IN-DEPTH SURVEY REPORT

CONTROL OF ANESTHETIC GASES IN DENTAL OPERATORIES

AT

Children's Hospital Medical Center
Dental Facility
Cincinnati, Ohio

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INTRODUCTION

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 (DHHS), it was established by the Occupational Safety and Health Act of 1970 This legislation mandated NIOSH to conduct a number of 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 Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control

Since 1976, ECTB has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques 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 a number of steps or phases Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concepts or 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

In October 1986, NIOSH began an evaluation of dental operatories which use scavenging systems This evaluation had two goals (1) to determine if there are scavenging systems which will reduce waste nitrous oxide (N_2O) levels in dental operatories to the NIOSH Recommended Exposure Level (REL) of 25 ppm during the time of administration, and (2) if such systems do not exist, then to determine why they fail to meet the NIOSH criteria and provide recommendations on how this criteria can be met [Note that waste N_2O will be referred to as N_2O in the text from this point on]

The purpose of this report is to present the results of our investigations of the function and uses of the Fraser-Harlake Scavenging System (presently called the OHMEDA Scavenger System) to control N_2O to NIOSH Recommended Exposure Levels (RELs) during dental surgery

DEVELOPMENT AND USE OF NITROUS OXIDE IN CONSCIOUS SEDATION

For more than 100 years, N_2O has been mixed with oxygen and used in dentistry as a general anesthetic agent, an analgesic, and as a sedative With the development of more effective local anesthetics to manage pain, N_2O is used today primarily for psychosedation Its use reduces fear and anxiety in the conscious patient It is estimated that 85 to 90 percent of the patients receiving N_2O and oxygen are well sedated with 40 percent N_2O and 60 percent oxygen [1]

In 1977, T W Jones and W Greenfield estimated that approximately 35 percent of the dentists in the United States have N_2O anesthetic systems at their facility [3] It is estimated that more than 100,000 dental personnel are involved in administering N_2O to about 4 5 million patients annually in the United States [4,5]

PHYSICAL AND TOXIC PROPERTIES OF NITROUS OXIDE

PHYSICAL PROPERTIES

N_2O is an odorless, stable, noncombustible, colorless, tasteless gas that is approximately 1 5 times heavier than air The oxygen atom accounts for the oxidizing capacity of N_2O, which is a thermodynamically unstable endothermic (i e , heat absorbing) compound N_2O is manufactured commercially by thermally decomposing ammonium nitrate and purification of its byproducts [6]

SYSTEMIC EFFECTS

N_2O does not combine with hemoglobin, but is carried in the blood in a physical solution [7] It is eliminated from the body unchanged by way of the lungs, a slight amount may be excreted through the pores of the skin [8] N_2O is a weak anesthetic with rapid onset and rapid emergence,[9] and will disappear from the body in 17 to 35 minutes after anesthesia is discontinued [8] N_2O can produce several changes in cardiovascular function N_2O may depress the myocardium while stimulating the heart by central activation of the brain nuclei [10] It decreases cardiac output, stroke volume, mean arterial pressure, stroke work, and minute volume [11] Similar effects are seen in blood pressure, pulse rate, and respiration [12] In 1979, Vean and King stated that N_2O acted solely on the cerebral cortex, thus causing a mild depression and that N_2O was not allergenic [13] Amess and coworkers point out that N_2O may interfere with the function of vitamin B_{12} [14] More recently, the toxic effects have been traced to the ability of N_2O to inactivate the enzyme methionine synthetase, by oxidizing the enzyme's vitamin B_{12} cofactor Methionine synthetase allows for the synthesis of methionine and folinic acid, which are needed for deoxyribonucleic acid (DNA) synthesis [15] Researchers believe that the enzyme inactivation may explain the epidemiologic, clinical, and animal evidence that N_2O can injure various tissues of the body, including the brain, blood-forming elements, lung, kidney, and the developing fetus Supporting documentation by Sweeney et al (1985) provided direct evidence that occupational exposure to N_2O may cause depression of vitamin B_{12} activity resulting in measurable changes in bone marrow secondary to impaired synthesis of DNA [16]

REPRODUCTIVE EFFECTS

Human Studies

This agent, along with others including halogenated anesthetic compounds, has been identified in epidemiological studies as suspected reproductive health hazard to those exposed The first published report of adverse reproductive effects of work in operating theaters was by Dr A.I Vaisman, in 1967 [17] Dr Vaisman noted that 18 of 31 female anesthesiologists who had been pregnant had experienced at least one miscarriage Studies in Sweden, the United

