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Recognition, Evaluation and Control of Waste Anesthetic Gases in the Post-Anesthesia Care Unit

White Paper

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ASPAN
American Society of PeriAnesthesia Nurses

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Authored by: AIHA: James D. McGlothlin, MPH, PhD, CPE, FAIHA; Stephanie Caler, MPH, CIH, CSP, REHS; Paul H. Lilley, CIH; Michelle C. Rosales, MPH, CIH
ASPAN: Elizabeth Card, MSN, APRN, FNP-BC, CPAN, CCRP, FASPAN; Dina A. Krenzischek, PhD, RN, MAS, CPAN, CFRE, FASPAN, FAAN; Linda Wilson, PhD, RN, CPAN, CAPA, NPD-BC, CNE, CNEcl, CHSE-A, FASPAN, ANEF, FAAN

Recently, it was discovered that patients expire a significant concentration of residual anesthetic gas, such as sevoflurane, in the breathing zones of nurses and associated healthcare personnel in the Post-Anesthesia Care Unit (PACU). These exhaled gases from the patient are defined as *Waste Anesthetic Gases* (WAGs). The anesthetic gases originate in the surgical suite, where patients are administered these gases by an anesthesiologist to induce anesthesia for surgery. WAGs include nitrous oxide and halogenated anesthetics such as halothane, enflurane, isoflurane, desflurane, sevoflurane, and methoxyflurane. It has been observed in the PACU that general dilution ventilation, at current air exchange rates, may not be enough to reduce WAG exposures below the National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limits (RELs), or the American Conference of Governmental Industrial Hygienists (ACGIH), Threshold Limit Limits/Time-Weighted Averages (TLVs/TWAs). Because of this deficiency, market available source control scavenging systems that control WAGs at the patient's breathing zone may be more effective in reducing and containing these emissions in the PACU.

To obtain the desired level of anesthesia of the patients during surgery, the anesthesia provider administers the anesthetic gases in percentages. In doing so, the patient's body becomes saturated with the administered agent and carries a significant amount of the gas in their bodies, including from their respiratory system into the PACU. When the patient is wheeled into the PACU following surgery, they can outgas a significant concentration of WAGs exceeding the NIOSH RELs for the above-mentioned gases into the breathing zone of nurses. Patients emitting WAGs can cross-contaminate the environment for patients at risk for anesthetic gas exposure.

The nurse's job is to help the patients recover before moving them to another clinical unit in the hospital or discharging them. Recovering patients lack coordination, awareness, and the ability to protect their own airways. This vulnerable state of consciousness requires that PACU nurses must work within close proximity to the patients' breathing zone to ensure safe emergence from anesthesia. For example, nurses encourage patients to take deep breaths and exhale, asking them to describe any discomfort. Also, the nurses have to be close at hand to monitor for post-operative nausea and vomiting, common side effects from anesthetic agents and surgery. Semi-conscious patients recovering from anesthesia lack the ability to protect their airway and if vomiting occurs without the nurse being very close by, aspiration (accidental inhaling) of stomach contents could occur resulting in pneumonia, serious lung infection, brain injury from reduced oxygen, or even death from blocked airways. These vomiting events can occur quickly and without warning, requiring a vigilant nurse for rapid rescue to ensure patient safety. Pruritus, or itching, is another common side effect resulting in accidental self-inflicted corneal abrasions (scratched surface of the eye from patients rubbing too vigorously with their hands). This is more likely to occur if nurses are not close by, again requiring the nurse to be in the breathing zone of these patients to prevent adverse events.

There are no federal Occupational Safety and Health Administration (OSHA) standards for WAGs. However, the NIOSH has RELs for these potent anesthetic agents, which are measured in parts per million (ppm). Despite OSHA's lack of standards for WAGs, OSHA (1970b) may issue citations under the General Duty Clause (5a1), which states that employers "shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees" (osha.gov/laws-regs/oshact/section5-duties).

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There are usually four conditions that OSHA may use in its decision-making for issuing a 5(a)1 citation:

1. The employer failed to keep the workplace free of a hazard to which employees of that employer were exposed;
2. The hazard was recognized;
3. The hazard was causing or was likely to cause death or serious physical harm; and
4. There was a feasible and useful method to correct the hazard.

In general, the Occupational Safety and Health Review Commission (OSHRC) and court precedent have established that these elements are necessary to prove a violation of the General Duty Clause.

Because it was discovered that nurses can be exposed to WAGs from the expired breath of patients recovering in the PACU, localized scavenging systems were developed to capture and control patient WAGs at their source. Figures 1 and 2 are examples of current market-available scavenging systems placed on patients. Seldom in the profession of industrial hygiene is there a control that is invented, developed, and manufactured to contain and control a problem before it is generally understood that a problem exists.

The motivation of this white paper is to:

1. raise awareness that WAGs are a significant health hazard to nurses from patient outgassing WAGs following surgery in the PACU/recovery room (RR), Intensive Care Unit (ICU) or other recovery areas receiving patients directly from operating room suites,
2. understand that other high-risk patients in the PACU may be at risk from exposure to WAGs,
3. acknowledge there are market-available scavenging systems to control WAGs at their source,
4. encourage the healthcare industry to implement these source control scavenging systems and prevent WAG exposures among nurses in the PACU,
5. perform periodic monitoring of WAG levels near the patient's breathing zone to assure these controls are working, and
6. develop a reporting system of nurse adverse health symptoms and trends due to exposure to WAGs.

