Comprehensive Report

Engineering Controls for Post-Operatory Waste Anesthetic Gases – Baseline Data Collection

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Sites Surveyed:

Community Health Surgery Center North
8040 Clearvista Dr.
Indianapolis, IN 46256

Community Surgery Center Hamilton
9700 E 146th St.
Noblesville, IN 46060

NAICS Code:

622110 – General Medical and Surgical Hospitals

Survey Dates:

May 15, 2019
June 12, 2019
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September 10, 2019
November 13, 2019
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None

Analytical Work Performed by:

All data was collected with real–time instrumentation

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Abstract

Waste anesthetic gases (WAGs) are small releases of anesthetic gases that leak from the patient's anesthetic breathing circuit into the air of operating rooms (OR) during delivery of anesthesia as well as during recovery from anesthesia in the Post Anesthesia Care Unit (PACU). Waste anesthetic gases include nitrous oxide and halogenated anesthetics such as halothane, enflurane, isoflurane, desflurane, sevoflurane, and methoxyflurane.

WAGs pose a significant health hazard in the hospital setting and must be controlled to protect health care workers in the OR, PACU, and other applications where anesthetic gases are used. Exposure to uncontrolled WAGs in health care environments has been associated with adverse health outcomes such as liver and kidney disease, fatigue, irritability, drowsiness, headaches, miscarriages, genetic damage, birth defects, and cancer. As a result, systems and work practices have been developed for hospital OR and dental treatment rooms to decrease occupational exposure by scavenging WAGs. However, few studies have addressed exposure to WAGs in the PACU.

Between May 2019 and January 2020, National Institute for Occupational Safety and Health (NIOSH) investigators conducted field assessments of three different PACUs that included collecting baseline WAG's data along with physical descriptions and ventilation parameters. Two of the PACUs evaluated were considered open concept units, one had a 12-patient capacity and about 1500 ft^2 of floor space and the other one had a 6-patient capacity and about 800 ft^2 floor space. The third PACU unit evaluated was considered a closed concept PACU. It had a 7-patient capacity and an approximate floor space of 2800 ft^2. A closed concept PACU is a room where each patient has an independent, three-sided recovery area with an open front. Area WAG concentrations were measured using a Fourier transform infrared (FTIR) spectrometer analyzer. The FTIR analyzer simultaneously collected real-time data for multiple gases, including sevoflurane, isoflurane, and nitrous oxide. Additionally, ventilation airflow measurements in the PACUs were collected. The number of air changes per hour (ACH) for each unit was calculated and compared to ANSI/ASHRAE Standards. ASHRAE Standard 170-2017 prescribes a minimum of 6 ACH of total ventilation air that includes a minimum of 2 ACH of outdoor air. PACUs 2 and 3 were above the ASHRAE recommendations. PACU 1 was slightly below ASHRAE recommendations at 5.75 ACH.

The WAG concentration measurements collected were area samples and not exposure concentrations measured from workers' breathing zones, however comparison of the observed results with occupational exposure limits can provide some context. Measurements in a patient's breathing zone are expected to give higher values of WAG concentrations. The five halogenated anesthetics currently used in the United States are halothane, isoflurane, enflurane, desflurane, and sevoflurane. No NIOSH recommended exposure limit (REL) exists for the three most currently used anesthetics (isoflurane, desflurane, and sevoflurane). In 1977, NIOSH recommended that occupational exposure to halogenated anesthetic agents, when used as the sole anesthetic, should be controlled so that no worker would be

exposed to time-weighted average concentrations greater than 2 ppm during anesthetic administration over a sampling period of less than 1-hour. When halogenated anesthetics are associated with nitrous oxide, NIOSH recommends that the limit value should not exceed 0.5 ppm over the same sampling period. This occupational exposure limit was recommended by NIOSH for the type of anesthetic gas to which isoflurane and sevoflurane belong, but before they effectively came into use. NIOSH also recommends that occupational exposure to nitrous oxide should not be greater than 25 ppm. Other standard setting bodies, like the Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH), don't have limits for many of the halogenated gases. However, ACGIH included a Threshold Limit Value (TLV) of 50 ppm for isoflurane over an 8-hour shift in the 2022 updates to its *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.*

The 1-minute maximum concentration of nitrous oxide in PACU 1 was 2.6 ppm which was well below the NIOSH REL. The maximum 1-minute average concentration of isoflurane was 4.6 ppm, and for sevoflurane the maximum was 34 ppm. PACU 1 routinely extubated patients in the PACU. The maximum 1-minute average concentration of nitrous oxide in PACU 2 was 0.3 ppm which was well below the NIOSH REL. The maximum concentration of isoflurane and sevoflurane were recorded at 11.2 ppm and 10.2 ppm respectively. The maximum 1-minute concentration of nitrous oxide in PACU 3 was recorded at 17.5 ppm and was caused by an instantaneous spike that was quickly diluted and dissipated by the PACU ventilation system. The 1-hour average nitrous oxide concentration for PACU 3 was consistently below the NIOSH REL. For the same PACU unit, the maximum 1-minute average concentrations of isoflurane and sevoflurane were recorded at 6.1 ppm and 46.2 ppm respectively which were both above the NIOSH recommendations for halogenated gases.

Collectively, these field assessment surveys reinforce the opportunity for engineering control approaches to reduce WAG concentrations within the PACU working environment. Although the observed concentrations were area samples and not worker breathing exposures, NIOSH recommendations were exceeded within all of the evaluated PACU units. Each PACU experienced at least 1-hour of cumulative time over the NIOSH recommendations for halogenated gases. These observations indicate that general dilution ventilation, at the current air exchange rates, was not enough to keep WAG concentrations near the patient below the NIOSH recommendations. Other engineering control techniques that control the emissions closer to the source might be required to reduce WAG emissions into the PACU environment. Additional research is needed to identify an effective approach to control WAG concentrations within the PACU.