Kingdom, and the United States generally showed adverse reproductive effects in females working in operating rooms [18,19,20] In a case-control epidemiological study of dentists, liver disease and spontaneous abortion were significantly higher among dentists (spouses of male dentists for spontaneous abortion) exposed to inhalation anesthetics more than 3 hours per week, compared with controls which used no inhalation anesthetics in their practice [21] The most comprehensive epidemiological study of health dysfunction associated with work in the operating room was conducted by NIOSH, where data were obtained from 40,044 respondents [21] Females working in the operating room demonstrated an increased incidence of spontaneous abortion and carcinoma Birth defects in their offspring were elevated, as were the offspring of nonoccupationally exposed wives of exposed male anesthetists Liver disease was also increased in both males and females In addition, spontaneous miscarriage and birth defects are confirmed in a survey of female anesthetists in the United Kingdom [21] The findings of several epidemiologic surveys were recently summarized by James T Purdham of the Occupational and Environmental Health Unit, University of Toronto, Toronto, Ontario [22] The consistent finding from these studies shows that women exposed to waste anesthetic gases have a higher than expected incidence of spontaneous abortions Congenital abnormalities in the offspring of exposed women were less strongly associated, but were slightly higher than normal [23]

Animal Studies

Supporting evidence of the toxic effect of anesthetic agents is shown in laboratory studies The evidence includes teratogenic effects in various species upon exposure to a wide group of inhalation agents at anesthetic concentrations,[31] decreased survival rate in various species, ultra-structural changes in the central nervous system of rat fetuses following a single maternal exposure, decreased ability to solve maze problems in rats, and evidence of testicular damage after a minimum of 2 days exposure to 20 percent N_2O [31]

Several animal studies have focused on anesthetic gases, principally N_2O and halothane, as a cause of miscarriage or congenital abnormalities When the animals were exposed to high levels of these anesthetics, spontaneous abortion (animal fetal resorption) and congenital abnormalities were observed In one study by Viera and coworkers, spontaneous abortion was observed in rats at 1,000 ppm or more [32] Concentrations of 1,000 ppm have been commonly found in operating rooms and dental operatories not equipped with scavenging systems

CARCINOGENICITY

Excess cancer was found in a small group of Michigan nurse anesthetists by Corbett in 1973 [24] However, another study which evaluated Corbett's work found that the high cancer rate was only for one year and when all data were considered, there was no significant difference between the nurse anesthetists and the control group [25] Tests for mutagenicity (a test for screening carcinogenic agents - those which are mutagenic also tend to be carcinogenic) in bacterial systems have been shown to be negative in most test systems except for the anesthetic fluroxene [26]

LIVER AND KIDNEY EFFECTS

A national study sponsored by the American Society of Anesthetists found that liver disease occurred more frequently among males and females exposed to anesthetic agents, however, kidney disease was less strongly associated with anesthetic exposure [23] Studies supporting these conclusions were also found in England [27] Because the workers were exposed to a mixture of anesthetic agents including halothane and methoxyflurane, it is not known what impact N_2O alone has on liver and kidney dysfunction In animal experiments, N_2O alone was shown to be without effect [22]

CENTRAL NERVOUS SYSTEM EFFECTS

Human studies testing cognitive and motor skills show that exposure to trace concentrations of anesthetic gas mixtures, N_2O/halothane or N_2O/enflurane, and N_2O by itself resulted in decreased ability to perform complex tasks [28,29] These studies suggest that exposed dentists may be working at less than peak efficiency Attempts to duplicate human performance decrements in other laboratory studies have not corroborated these earlier studies [30] While habitual use of N_2O has been linked to damage of the peripheral nervous system, it appears that further research needs to be performed to resolve the safe level of occupational exposure which does not impair performance

CONTROLS

PRINCIPLES OF CONTROL

Occupational exposures can be controlled by the application of a number of well-known principles, including engineering measures, work practices, personal protection, and monitoring These principles may be applied at or near the hazard source, to the general workplace environment, or at the point of occupational exposure to individuals Controls applied at the source of the hazard, including engineering measures (material substitution, process/equipment modification, local ventilation) and work practices, are generally the preferred and most effective means of control in terms of both occupational and environmental concerns In dental operatories, exposure to N_2O may be controlled by