In as much as there are no federal standards to control WAGs, healthcare administrators may be hesitant to implement such controls related to costs. Educating and raising awareness about source control solutions to control and prevent WAG exposures in the PACU is a critical step toward improving patient and nurse health and safety. Patients may have allergic reactions to trace amounts of WAGs from other patients, while nurses may experience headaches and fatigue, resulting in potential medical errors from WAG exposure. The remainder of this white paper outlines the scope of the problem and highlights the challenges and opportunities of controlling WAGs in the PACU.

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The AIHA Partner and Advocacy Organization: The American Society of PeriAnesthesia Nurses

The American Society of PeriAnesthesia Nurses (ASPAN) is the premier organization for peri-anesthesia nursing excellence whose purpose is to empower and advance the unique specialty of peri-anesthesia nursing. Peri-anesthesia nurses work in any space before or after patients receive anesthesia, primarily in the post-anesthesia care unit, assisting recovering patients from surgery.

PACU nurses have an advocacy society in ASPAN. It represents the interests of over 60,000 nurses who specialize in peri-anesthesia and post-anesthesia care, ambulatory surgery, and pain management. ASPAN provides its members with the latest in peri-anesthesia education, research, clinical practice expertise, standards, and advocacy. In parallel with this white paper, ASPAN is developing a position statement to gain support for control of WAGs in the PACU among many of its sister organizations (ASPAN, 2021).

Figure 1. The ISO-Gard®[1] Scavenging Mask on a Volunteer Patient
Source: Teleflex.com.

Figure 2. The FELIX-1[2] Negative Pressure Scavenger Kit on a Volunteer Patient
Source: Vopotherm.com.

[1] The ISO-Gard® scavenging mask is manufactured by Teleflex.
[2] The FELIX-1 Negative Pressure Scavenger Kit by Vapotherm

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Guidelines and Recommended Exposure Limits for WAGs

Reduction of occupational exposure to WAGs for healthcare personnel by the scavenging of WAGs is recommended by every professional organization and government agency involved with anesthesia (McGregor, 1999). Adverse health outcomes from WAGs in unscavenged healthcare environments have been documented for decades (Cohen et al.,1971; Rosenberg & Kirves, 1973; Cohen, 1974; Corbett et al., 1974; Cohen et al., 1980; Ericson & Kallen, 1979; Axelsson & Rylander, 1982; Tannenbaum & Goldberg, 1985; Guirguis, et al., 1990; Rowland, et al., 1992; Rowland et al., 1995). However, there are methods to significantly decrease and prevent occupational exposure by scavenging WAGs to minimize potential adverse health outcomes, particularly in operating rooms and in the PACU (Mazze et al., 1981; ADA, 1997).

The Occupational Safety and Health Act of 1970, Public Law 91-596 (Act, A. 1970) was created to ensure that employers provide safe working conditions for employees. This act created OSHA under the United States Department of Labor, and NIOSH under the United States Department of Health and Human Services (DHHS). OSHA and NIOSH are federal agencies focused on enforcing OSHA and protecting employees from safety and health hazards, including exposure to WAGs.

ACGIH, the American Society of Anesthesiology (ASA), the American Dental Association (ADA), and The Joint Commission (formerly the Joint Commission on Accreditation of Healthcare Organizations, or JCAHO) are four other recommending organizations that publish occupational exposure information related to WAGs.

Table 1 shows the NIOSH RELs for selected WAGs that result from commonly administered anesthetic agents that are inhaled by the patient during surgery. Nitrous oxide, once commonly used as an analgesic agent during surgery, is less commonly used today. Sevoflurane is one of the most used anesthetic agents for patients undergoing surgery. While there are no NIOSH RELs for the three most currently used anesthetics (isoflurane, desflurane, and sevoflurane), NIOSH recommends that no halogenated agent, including the three analgesic agents listed above, should exceed a ceiling value of 2 ppm, not to exceed 1 hour. OSHA does not have WAG standards for nitrous oxide, nor any patient-inhaled anesthetic agents, including the halogenated agents listed in Table 1.

The American Conference of Governmental Industrial Hygienists (ACGIH) has recommended Isoflurane have a Threshold Limit Value of 50 ppm/8-hours. However, it is important to note that the volatility and variability of exposure to WAGs can easily exceed the ACGIH guidelines that would restrict exposure to a Short-Term Exposure Limit of 15 minutes. In addition, ACGIH (2023) has added Sevoflurane to the list of anesthetic agents to be studied recommending 50 ppm/8-hrs of exposure. Recently, California OSHA (2019) has mandated that Isoflurane should not exceed 50 ppm/8-hrs of exposure.

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Table 1. List of Commonly Used Analgesics (Nitrous Oxide) and Anesthetics (Halogenated) Administered to Patients During Surgical Procedures

Anesthetic Agent (trade name)*	NIOSH REL
Nitrous oxide	25 ppm during the time of administration
Halogenated agents	
Halothane (Fluothane®)	2 ppm ceiling not to exceed 1 hour
Enflurane (Ethrane®)	2 ppm ceiling not to exceed 1 hour
Isoflurane (Forane®)	2 ppm ceiling not to exceed 1 hour**
Desflurane (Suprane®)	2 ppm ceiling not to exceed 1 hour**
Sevoflurane (Ultane®)	2 ppm ceiling not to exceed 1 hour**

* Common trade name for the halogenated agents listed in this table.