Introduction

Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering and Physical Hazards Branch (EPHB) of the Division of Field Studies and Engineering has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, EPHB has conducted many assessments of health hazard control technologies on the basis of industry, common industrial process, or specific control techniques. Examples of these completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve several steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concept techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

Background for this Study

Waste anesthetic gases (WAGs) are small releases of anesthetic gases that leak from a patient’s anesthetic breathing circuit during delivery of or recovery from anesthesia. Waste anesthetic gases include nitrous oxide and halogenated anesthetics such as halothane, enflurane, isoflurane, desflurane, sevoflurane, and methoxyflurane (which is no longer used in the United States). The halogenated anesthetics are often administered in combination with nitrous oxide and may pose a hazard to hospital workers. The anesthetic breathing circuit includes the mask, endotracheal tube, anesthetic gas machine, ventilator, pumps, scavenging devices that limit WAG releases, plus connecting tubing and other elements, depending on the delivery system, and are typically only used in the operating room (OR) [NIOSH 2007]. In the OR, the anesthesia gas scavenging system collects and removes waste gases from the patient ventilation circuit. Once the gas delivery is discontinued and the patient becomes the primary source of the WAG, the protective controls offered by the scavenging system are lost as the patient progresses into the post-anesthesia care unit (PACU).

WAGs pose a significant health hazard in the hospital setting and must be controlled to protect health care workers in the OR, the PACU, and other applications where anesthetic gases are used (such as dental operatories) [McGlothlin 2013]. Occupational exposure to WAGs in health care environments has been associated with adverse health outcomes such as liver and kidney disease, fatigue, irritability, drowsiness, headaches, miscarriages, genetic damage, birth defects, and cancer [NIOSH 2007]. As a result, systems and work practices have been developed for hospital OR and dental treatment rooms to decrease occupational exposure by scavenging WAGs. However, few studies have addressed exposure to WAGs in the PACU. The monitoring of WAGs, primarily nitrous oxide (N_20), has been done using tracer gas, dosimetry badges, handheld monitoring devices, and visualized with infrared (IR) thermography [Crouch 2000, Krenzischek 2002, McGlothlin 2013].

In 2016 and 1996, the American Society of PeriAnesthesia Nurses (ASPAN) released position statements regarding air quality and safety in the PACU [ASPAN 2016, 1996]. The position statement maintained that necessary, suitable, and protective engineering controls, technologies, work practices, and personal protective equipment (PPE) should be applied in the PACU. ASPAN recommended that occupational exposure to WAGs, as well as blood-borne and respiratory pathogens, should be controlled by following the regulations and guidelines established by nationally recognized agencies, such as NIOSH, and OSHA. These approaches should also consider the hierarchy of controls, which are principles of good industrial hygiene.

In dental applications, studies have shown that WAGs can be controlled in the breathing zone by effective engineering controls such as scavenging systems [Crouch 2000] yet the use of scavenging systems has not been widely adopted into the PACU working environment. The accumulation of WAGs in the PACU should be reduced through cost-effective means that are compatible with established work practices and also promote and protect healthcare personnel.

The overall goal of this project is to identify and assess effective engineering control solutions that protect workers while meeting feasibility and operational requirements of the hospitals and clinics. Through observations during field studies, such as those described here, and interactions with healthcare personnel, the researchers seek to gain a better understanding of the barriers to adopting potential engineering control solutions for WAGs. These field studies will inform the next phase of this project, which will assess engineering control solutions in a controlled laboratory setting.

Survey Site and Process Description

Introduction

A post-anesthesia care unit (PACU) is a vital part of hospitals, ambulatory care centers, and other medical facilities. It is an area normally attached or in close physical proximity to an operating room and is designed to provide care for patients recovering after surgery or any procedure requiring anesthesia. The PACU is a critical care unit where the patient's vital signs are closely observed, pain management begins, and fluids are given. Patients are admitted to the PACU immediately after surgery or a procedure involving anesthesia.

Once surgery or procedure is finished, the patient is moved to the PACU where they breathe in fresh air and breathe out a mix of air and anesthetic gases residual in their respiratory system. The highest WAG emission rate is upon patient arrival to the PACU, and the emissions decrease as the patient continues to inhale anesthetic-free air. Thus, the patients themselves are the sources of WAGs that enter the PACU environment and potentially expose PACU staff. While variations occurred due to PACU size and patient volume, about 4 or 5 nurses staffed the PACU in the locations where this study was conducted. PACU nurses spend the majority of their time doing patient care activities at the patient bedside (in close proximity to the patient breathing area where the highest concentrations are expected to be measured), and the rest of the time at the nurse's station where they can oversee all the patient beds and conduct data entry on the hospital's computer system.

Occupational Exposure Limits and Health Effects

In the U.S., occupational exposure limits (OELs) have been established by Federal agencies, professional organizations, state and local governments, and other entities. The U.S. Department of Labor OSHA Permissible Exposure Limits (PELs) [29 CFR 1910.1000 2003] are OELs that are legally enforceable in covered workplaces under the Occupational Safety and Health Act. NIOSH recommended exposure limits (RELs) are based on a critical review of the scientific and technical information available on the prevalence of health effects, the existence of safety and health risks, and the adequacy of methods to identify and control hazards [NIOSH 1992]. They have been developed using a weight of evidence approach and formal peer review process. Other OELs that are commonly used and cited in the U.S. include the Threshold Limit Values (TLVs®) recommended by American Conference of Governmental Industrial Hygienists (ACGIH®), a professional organization [ACGIH 2022]. ACGIH® TLVs are considered voluntary guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards." Most OELs are expressed as a time weighted average (TWA) exposure. A TWA exposure refers to the average airborne concentration of a substance over a designated time period, usually a normal 8- to 10-hour workday. Some substances have a recommended Short-Term Exposure Limit (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

The five halogenated anesthetics currently used in the United States are halothane, isoflurane, enflurane, desflurane, and sevoflurane. No NIOSH RELs exist for the three most currently used anesthetics (isoflurane, desflurane, and sevoflurane) [OSHA 2000]. In 1977, NIOSH recommended that occupational exposure to halogenated anesthetic agents, when used as the sole anesthetic, should be controlled so that no worker would be exposed to time-weighted average concentrations greater than 2 ppm over a sampling period not to exceed 1-hour. When halogenated anesthetics are associated with nitrous oxide, NIOSH recommends that the limit value should not exceed 0.5 ppm over the same sampling period. This occupational exposure limit was recommended by NIOSH for the type of anesthetic gas to which isoflurane and sevoflurane belong, but before they effectively came into use. NIOSH also recommends that occupational exposure to nitrous oxide should not be greater than 25 ppm [NIOSH 1977]. ACGIH included a Threshold Limit Value (TLV) of 50 ppm for isoflurane over an 8-hour shift in the 2022 updates to its *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices* [ACGIH 2022].