1) effective scavenging devices that remove excess anesthetic gas at the point of origin,

2) proper maintenance of equipment,

3) regular monitoring of environmental exposure for leaks in the anesthesia equipment delivery systems, and

4) good work practices on the part of the dentist and dental assistant

Additional controls which may be applied to anesthetic agent control include dilution, ventilation, and good housekeeping

In general, a system comprised of the above control measures is required to provide worker protection under normal operating conditions, as well as under conditions of procedure malfunction or failure Workplace monitoring devices, personal exposure monitoring, and medical monitoring are important mechanisms for providing feedback concerning the effectiveness of the controls in use The education of dental personnel and commitment of management to reduce and eliminate occupational health problems are also important elements for a complete, effective, and durable control system In dental operatories, a principal control for waste anesthetic gases is the use of nasal scavenging systems The sections which follow, briefly examine the guidelines and controls to reduce sources of N_2O exposure with and without the use of scavenging systems

American Dental Association Guidelines for Design of Scavenging Equipment

The American Dental Association (ADA) has developed guidelines for scavenging equipment [37] According to the ADA guidelines, the scavenging system equipment should have the following characteristics

- adaptable to most existing sedation, anesthesia, and exhaust systems,

- constructed so that it does not significantly interfere with normal breathing system and delivery of selected gas concentrations,

- capable of providing N_2O-O_2 levels which comply with or improve upon minimum levels indicated in current NIOSH and OSHA documents,

- effective regardless of the heating and air conditioning system in use,

- constructed to permit safe and efficient disposal of the gases,

- effective when more than one device is being used simultaneously, and

- constructed such that patient rebreathing will be insignificant

The scavenging system characteristics described by the ADA are thought to be prudent as well as pragmatic, because these guidelines encourage good, cost-effective design that will be accepted by dental practitioners

ENGINEERING CONTROLS

Anesthesia Equipment Without Scavenging Machines

When N_2O leakage is controlled by securing valve fittings and gaskets connected to the anesthesia equipment, gas concentrations will be highest around the breathing zone of the patient, especially the nosepiece where the anesthetic is administered The administered gas concentrations escape from the patient and are diluted by mixing with room air Mixing occurs from the movement of supplied air through ducts or wall-mounted air conditioners, and from the movement of the dentist and dental assistant N_2O concentrations will vary according to the amount of fresh air supplied to the dental room and the room configuration (i e , open or closed architecture)[5] Personal exposure to the anesthetic will vary according to the proximity of the dentist and dental assistant to the breathing zone of the patient Previous survey observations have shown that the dentist usually works within 6 to 12 inches above the patient's breathing zone, while the dental assistant works within 12 to 24 inches of this zone In a still environment, little dilution of N_2O takes place between the working level of the dental personnel and the patient The concentration of N_2O may increase or decrease in the room, dependent upon the general room air ventilation This becomes particularly evident when performing gas analysis with a direct-reading instrument over the course of the dental surgery If the room is not well ventilated, gas concentrations may not return to base line levels, and background concentrations may increase as other operations using N_2O are performed Personal exposures of N_2O found in earlier surveys conducted by NIOSH researchers varied from 25 ppm to 2,400 ppm[38]

Anesthesia Equipment With Scavenging Machines

After the 1977 NIOSH document on controlling waste anesthetic gases in dental operatories was published and recommended the use of scavenging systems,[5] several other publications have presented various systems for controlling these gases [39,40,41] Anesthetic scavenging systems are broken into three components a scavenging or collection device to contain the anesthetic gas in a breathing circuit and ventilator, a disposal system to carry the collected gases from the operating room (i e , a vacuum system), and a device for ensuring that negative or positive pressures in the system do not adversely affect the patient The most common scavenging system design includes a scavenging circuit (Mapelson D), a nasal mask, and a vacuum system The most common nasal mask for scavenged systems has two concentric masks in which anesthetic gases are supplied through a pair of tubes to the center of the mask A second set of tubes are also attached to the outer space of the mask to provide exhaust at a recommended flow rate of 45 liters per minute [5] This configuration allows for scavenging of excess gas supplied to the patient, as well as excess gas which may escape around the edges of the mask.