** Isoflurane, desflurane, and sevoflurane came to market after the NIOSH Criteria for a Recommended Standard: *Occupational Exposure to Waste Anesthetic Gases and Vapors* was published (CDC, 1977). To date, NIOSH has not indicated whether the toxicology or epidemiology of this class of halogenated agents should be changed for a higher or lower REL. As such, the RELs for this class of compounds applies to the criteria established by NIOSH.

Sources: CDC (1977a), Dexter & Epstein (2023), and NIH (2024).

Historical Perspective of the U.S. Government's Role in the Control of WAGs

The Centers for Disease Control and Prevention (CDC, 1977b) promoted research on the effects of occupational exposure, the means for preventing occupational injuries, and the recommended occupational safety standards. It made recommendations in four areas of occupational health:

- scavenging and exposure to trace concentrations of WAGs,
- work practices to minimize WAG concentrations,
- medical surveillance for possible occupational exposure in the healthcare environment, and
- monitoring of WAGs.

NIOSH recommended that workers should not be exposed to halogenated agents at concentrations of >2 ppm when used alone, or >0.5 ppm when used in combination with nitrous oxide, over a sampling period not to exceed 1 hour.

In addition, NIOSH recommended that occupational exposure to nitrous oxide, when used as the sole anesthetic agent, should not exceed a TWA of 25 ppm during the time of anesthetic administration. It further stated that all anesthetic gas machines, non-rebreathing systems, and tympanostomy tube (t-tube) devices should have an effective scavenging device that collects all WAGs. Also, they provide best practice recommendations such as turning on the scavenging system before administering anesthetic gases to the patient to minimize WAG exposure to medical staff.

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In 1989, ACGIH adopted a 50-ppm TLV/TWA for nitrous oxide. This TLV/TWA concentration is for a normal 8-hour workday and a 40-hour workweek. However, excursions above the TLV/TWA should be controlled when the 8-hour limit is within these limits. ACGIH (2021) recommends that short-term exposures should not exceed three times the TLV/TWA (150 ppm) for no more than a total of 30 minutes during a workday. Further, they recommend that under no circumstances should they exceed five times the TLV/TWA (250 ppm), provided that the TLV/TWA is not exceeded. A recent overview article on the *Guidelines for Non-Operating Room Anesthesia Locations* agreed with the ASA and recommended that in any location where inhalation agents are administered, there should be adequate and reliable systems for scavenging WAGs (Kilic, 2020). ADA recommends the scavenging of all WAGs for all procedures involving anesthetic gases in the dental office. (ADA, 2021). The Joint Commission recommended that educational programs and orientation be established for all personnel who have contact with hazardous materials and waste (TJC, 2021)