Table 1 – Occupational Exposure Limits

Anesthesia Gas	NIOSH REL+	ACGIH TLV	OSHA PEL
Nitrous Oxide	25 ppm	50 ppm	None
Isoflurane	None *	50 ppm	None
Sevoflurane	None *	None	None

+ The 1977 NIOSH REL for halogenated gases is 2 ppm, established over a sampling period not to exceed 1-hour, but it does not explicitly include isoflurane or sevoflurane.
* When used in combination with nitrous oxide, NIOSH recommends exposures to halogenated gases to be kept below 0.5 ppm over a sampling period not to exceed 1-hour

Methodology

This report summarizes the results of three surveys conducted between May 2019 and January 2020 that ranged from one to three days in length, depending on the size of the hospital or clinic PACU. At each field site, clinic/hospital staff provided information about the day-to-day activities and the frequency of patient flow in the PACU and OR units. Discussions also included the use of personal protective equipment (including surgical masks, goggles, and other hospital required equipment), engineering controls (especially those using ventilation), and work practices. Initial characterization of each PACU included documentation of the number of patients during the evaluation, the anesthetic gases in use during surgery, the length of anesthesia, measurement of room ventilation and calculation of air change rates, characterizing area WAG concentrations and the capabilities of the PACU/OR room ventilation system to dilute/remove observed concentrations. In addition to ventilation measurements, a smoke tracer was used to evaluate the direction of the airflow and to assess the control performance. Unlike in the OR, where doors are intended to remain closed, the PACU doors are constantly opened and closed for patient flow. The smoke tracer evaluations sought to determine the extent to which this movement potentially impacted protective ventilation airflows.

Sampling Strategy and Procedures

Hospital and PACU access were coordinated through research partners, including staff from ASPAN and Indiana Oral and Maxillofacial Surgery. Three PACU units were evaluated:

1. PACU 1: was an open-concept PACU with soft fabric curtain dividers between patients to provide patient privacy when needed or requested. This PACU had an approximate capacity for 12 patients at any given time. During the evaluation, only half of the unit was being used for patient care activities. The other half was used as bed storage/preparation for additional patient flow. Patient care in this PACU included the use of an engineering control device that scavenged the WAG once the patients arrived in the PACU and were responsive and extubated. However, pre-extubation times, before the scavenging device could be placed, could be up to 15 to 20 minutes after entering the PACU. The engineering control was a mask that delivered oxygen to the patient while providing suction to remove the exhaled gases. The floor plan of this PACU was of two irregular rectangles with an approximate floor area of 1500 ft^2 and 9 ft ceilings, resulting in a total volume of 13500 ft^3. See Figure A1 in the Appendix Section.
2. PACU 2: was a closed-concept PACU with 3 solid walls per bay and a soft fabric curtain on the front of the bay for patient privacy. This PACU consisted of 7 bays (7-patient capacity) with 2 bays rated as negative pressure rooms. The two negative pressure rooms had a glass sliding door to allow the room to seal with respect to the rest of the PACU. The PACU unit is part of a larger wing of the hospital with an approximate PACU floor area of 2800 ft^2 and 9 ft ceilings for a total volume of 25200 ft^3. See Figure A2 in the Appendix section.
3. PACU 3: was an open-concept PACU with soft fabric curtain dividers between patients to provide patient privacy when needed or requested. This PACU had capacity for 6 patients, including a private examination room adjacent to the PACU. The floor plan of this PACU was of three irregular rectangles with an approximate floor area of 800 ft^2 and 9 ft ceilings for a total volume of 7200 ft^3. See Figure A3 in the Appendix section.

Area concentrations of WAGs were evaluated with up to three GASMET DX4040 Fourier transform infrared (FTIR) spectrometer analyzers (GASMET Technologies, Helsinki, Finland). The GASMET can collect real time data for multiple gases simultaneously, including sevoflurane, isoflurane, nitrous oxide, water vapor, carbon dioxide, carbon monoxide, methane, nitrogen monoxide, and nitrogen dioxide. The analog output signal from the GASMET was displayed and logged at six-second intervals in real-time on a portable computer. Area measurements were collected at the nurses' station, and in close proximity to two patient beds. No personal or breathing zone samples were collected in this portion of the study. When more than one patient bed was sampled, the instruments were positioned so there was at least one bed/patient in-between the two samples. A zero offset error was observed in some datasets, so a correction was made for all data based on an average background in the first 5 minutes of the data collection for each sampling session.

As indicated in the Occupational Exposure Limits section of this report, NIOSH recommends that occupational exposure to halogenated anesthetic agents, when used as the sole anesthetic, should be controlled so that no worker is exposed to time-weighted average concentrations greater than 2 ppm during anesthetic administration over a sampling period of less than 1-hour. When halogenated anesthetics are associated and used with nitrous oxide, NIOSH recommends that the limit value of the halogenated anesthetic not exceed 0.5 ppm over the same sampling period. This occupational exposure limit was recommended by NIOSH for the type of anesthetic gas to which isoflurane and sevoflurane belongs, but before they effectively came into use. No specific NIOSH RELs exist for isoflurane, desflurane, and sevoflurane. NIOSH also recommends that occupational exposure to nitrous oxide should not be greater than 25 ppm. For these reasons, the concentration data for each WAG was averaged over 1-minute and then a 1-hour rolling average was calculated for each of the collected datasets (sevoflurane, isoflurane, and nitrous oxide). Excursions over the NIOSH recommendations for halogenated gases were quantified based on the following two conditions:

