15 air changes per hour. Because patients continue to exhale residual inhalants for a period of time post-operatively, remain at least three feet away from the faces of these recovering anesthetic patients.
Fill vaporizers at the end of the day, or when the least amount of staff is present. Ideally, fill anesthetic machines outdoors. Liquid anesthetic can be absorbed through the skin, so it is imperative to wash hands immediately after filling the vaporizer, or wear plastic or vinyl gloves or other protective outer wear (gowns, respirators, etc). Using keyed fillers, or other specially designed filling nozzles can minimize spills. Sealed plastic bags are a safe place to store filling nozzles when not in use, and remember to cap empty bottles before discarding them.

Spilling only 1 ml of a liquid anesthetic can vaporize up to 200 mls of gas, and result in a concentration of 1,000,000 ppm (greatly exceeding NIOSH guidelines!). Accidental volume spills will require immediate action. Increase room ventilation by using fans and opening windows. Try to isolate the contaminated area by closing doors and pass-throughs, and turn the central vacuum off to avoid the spread of the fumes to other areas. Absorbent materials such as kitty litter can be used to clean up as much of the spill as possible. Contaminated articles of clothing should be removed and placed in an airtight container outdoors, along with the contaminated absorbent material used to clean up the spill. Only staff wearing the proper protective vinyl or plastic clothing and gloves (not rubber or latex), and respirators should be allowed access to the contaminated area. For large spills or if the facility affected is not prepared to properly manage a liquid anesthetic spill clean up, the building should be immediately evacuated and the local fire department should be summoned.

Hospitals desiring monitoring of WAGs in their work environment have several options. Badges or detector tubes can be purchased and worn for a period of time, and then returned to the supplier for analysis, or professional industrial hygienists can be consulted. Industrial hygienists are typically located in the yellow pages, under the heading of Occupational Safety.

REFERENCES