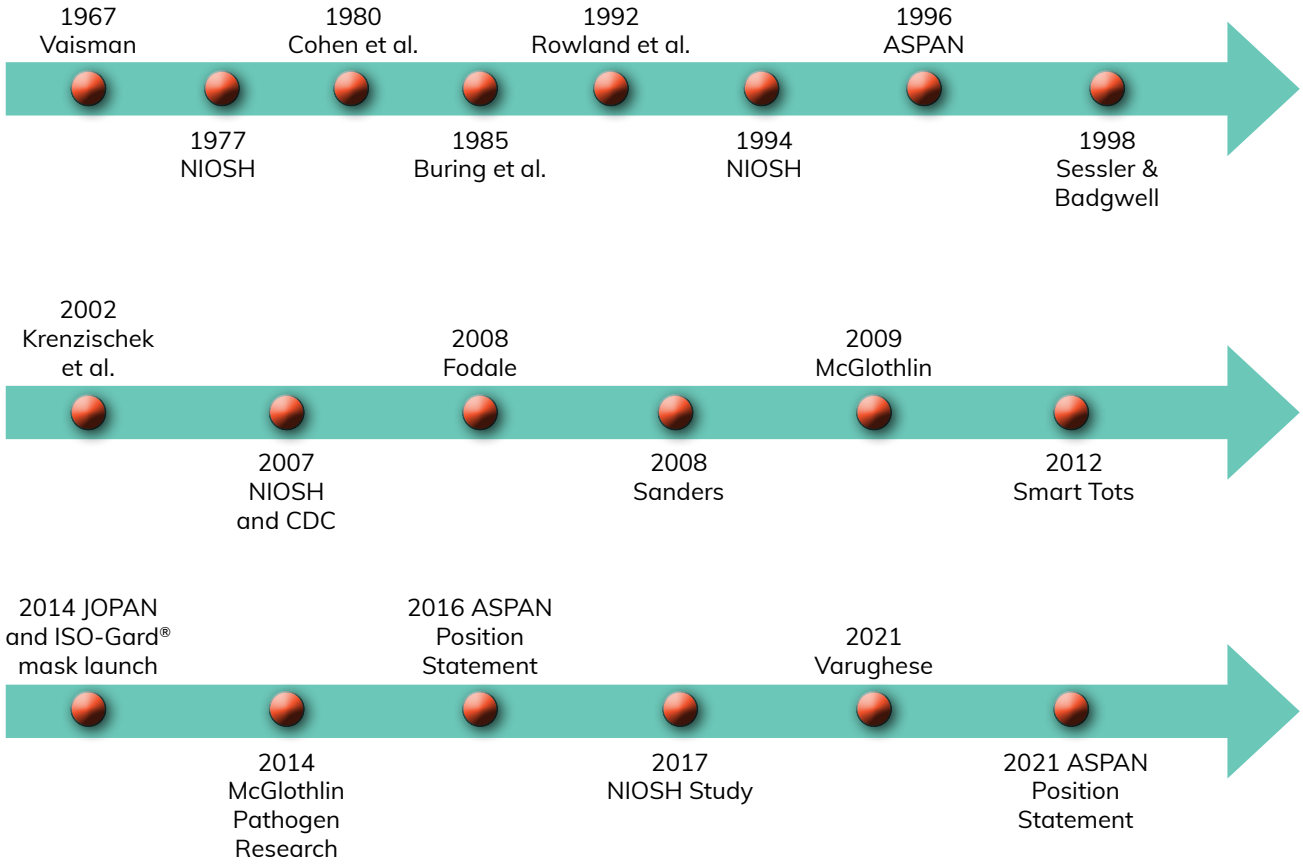

Figure 3. Timeline for Discovering WAGs as an Occupational Health Exposure
Note. From J. Moenning, as presented by J.D. McGlothlin at American Society of Peri-Anesthetic Nurses 2021 National Conference (McGlothlin, 2021).

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Other countries have established guidelines for occupational exposure standards, ranging from 25 ppm (the Netherlands) to 100 ppm (Italy, Sweden, Norway, Denmark, Great Britain) (Gardner, 1989; HSAC, 1995). While these occupational exposure standards vary, they all agree that the process of scavenging WAGs should be utilized.

OSHA is well known for its responsibilities to adopt and mandate job safety and health standards, establish the rights and responsibilities of employers and employees for safe occupational conditions, establish recordkeeping and reporting procedures of injuries, and evaluate work-related safety practices. However, it also is responsible for considering and carrying out NIOSH recommendations. Currently, OSHA recognizes NIOSH-recommended exposure limits (RELs) to WAG exposure, but to date, it has not set its own standards for WAGs. Like many hazards that do not have OSHA standards, OSHA (1970b) can issue citations under the General Duty Clause 5a(1), which states, "each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees."

In 2007, NIOSH reemphasized these recommendations to control WAGs (CDC, 2007). This publication helped to increase awareness and remind those in the healthcare profession of the adverse health effects of WAGs. Steege et al., in their 2014 NIOSH funded survey, found that 56% of workers dealing with anesthetic gases were unaware if their employer had standard procedures for the handling and minimizing of exposure to these gases. A timeline highlighting the discovery of WAGs being an occupational health hazard and its associated health effects is shown in Figure 3. (See also Appendix A.)

Brief Overview of Toxicology and Mechanisms from WAG exposure

As far back as 1956, Lassen et al. found that severe bone marrow depression could occur after prolonged nitrous oxide anesthesia in some patients who were being treated for tetanus. Later, Vaisman et al. (1967) found that anesthetic gases could be a problem for humans. They reported that female anesthesiologists had had problems with fatigue, nausea, and headaches, and that 18 of 31 of their pregnancies ended in spontaneous abortion. Banks et al. (1974) and Amess (1978) reported that nitrous oxide can inactivate vitamin B-12 and thus cause biochemical derangements such as those seen in pernicious anemia. Bruce et al. (1974) reported health effects of audiovisual impairment when exposed to nitrous oxide. Three years later, NIOSH (1977) reported that levels of 50 ppm were the lowest level at which human effects had been reported.

Cohen et al. (1980) published an article reporting on health problems experienced by dentists and chairside assistants who had been exposed to nitrous oxide in their jobs. They considered dentists to have light exposure if they used nitrous oxide 1 to 8 hours a week, or heavy exposure if they were >8 hours a week. They found that nitrous oxide use doubled the likelihood for congenital abnormalities or spontaneous abortions. Moreover, nitrous oxide was shown to have an increased effect on neurological problems, as well as liver and renal problems for male dentists and assistants. Lastly, nitrous oxide exposure doubled the likelihood for cervical cancer in the female study group.

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Buring et al. (1985) reviewed 17 published studies, and after evaluating these studies for the best statistical controls, concluded that there was a 30% increased risk of spontaneous abortion for women working in operating rooms and a similar, but less consistent increase in congenital abnormities among offspring of exposed physicians (Greenberg & Colton, 1985).

Rowland et al. (1992) reported that fertility problems occurred in women exposed to high levels of unscavenged nitrous oxide. These researchers also found a 2.5-fold increase in spontaneous abortions experienced by women who worked in dental operatories that did not scavenge nitrous oxide, and they found no increase in infertility or spontaneous abortion in women who worked in dental operatories that scavenged waste nitrous oxide.

In a government technical report, OSHA (1991) reported similar findings from a review of the literature, where the effects of acute and chronic occupational exposure had been shown to cause bone-marrow depression (primary granulocytopenia), paranesthesia, difficulty concentrating, equilibrium disturbances, and impaired visual effects. NIOSH updated this report in 2007 (CDC, 2007).