1. When no nitrous oxide was detected, excursions above the NIOSH recommendations were considered as the number of minutes that the 1-hour rolling average was over 2 ppm
2. When nitrous oxide was detected, excursions above the NIOSH recommendations were considered as the number of minutes that the 1-hour rolling average of halogenated anesthetic concentration was over 0.5 ppm

A TSI Accubalance® Plus Air Capture Hood Model 8373 (TSI Incorporated, St. Paul, MN) was used to measure airflow for the room supply and return ventilation in the evaluated PACUs. The instrument was setup according to the manual and using the 2 ft x 2 ft flow hood to match the geometry of the supply and exhaust louvers. The measured airflow was displayed in cubic feet per minute (cfm). This information was used to calculate the number of air changes per hour (ACH) and compared to the prescribed values within *ANSI/ASHRAE Standard 170-2017 Ventilation for Health Care Facilities*.

A Wizard Stick (Zero Toys, Inc., Concord, MA) handheld "smoke" generator was used to visualize air movement inside the PACU and around the periphery of the door openings. The wizard stick produces a stream of condensed vapor droplets that result in a visual tracer whose flow path reveals flow patterns within the PACU. The tracer released around the periphery of the PACU door openings provided a visual indication of room pressurization. If the smoke escaped the PACU, then the PACU was under positive pressure relative to adjacent rooms and hallways. If the smoke was pulled into the PACU, then the PACU was under negative pressure. This was done to assess the potential for WAG migration to other sections of the hospital. ASHRAE Standard 170-2017 does not include PACU requirements for pressure relationship to adjacent areas [ASHRAE 2020].

Results

The aim of this series of surveys was to collect baseline area concentrations of WAGs from different PACU configurations. The GASMET instruments provided data for multiple gases. Table 2 below presents general sample information and the maximum 1 minute average value for each of the sampled gases expressed in ppm. Sample times varied based on PACU access and patient flow throughout the day.

Table 2 – General Sample Information

				Maximum Concentration (ppm)		
Date		**Sample Time (min)**	**PACU**	**Nitrous Oxide**	**Isoflurane**	**Sevoflurane**
15-May	Bed 2	159	1	0	N/A	16.1
12-Jun	Bed 2	498	1	0.01	4.6	27.5
	Bed 4	510	1	2.6	0.55	34.3
20-Aug	Bed 2	542	1	0.10	N/A	19.3
	Bed 4	470	1	2.0	1.1	17.7
	Nurse Station	487	1	0	0.50	0.65
21-Aug	Bed 2	211	1	0.06	0.25	2.9
	Bed 4	271	1	0.07	0.18	13.9
10-Sep	Bed 17	755	2	0	0.53	8.9
	Nurse Station	698		0.33	0.94	10.2
13-Nov	Bed 21	651	2	0.3	7.9	9.1
	Nurse Station	612	2	0.05	11.2	8.2
14-Jan	Beds 1 & 2	424	3	3.9	6.0	9.2
	Beds 2 & 3	477	3	17.5	6.1	46.2

15-Jan	Beds 2 & 3	179	3	2.6	2.1	5.6
	Nurse Station		3	0.6	0	0.3

Table 3 below includes the number of minutes, reported for each of the GASMET sample positions, where the 1-hour rolling average area sample concentration of halogenated WAG's were above 2 ppm (when no nitrous was present) or above 0.5 ppm (when nitrous gas was present).

Table 3 – Time (minutes) when area sample concentrations were above the NIOSH recommendations for halogenated anesthetics

Monitor Location		Nurse's station		Near patient bed A			Near patient bed B		
Date	**PACU**	**No nitrous oxide**	**With nitrous oxide**	**No nitrous oxide**	**With nitrous oxide**	**Number of patients**	**No nitrous oxide**	**With nitrous oxide**	**Number of patients**
15-May	1	N/A	N/A	59	0	3	N/A	N/A	N/A
12-Jun	1	N/A	N/A	13	133	5	0	69	6
20-Aug	1	0	0	109	6	7	0	25	6
21-Aug	1	N/A	N/A	0	2	4	0	7	3
10-Sep	2	86	22	0	0	5	N/A	N/A	N/A
13-Nov	2	158	0	92	189	4	N/A	N/A	N/A
14-Jan	3	N/A	N/A	0	302	4	0	236	7
15-Jan	3	0	0	0	2	4	N/A	N/A	N/A

Note: NIOSH recommendations with no nitrous oxide: 2 ppm NIOSH recommendations with nitrous oxide: 0.5 ppm. N/A means no measurements were collected at these locations.

For PACU 1: On May 15, June 12, and Aug 20 and 21: Monitor A was placed near bed 2 and monitor B near bed 4 except for May 15 when monitor B was not used.

For PACU 2: On Sept 10: Monitor A was placed near bed 17.

On Nov 13: Monitor A was placed near beds 21 & 20.

For PACU 3: On Jan 14: Monitor A was placed near beds 1 & 2 and monitor B near beds 3 & 2.

On Jan 15: Monitor A was placed near beds 2 & 3.

Plots were developed for each instrument used during the multiple days of sampling for analysis. Additionally, plots were generated for each gas and the calculated rolling average was included to visualize those excursions where the rolling average was above the NIOSH recommendations for halogenated anesthesia gases. Figures 1 – 3 below are provided to illustrate the 1-minute and 1-hour rolling average WAG concentrations over various sampling days and locations.