A study by Krajewski et al. (2007) examined alterations in the vitamin B12 metabolic status of 95 operating room nurses with a history of exposure to nitrous oxide and compared them to 90 nurses who were not exposed to nitrous oxide. They found significantly lower vitamin B12 status in personnel exposed to nitrous oxide with higher total homocysteine levels. The changes in vitamin B12 status were found to be primarily in subjects who were exposed to nitrous oxide in concentrations substantially exceeding occupational exposure limits.

Sanders et al. (2008) published a thorough review of the biological effects of nitrous oxide, including how nitrous oxide affects methionine synthase function. They found that, because of the interaction of vitamin B12 with nitrous oxide, methionine synthase is inactivated, resulting in alterations to one carbon and a methyl group transferred. Methionine synthase is important for DNA, purine, and thymidylate synthesis. These alterations are potentially a pathway to adverse health effects: they result in increased risk for reproductive consequences, megaloblastic bone-marrow depression, neurologic symptoms, and increased levels of homocysteine, which can cause cardiovascular changes.

Although the anesthetic use of nitrous oxide with halogenated agents may be decreasing, the use of halogenated agents has not gone down. These agents—sevoflurane, isoflurane, and desflurane—comprise most inhalation anesthetic gases for modern surgical procedures. Fodale et al. (2008) reviewed 54 articles on the health effects of nitrous oxide and halogenated gases and found that these agents were associated with general health and genotoxic risks. They stressed the need for further studies. Recently, studies on humans and rodents have shown that low-dose anesthetic gases can cause changes in liver blood chemistry, DNA damage and antioxidant status. (Casale, et al., 2014; Paes et al., 2014; Rocha, 2015; Deng, 2018). These possible health changes become even more concerning in the developing brains of children and the elderly, and these neurocognitive issues are being investigated by the U.S. Food and Drug Administration (FDA, 2021). There is consensus that good scavenger systems are needed to decrease these possible health consequences from exposure to WAGs with halogenated agents and nitrous oxide gas.

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In addition to WAG exposure issues, a recently published article by Varughese and Ahmed (2021) discussed the impact of these anesthetic agents on global warming. They estimated that 266 million surgeries were performed worldwide in 2015. These authors note that the volatile anesthetics such as nitrous oxide and the highly fluorinated gases sevoflurane, desflurane, and isoflurane are greenhouse gases and ozone-depleting agents. They point out that these anesthetic agents undergo minimal metabolism in the body during clinical use and are primarily (≥95%) eliminated unchanged via exhalation in the form of waste anesthetic gases (WAGs) in operating rooms and PACUs (Kharasch, E.D., 1995; Sherman J. et al., 2012)

Because these agents are relatively unchanged, they pose challenges for occupational exposure as well as environmental elimination. Based on the chemical properties of these gases, global warming impacts can vary. The authors report that atmospheric lifetimes of 1 to 5 years for sevoflurane, 3 to 6 years for isoflurane, 9 to 21 years for desflurane, and 114 years for nitrous oxide. This is in addition to unscavenged WAGs that result in chronic occupational exposure of healthcare workers to potential associated adverse health effects (Varughese & Ahmed, 2021).

WAGs in the PACU

In 1996, ASPAN issued a position statement regarding air safety in the post-anesthesia environment (ASPAN, 1996). It recommended that necessary, appropriate, and protective engineering controls, technologies, work practices, and personal protective equipment be utilized in the peri-anesthesia environment. ASPAN recommended that occupational exposure to WAGs and bloodborne and respiratory pathogens be controlled by adherence to regulations and guidelines, as set forth both by nationally recognized agencies, such as NIOSH, and by OSHA's hierarchy of controls, based on principles of good industrial hygiene.

Badgwell et al. (1997) discussed air safety source control technology for the PACU. They also reviewed literature related to exposure of PACU personnel to WAGs and concluded that WAGs levels in the breathing zone of personnel in the PACU appeared to exceed NIOSH RELs. Over the last 10 years, more articles are appearing on WAG levels in the PACU.

Prospective studies have looked at exposure levels in the PACU. Sessler (1998) summarized several papers on healthcare personnel exposed to WAGs and possible health concerns from this exposure. They reported that most of these studies concluded that there is a correlation between reproductive toxicity and exposure to WAGs. Sessler's team of researchers found that postoperative nurses were frequently exposed to exhaled anesthetic gas concentrations exceeding NIOSH-recommended exposure levels. Interestingly, they found that volatile anesthetic curves did not demonstrate the expected exponential decrease over time. They found that one-fourth of the nurses demonstrated time-weighted averages that exceeded the 25 ppm NIOSH recommendations, even though they had been caring for patients who had received nitrous oxide free anesthesia. The researchers point out that this could have been due to limitations in ventilation air exchanges in the PACU design. Their data suggested that PACU nurses were exposed to exhaled anesthetic gases that exceeded the NIOSH RELs.

Krenzischek et al. (2002) found that concentrations of nitrous oxide were close to 300 ppm in a patient's breathing zone. Their pilot study identified the potential for staff exposure to WAGs in the PACU setting.

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A simulated PACU environment was constructed to obtain an understanding of how the concentration of nitrous oxide varies with distance from the patient. Austin (1996) found that the concentration of nitrous oxide decreases with distance from the patient, and the patient's respiration increases the level of nitrous oxide based on the location of the nurse. Also, the respiration of the nurses pulls the nitrous oxide plume toward the patient, increasing the patient's exposure to the gas. Austin questioned the inadequacy of attempting to measure levels of gas exposure at random points in a room. Other articles have examined breath analysis to determine whether PACU personnel or operating room personnel are inhaling the gases and then exhaling them at a measurable limit.

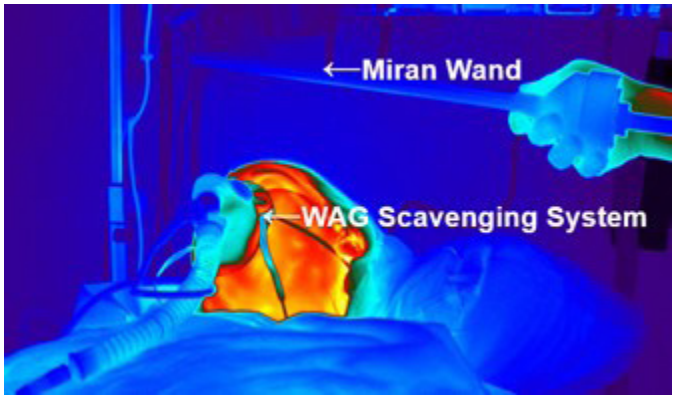

Figure 4. Scavenging System and Sampling Wand

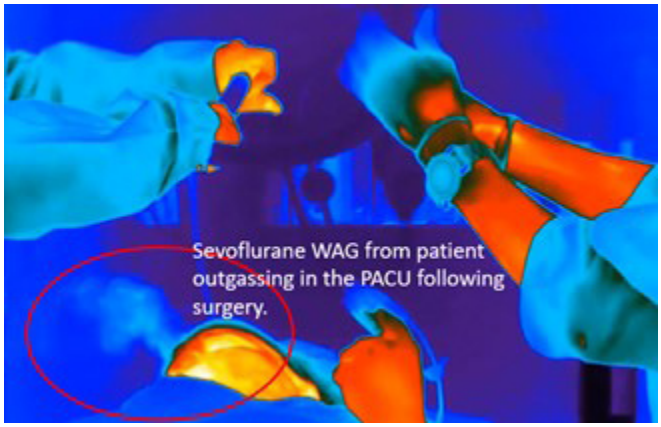

Figure 5. Patient Outgassing Sevoflurane
Note. Photo taken while nurses prepare the patient for recovery in the PACU.

Figure 6. Proximity of Nurse to Patient Who Is Outgassing Sevoflurane
Note. Nurses in the PACU must get very close to the patient to get their attention, to assure their safety as they transcend from sedation to consciousness.

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In a field study at an Indianapolis, Indiana-based hospital PACU, Purdue University researchers (McGlothlin et al., 2014) found nitrous oxide and sevoflurane levels 3 to 4 times higher than NIOSH recommended RELs, but also reported that the accumulated exposure over an 8-hour day was 4 to 5 times higher when patients did not wear a scavenging mask, compared to when patients did wear a scavenging mask. During this same study, many nurses reported that they could smell WAGs coming from the patients' nose and mouth, indicating that the amount was 125 times higher than the NIOSH REL (CDC, 2007). Real-time plots of the WAG data showed that the concentrations of WAG were highest during the first 5 to 10 minutes the patients were brought into the PACU. As mentioned earlier, this is the same time when the nurses are most engaged with the patient and very close to their breathing zone for WAG.

Cope et al. (2002) and Summer et al. (2003) have found that exhaled anesthetic agents are present in the breath of personnel. In 2015, Cheung et al. found that WAG concentrations are higher in the patients breathing zone when patients' airway devices are removed in the PACU vs. in the OR. (Cheung et al., 2015). As a result of these studies, it shows that PACU personnel may be exposed to WAGs that can be well above NIOSH RELs.

Figure 7. Scavenging Mask Suspended in a Photo Light Box
Note. Light box is approximately 16 in. × 16 in.

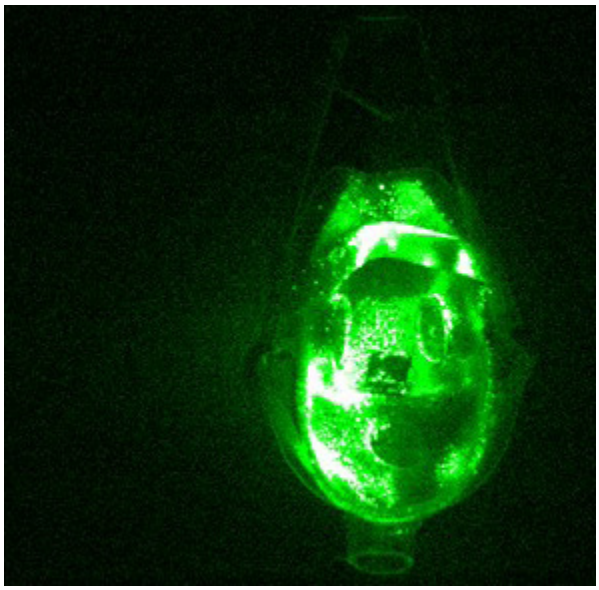

Figure 8. Image of Pathogens Collected in the Scavenging Mask
Note. Complementing Figure 7, this bioluminescent image shows bacteria and bacteriophage (viruses) collected inside the scavenging mask. Proof-of-concept laboratory study using bioluminescent techniques to demonstrate efficacy of scavenging systems to capture pathogens to protect nurses in the PACU.