Figure 1 – Plot of 1-minute average nitrous oxide concentration and 1-hour rolling average on 01/14/2020 at beds 2 and 3

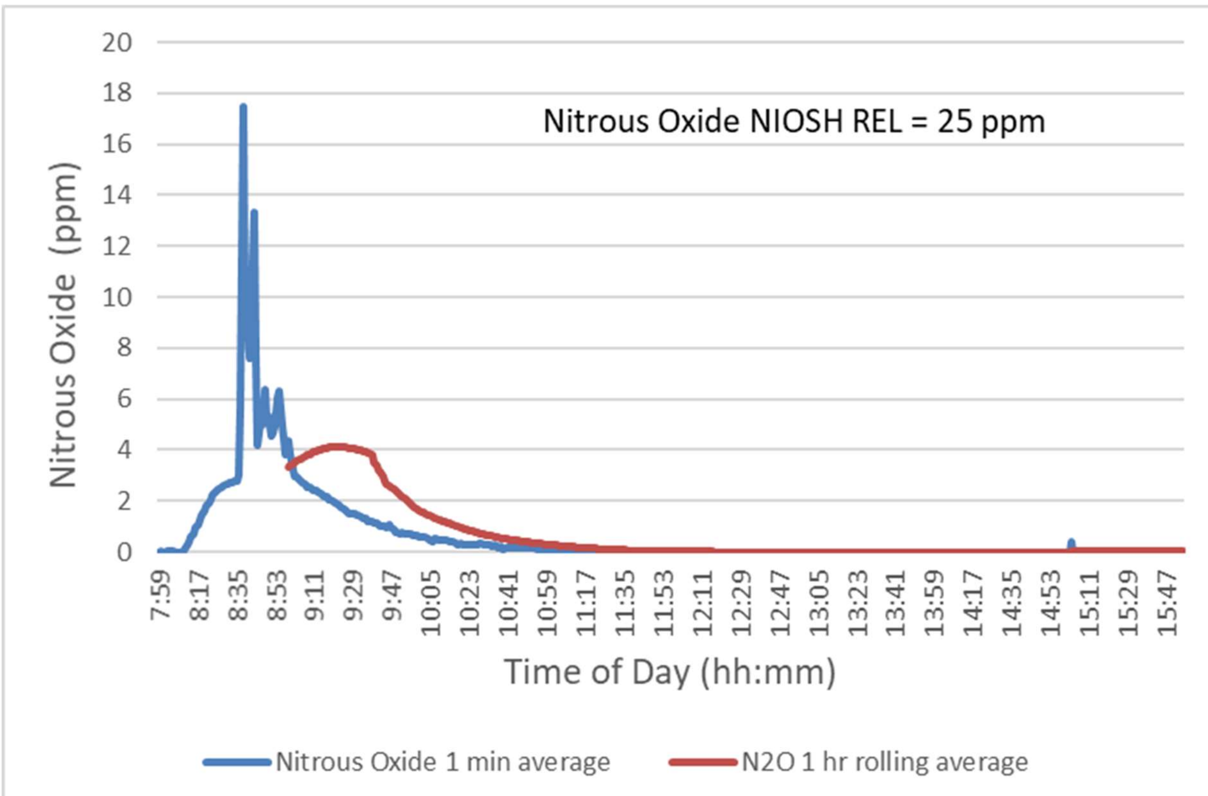


Figure 2 – – Plot of 1-minute average isoflurane concentration and 1-hour rolling average on 11/13/2019 at bed 21

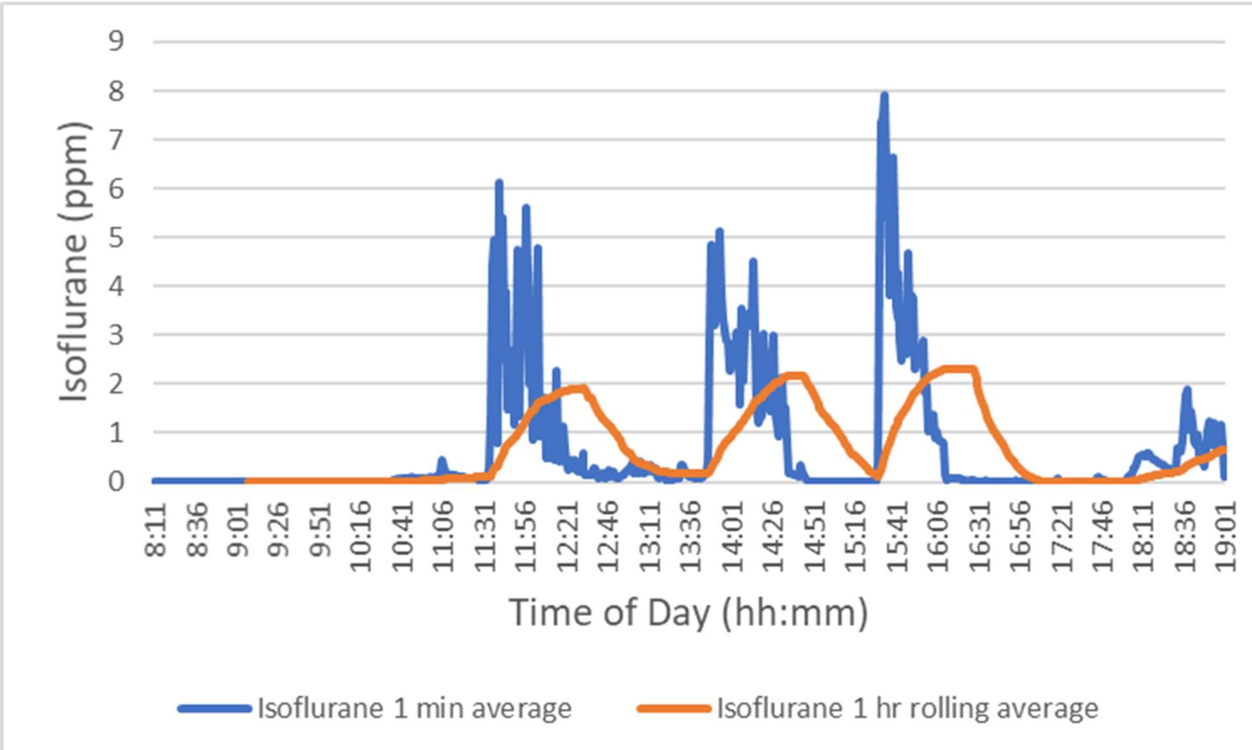
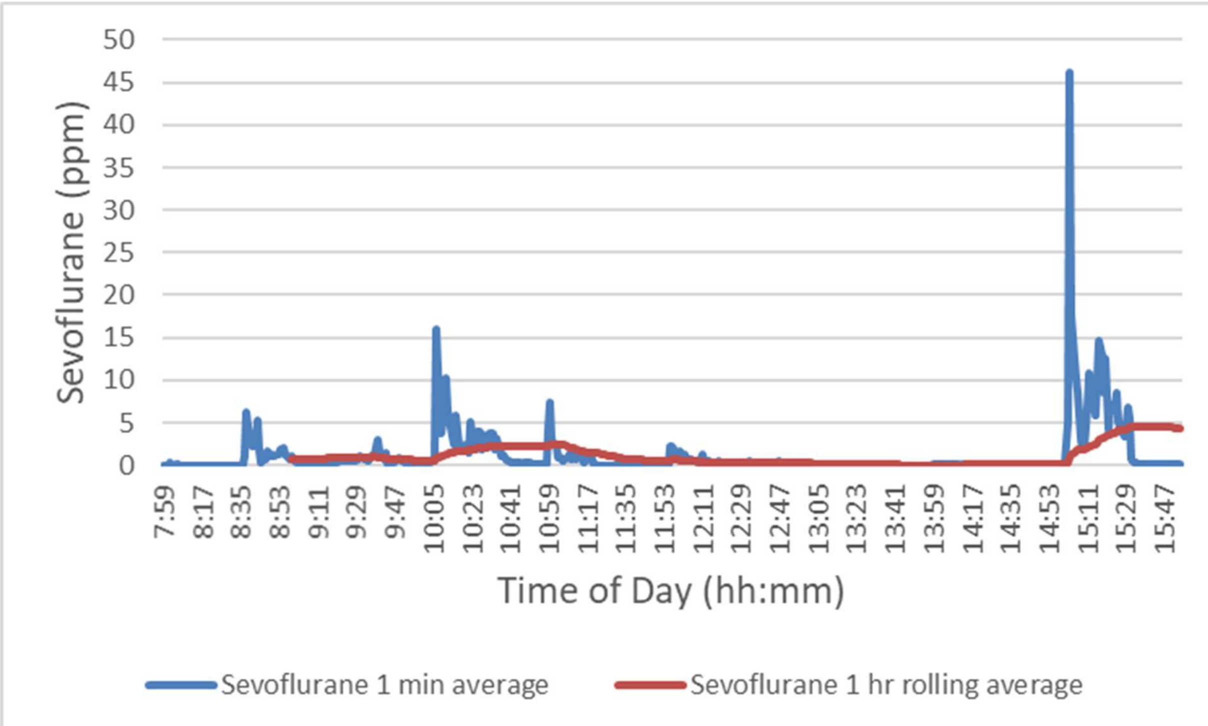


Figure 3 – Plot of Real Time Sevoflurane Concentration and Calculated 1-hour Rolling Average 01/14/2020



The TSI Accubalance® Plus Air Capture Hood was used to measure PACU supply and exhaust airflows. Table 4 reports the measured supply and exhaust flow rates, the calculated number of ACH, and the room pressurization status as observed using the tracer smoke method previously described. Each PACU's room volume and exhaust airflow were used to calculate the ventilation rate in ACH.

Table 4 – Ventilation Summary

PACU	Volume (ft^3)	Supply (cfm)	Return (cfm)	ACH	Pressurization
1	13331	1278	421	5.75	Positive
2	24878	3227	2498	7.78	Positive
3	7128	952	674	8.01	Positive

Discussion

This series of field surveys reinforces the need for engineering control approaches to reduce area concentrations of WAGs such as nitrous oxide and halogenated anesthetic agents that can contribute to potential overexposures. Since the patient becomes the source of the WAG, the protective controls offered by the scavenging system in the OR are lost as the patient progresses into the post-anesthesia care unit (PACU). In PACU units, because there are limited engineering source controls, dilution ventilation is typically the only strategy used to reduce the concentrations of WAGs. ASHRAE Standard 170-2017 prescribes a minimum of 6 ACH of total ventilation air that includes a minimum of 2 ACH of outdoor air [ASHRAE 2020].

While they did not directly represent actual occupational exposures, the observed area sample WAG concentrations were compared against NIOSH recommendations for halogenated anesthesia gases for relative interpretation. All of the evaluated PACU units had area sample concentrations that exceeded one or more of the NIOSH recommendations for halogenated gases. As mentioned in the occupational exposures section, no NIOSH REL exists for sevoflurane and isoflurane. In 1977 an occupational exposure limit was recommended by NIOSH for the type of anesthetic gas to which isoflurane and sevoflurane belong, but this occurred before they effectively came into use. NIOSH recommends limiting exposure for halogenated waste anesthetic gas to 2 ppm in a 1-hour time period when used as the sole anesthetic. When halogenated anesthetics are associated with nitrous oxide, the NIOSH recommendation is 0.5 ppm over the same sampling period.

The maximum 1-minute average concentration of nitrous oxide in PACU 1 was recorded at 2.6 ppm which was well below the 25 ppm NIOSH REL for nitrous oxide (see Table 2). The maximum 1-minute average concentrations of isoflurane and sevoflurane were recorded at 4.6 ppm and 34 ppm respectively. There were excursions over the NIOSH recommendations which indicates that the PACU ventilation system was not always able to effectively remove and/or sufficiently dilute contaminants below the applicable 0.5 ppm recommendation. For PACU 1, cumulative excursions above the NIOSH recommendations lasted between 1 and 2 hours depending on the day. PACU 1's HVAC ventilation rate was 5.75 ACH which is slightly below the 6 ACH total air requirement prescribed by ASHRAE.

The maximum 1-minute average concentration of nitrous oxide in PACU 2 was recorded at 0.3 ppm which is well below the NIOSH recommendations for halogenated gases (see Table 2). The maximum 1-minute average concentrations of isoflurane and sevoflurane were recorded at 11.2 ppm and 10.2 ppm respectively. PACU 2 also had multiple excursions where the rolling average concentration exceeded the NIOSH recommendations. The length of these excursions over the NIOSH recommendations ranged from approximately 1.5- 3 hours, which indicates that the PACU ventilation was unable to provide adequate airflow to keep concentrations below the recommended limits at all times throughout the shift. Total air ventilation rates for PACU 2 were measured to be 7.78 ACH, which were above the 6 ACH prescribed by ASHRAE.