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Appendix A shows a brief timeline for the reporting of WAGs in healthcare settings and recommendations for controlling and preventing such exposures using market-available scavenging systems to protect healthcare personnel from adverse health effects.

Figures 4, 5, and 6 show research conducted at a Midwest hospital to measure nitrous oxide and sevoflurane WAGs outgassing from patients recovering in the PACU (McGlothlin et al., 2014). These patients were administered these anesthetic agents during surgery and recovery in the PACU. The WAG concentrations were measured using the MIRAN SapphIRe Portable Ambient Analyzer (ThermoFischer.com), and pictures and video of these PACU patients were documented using infrared imaging with a specialized wavelength lens to visualize these WAGs. Most nurses in the PACU engage the patient as soon as they are transported into their bay area by getting very close to the patient's breathing zone to ensure the safety of the patient and speedy recovery from the anesthetics. Patients outgas the highest concentrations of WAGs in the PACU in two situations: just after they are brought in and when the nurses are actively engaged (often within 6 to 12 inches) with them.

Figure 7 shows the image of a scavenging mask that was used in a laboratory setting to determine how and where the colonies of bacteria and viruses collected on the mask. Figure 8, using a specialized camera and bioluminescent bacteria and viruses, shows the efficacy of the scavenging mask to collect and measure the density of the pathogens (Horton, 2014). This research followed the work done on WAG exposure conducted in the Midwest hospital as shown in figures 4, 5, and 6.

Summary

Most of the PACU nurses and other nurses from the RR, ICU labor and delivery units or procedural areas (such as cardiac catheter laboratories, interventional radiology, or endoscopic areas) receiving patients directly from the operating room suite or procedure area that had anesthetic gases may not be aware of the WAG exposure and health and safety risk in their workplace environment.

Understanding the evidence and putting it into practice is a start, especially toward increasing awareness. However, evidence and awareness are only meaningful when translated into practice. The assessment of potential risk in the clinical area and collaboration with the appropriate resources (clinical chain of command and health and safety professionals) are necessary steps in the implementation process.

The professionals in the health and safety department are responsible for monitoring and controlling potential WAGs in the operating room or theater. In the PACU, WAG assessment within the breathing zone of the patient can be monitored by health and safety professionals using appropriate monitoring devices. Monitoring of WAGs in the PACU must be done on a routine basis whenever patients with anesthetic gas are admitted to the unit.

Controlling the source of WAGs (typically from a patient's exhalation in the PACU), protects not only the nurses but other health-compromised patients. The role of a peri-anesthesia nurse in the PACU, RR, or

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radiology post-recovery phase is to provide safe and quality care to their patients, and to advocate for a safe workplace environment. Protecting nurses and other healthcare staff from any risk of exposure—be it WAGS, airborne pathogens, infection, or any adverse outcome—is a responsibility of the entire health care team.

Recommendations

Engineering Controls

1. Use market-available scavenging systems on the patient in the PACU to capture WAGs at their source: patient outgassing of the anesthetic agent administered to them during surgery.
2. Assure adequately designed PACU room ventilation in general area.
3. Upgrade general ventilation in the PACU to the same recommended levels as those in operating rooms. Include a minimum of 6 air changes per hour, with a minimum of 2 air changes of fresh air per hour.
4. Design supply air register louvers located in the ceiling in a way that directs the fresh air toward the floor and toward the healthcare workers, to provide dilution and removal of the contaminated air from the operatory or PACU.
5. Locate exhaust register louvers properly (low on the wall, near the floor level) 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.

Administrative Controls

1. Increase evidence-based awareness and educate professionals in organizations such as AIHA and ASPAN regarding nurse and healthcare worker exposure to hazardous levels of WAGs in the PACU.
2. Assure periodic measurement of WAG exposure in the PACU (such as twice per year) during high-use periods, to evaluate nurse exposure to WAGs.

Additional Administrative Controls

(adapted from NIOSH and OSHA)

1. Establish a hazard communication program. Develop and implement a safety and health plan that includes information about exposure hazards and methods to control them.
2. Train all PACU nurses in hazard awareness, prevention, reporting and control of exposures to waste anesthetic gases.
3. Develop a monitoring program supervised by a knowledgeable person in every operating facility. Such a program should include, at least quarterly:
   - quantitatively evaluating the effectiveness of a waste-gas control system, and

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- repeatedly measuring concentrations of anesthetic gas in the breathing zones of the most heavily exposed workers while they perform their usual procedures.

4. Keep records of all collected air sample results for at least 30 years.
5. Keep medical records of a PACU nurse's exposure for 30 years after their employment has ended and include any event reports. (See Access to Employee Exposure and Medical Records, 29 CFR 1910.1020).
6. Record medical histories for workers and their families, including occupational histories and outcomes of all pregnancies of female workers as well as wives or partners of male workers.

Best Practices for Nurses

If a nurse can smell WAGs coming from a patient in the PACU, this means that the concentration of these anesthetic gases, like sevoflurane, is likely 125 times the NIOSH REL.