The maximum 1-minute average concentration of nitrous oxide in PACU 3 was 17.5 ppm (see Table 2). An instantaneous spike of nitrous oxide occurred during this sampling session but it was quickly diluted and dissipated by the PACU ventilation system. The average nitrous oxide concentration for that specific unit was consistently below the NIOSH recommendations for halogenated gases. The maximum 1-minute average concentrations of isoflurane and sevoflurane were 6 ppm and 46 ppm respectively. Though the spikes observed in isoflurane and sevoflurane were instantaneous, they were sufficiently large that they caused the rolling average to exceed, in certain cases, the applicable NIOSH recommendations. When there was no nitrous oxide present in the room, the ventilation system in PACU 3 maintained isoflurane and sevoflurane area concentrations below the applicable 2 ppm recommendation. However, when nitrous was present, the rolling average area concentration exceeded the 0.5 ppm recommendation on several occasions. These excursions lasted between 4 and 5 hours in the patient room areas. The total air ventilation rate for PACU 3 was measured to be 8.0 ACH, which was above the 6 ACH prescribed by ASHRAE.

When matched with the patient flow and activity data, the generated plots for each of the sampled halogenated gases revealed that most peaks occurred when multiple patients were moved into the PACU or when patients were extubated. In addition, these plots provide visual feedback on how the calculated 1-hour rolling average compares to the NIOSH recommendations. The generated plots indicate that all three PACU's experienced several excursions where the 1-hour rolling average exceeded the NIOSH recommendations. Additionally, all PACU's were under positive pressure when compared to adjacent hallways and rooms, which indicates the potential for migration of the WAGs into other sections of the healthcare facility.

Routinely, a large percentage of patients (if not all) arriving to the PACU are still sedated and intubated. This appears to adversely impact occupational WAG exposures in the PACU since the amount of WAG's emitted by a patient is highest immediately following disconnection from the anesthesia delivery and scavenging systems. The WAG concentration in patient-exhaled breath slowly decreases as time elapses and the patient inhales anesthetic-free air that clears the respiratory system. The presence of the intubation tube also interferes with some local source control interventions. The increase in intubated patients coming into the PACU might require modifications to work practices (e.g. extubations in highly ventilated OR), design standards, and occupational protections to better control higher emission rates within the PACU. Additionally, engineered source control solutions may be necessary to capture emissions and control exposures more effectively below applicable recommended exposure limits.

Conclusions and Recommendations

Controlling exposures to occupational hazards is the fundamental method of protecting workers. Traditionally, a hierarchy of controls is used to determine how to implement feasible and effective controls [NIOSH 2015]. One representation of the hierarchy of controls can be summarized as follows:

- Elimination
- Substitution
- Engineering Controls (e.g. ventilation)
- Administrative Controls (e.g. managed work schedules)
- PPE (e.g. respirators)

The idea behind this hierarchy is that the control methods at the top of the list are potentially more effective, protective, and economical (in the long run) than those at the bottom. Following the hierarchy normally leads to the implementation of inherently safer systems, ones where the risk of illness or injury has been substantially reduced.

Although the observed concentrations were area samples and not worker breathing exposures, all three evaluated PACU's experienced area concentration excursions above the NIOSH recommendations for halogenated gases. All of them on any given day experienced at least 1-hour over the NIOSH recommendations. These observations showed that the room dilution ventilation, at the current air exchange rates, was insufficient to keep WAG area concentrations below the NIOSH recommendations for halogenated gases. Work practice changes regarding patient intubation and anesthesia status may be contributing to elevated WAG concentrations in the PACU environment. ASHRAE Design Standard 170, Ventilation for Health Care Facilities, may or may not reflect this changing practice. In addition, engineered source control techniques might provide a more efficient way to control these emissions and exposures prior to their wider release into the overall PACU environment. Effective source control is a proven way to minimize WAG exposure and prevent the release of WAGs into the PACU environment.

As mentioned in the methodology section, PACU 1 used an engineering control device that scavenged the WAG once the patients arrived in the PACU and were responsive and extubated. This provided PACU staff with a tool to control WAG emissions for the post-extubation time period, which could be up to 15-20 minutes after entering the PACU. However, field study observations and healthcare worker feedback revealed some limitations that could prevent it from being fully effective. Potential limitations included:

1. The scavenging device can only be used once the patient is extubated, which leaves the period when patients are off gassing the highest WAG concentrations unprotected by local source control. Once the patients are extubated, an engineered source control may effectively help minimize exposure to WAGs.

2. There is no pediatric alternative for this engineering control solution.
3. Some patients wake up combative and remove the engineering control device for a brief period of time, until the source control device can be reapplied.
4. Patients that had facial procedures are not able to use the engineering control solution.

The following considerations associated with hospital work practices as well as the PACU design itself could reduce unintentional exposures to WAG:

- Ensure that all PACU staff are aware of the presence and potential health effects associated with exposures to WAGs.
- Industrial hygiene evaluations should be conducted to document WAG exposures within the breathing zones of PACU healthcare workers.
- ASPAN and/or NIOSH should continue research and engage with healthcare facility design professionals such as ASHRAE to investigate if the prescribed ventilation rates for PACUs are sufficient given current patient flow and anesthesia practices that impact the WAG emissions/loads experienced within the modern-day PACU.
- ASPAN, possibly in conjunction with the American Industrial Hygienists Association, might consider publishing a best practices document that addresses OR/PACU work practices with the potential to reduce worker exposures to WAGs.
- Continue research to identify engineered local source controls that reduce dependence on dilution ventilation to control WAG exposures in the PACU.

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Appendices

Figure A1: Floor Plan of PACU 1.

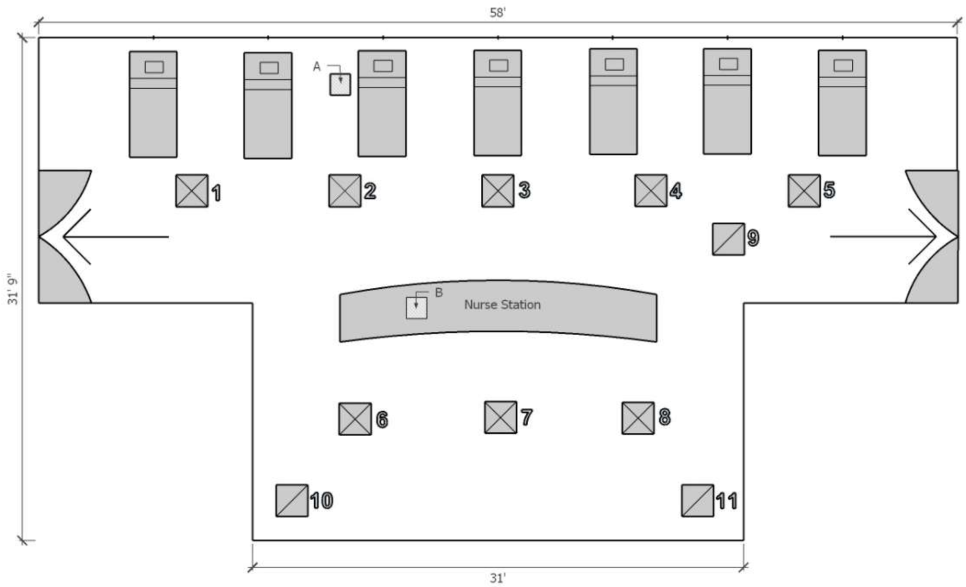


Figure A2: Floor Plan of PACU 2

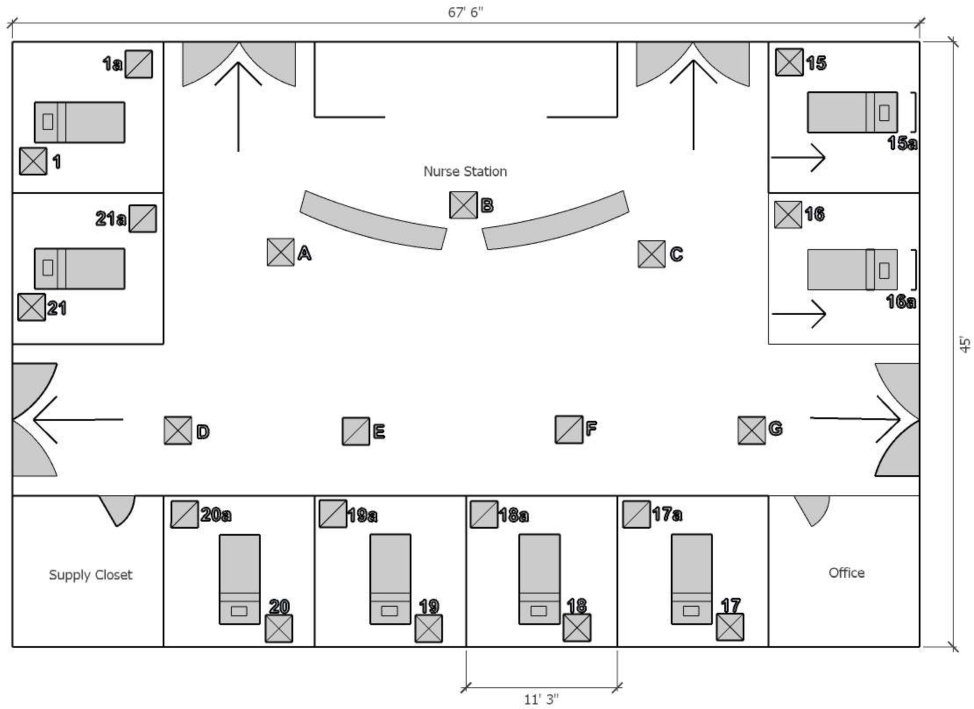
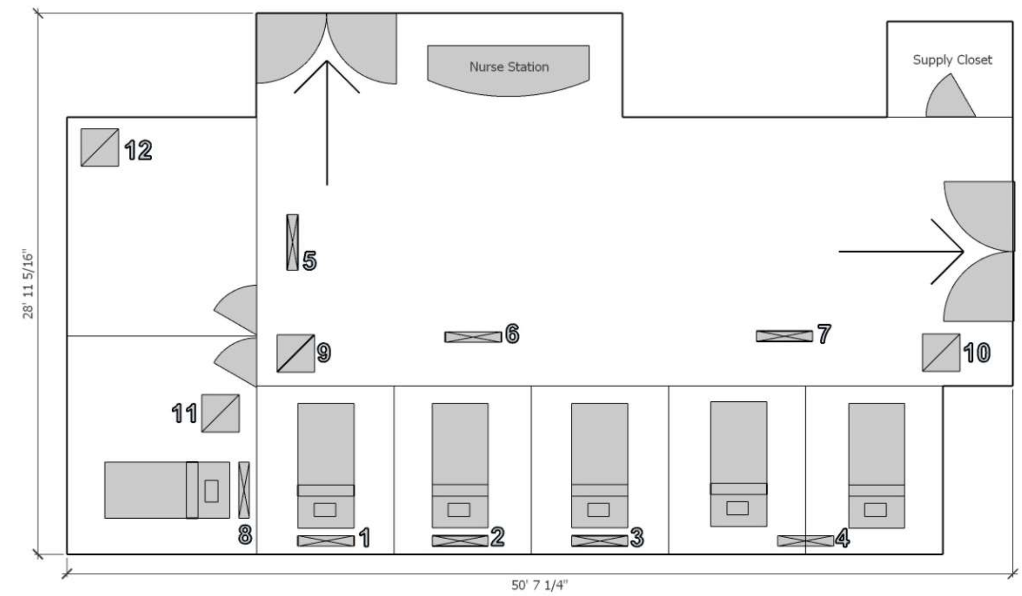


Figure A3: Floor Plan of PACU 3



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