To reduce potential exposures to the high levels of WAGs, the nurse should:

1. Determine the safest and most expedient way to use a source control scavenging to capture WAGs from the patient. Note that the highest concentration of WAGs will occur when the patient first comes into the PACU and when the patient is also the most vulnerable requiring close proximity and increased vigilance by the PACU nurse.
2. Assure that the scavenging system hose from the patient's mask is attached to the wall regulator and the vacuum setting is to the appropriate 45 liters per minute (lpm), of exhaust.
3. Assure that the patient is getting the proper amount of oxygen through the mask.
4. Make sure the mask is placed over the mouth and nose of the patient and is secured to the head of the patient by using the elastic bands fastened to the scavenging mask. Proper fit and size for the patient is warranted, especially for children recovering from surgery.
5. When possible, maintain at least 24 to 36 inches of space between them and the breathing zones of the patient for less direct exposure.

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Appendix A.
Timeline for the Discovery of WAGs as a Source of Exposure to the Development of Source Control Scavenging Systems for Post-Anesthesia Care Unit Nurses

- 2001–2005: Dr. John Moenning, an oral maxillofacial surgeon, researches and develops a unique scavenging device for waste anesthetic gases (WAGs) in a dental office.
  - King Systems partners with Dr. Moenning to manufacture a pediatric anesthesia mask featuring a nasal cannula that goes through the mask and can be placed into the patient's nose.
  - Real-time sampling of this dental scavenging system shows a significant reduction in WAGs.
- 2005–2007: Dr. Jim McGlothlin from Purdue University assists in a study by using infrared techniques to "visualize" WAG exposure from dental patients.
  - As a result of this published research, King Systems introduces the Safe Sedate mask, which receives 510(k) approval from the FDA. (The 510(k)-approval process requires manufacturers to demonstrate "substantial equivalence" to a legally marketed device. Premarket notification requires companies to report their intents to the FDA at least 90 days before marketing.)
- 2007: Results of Dr. McGlothlin's research are presented to the American Association of Oral and Maxillofacial Surgeons.
- 2007: In the conduct of this research, it is discovered that even after the anesthetic gas is turned off, the patient is still outgassing the nitrous oxide 20 minutes later, as visualized with the infrared (IR) lenses.
- 2007: Based on this observation, Dr. Moenning takes the IR camera to a hospital recovery setting to see whether patients are outgassing nitrous oxide after their inhalation general anesthesia. This leads to significant surprise by the anesthesiologist, as everyone thought that these WAG levels were not present after a general anesthetic.
- 2008: Dr. McGlothlin's research in the dental setting is completed and accepted by the *Journal of the American Dental Association* (February 2009).
- 2008: Because there appears to be a WAG exposure problem in the post-anesthesia care unit (PACU), Dr. Moenning invents a prototype scavenging system to capture WAGs that are outgassing from patients in the PACU.
- 2009: Dr. Moenning partners with Teleflex to make a scavenging system to protect nurses and related healthcare personnel in the PACU.
- 2010: Dr. Moenning works with Community Health Network (CHN) in Indianapolis, Indiana, to obtain Institutional Review Board (IRB) approval for research of WAGs in the PACU. The IRB is concerned with protecting the welfare, rights, and privacy of human subjects.
- 2011 and 2012: Research is conducted at the Indiana Surgery Center PACU, using the IRB from CHN.
- 2012: A presentation on WAGs in the PACU is given to the American Society of Anesthesia.

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- 2013: A research article is submitted to the *Journal of PeriAnesthesia Nursing* (JOPAN).
- 2014: A scavenging system (called ISO-Gard® mask system) from Teleflex Medical product is launched after gaining 510K approval. (See Figure 1 showing patient with scavenging mask and use of Miran real-time sampling probe to detecting nitrous oxide, sevoflurane, and related halogenated compounds administered as sedative agents to patients during surgery.)
- 2014: JOPAN publishes the research.
- 2014: Drs. James D. McGlothlin and Bruce Applegate, at Purdue University, begin research on the capture of pathogens (bacteria and viruses).
- 2015: A new IRB study is approved by CHN to research the capture of sevoflurane and visualization with new IR lenses to see the wavelength of sevoflurane. (See Figures 4-6 showing sevoflurane, using infrared imaging and a lens calibrated to show the wavelength of the sevoflurane outgassing from a patient following surgery and recovering in the PACU.)
- 2015, April: WAG research is presented to NIOSH in Washington, DC.
- 2016: Drs. McGlothlin and Applegate complete their research on the capture of pathogens.
- 2016: The American Society of PeriAnesthesia Nurses (ASPAN) finalizes and publishes a new position statement, Air Quality and Occupational Hazard Exposure Prevention.
- 2017: NIOSH funds a four-year research project to evaluate the PACU environment for WAGs.
- 2018 and 2019: NIOSH conducts an industrial hygiene study on WAGs in 3 different hospital PACUs in Indianapolis.
- 2020: The year of COVID-19. An ISO-Gard® mask is submitted to the FDA for emergency use authorization to help capture COVID-19. The FDA decides it is not an emergency need.
- 2021: The executive committee of the AIHA Healthcare Workgroup Committee and ASPAN Action Coalition develops this white paper on WAGs.

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