While such scavenging systems have been shown to significantly reduce anesthetic gas exposure, field studies conducted by NIOSH researchers have shown that, under normal operating conditions, such systems do not consistently reduce N_2O to the recommended exposure limit (REL) of 25 ppm during the period of anesthetic administration [42-48]

A study to determine the efficiency of different scavenging devices by means of a standardized experimental model was conducted by Hallonsten in 1982 Eight different masks were tested under well-controlled sedation techniques Efforts were made to reduce N_2O leakage by employing leak-proof equipment and carefully positioning the nose mask The median dentist breathing zone N_2O concentrations varied from 4 to 385 ppm and the ambient air concentrations (i e , in the dental facility, but not in the dentist's breathing zone) ranged from 0 to 55 ppm [49] These results appear consistent with the NIOSH studies mentioned above for operatories using scavenging systems which showed a range from 0 ppm to 1,300 ppm [42-48]

Ventilation

Fresh air conditioning also may reduce the concentrations of N_2O in the dental suite The recirculating type of air conditioning system is the one most often employed In a recirculating system, a percentage of air is mixed with fresh air and recirculated back into the room Therefore, increasing the amount of fresh air decreases the recirculated N_2O Recirculating systems, which are temperature controlled for fresh air mixing, may supply 100 percent fresh air depending upon the temperature outside In many buildings with recirculating systems, the most cost-effective temperature setting is 55° When the outside air is above or below the 55°F temperature, inside air is mixed with the outside air in varying percentages

In addition to recirculating air conditioning systems, there are "one-pass" nonrecirculating systems which exhaust all dental air outside the building Unfortunately, such systems are expensive to operate because of the amount of air conditioning required for comfortable room temperatures Wall-mounted air conditioning units are another alternative to bringing fresh air into the work environment The drawback of the wall-mounted units is that the dampers are usually manually controlled for bringing in outside air In some units, the dampers are not easily accessible and, therefore, not adjusted for the changing seasons In many buildings where energy efficiency is required, the dampers of these units are locked closed by maintenance personnel, so that only room air is recirculated

METHODS

SCAVENGING SYSTEM AND SITE SELECTION

Based on the available information from the American Dental Association (ADA) regarding scavenging devices for control of waste anesthetics in dental operatories and telephone contact with the manufacturers listed by the ADA, four scavenging systems were recommended for evaluation by NIOSH Fraser-Harlake, Porter-Brown, Blue, and the Comfort Cushion The Fraser-Harlake N_2O Scavenging System was the first of these scavenging systems to be evaluated

Children's Hospital Medical Center (CHMC) Dental Facility in Cincinnati, Ohio, was chosen because it met with the project protocol including one of the four scavenging systems to be evaluated (the Fraser-Harlake scavenging system), a minimum of four dentists, a minimum of four dental surgeries, performance of operations in separate operating rooms, the appearance of good work practices, and sound management of scavenging system use

As mentioned in the introduction of this report, the first goal of this project is to examine the effectiveness of scavenging systems to reduce N_2O to the NIOSH REL To help achieve this goal, preliminary and in-depth surveys were conducted at CHMC Dental Facility in Cincinnati, Ohio, in June 1987, and in April and June, 1988, respectively This facility has nine dentists, eight dental assistants, and eight support staff The facility performs dental work on an average of 41 patients per day with approximately 7 percent of those receiving N_2O during dental surgery This facility has ten dental chairs, all equipped with anesthetic gas delivery and scavenging systems The dental work area has over 3,260 square feet of working space with three basic types of dental operatories closed (one chair - one room), semi-open (two chairs - with 6 foot high partitions), and open (3 chairs - no partitions) The CHMC Dental facility has used the Fraser-Harlake scavenging system for the past 7 years

CONDUCT OF SURVEYS

The preliminary and in-depth site visits were conducted according to the Regulations for Investigations of Places of Employment, Code of Federal Regulations (CFR), Title 42, Part 85a The project officer contacted the dental office in advance of the planned visit and provided details about the goals and objectives of this project

On June 25, 1987, NIOSH researchers performed a preliminary survey at CHMC Dental facility, and on April 21, 1988, NIOSH started its in-depth survey at the same dental facility During this survey, seven dental operations were monitored On June 15, 1988, two more dental operations were monitored in which infrared thermography was used to "visualize" N_2O during surgery The following sections report the aspects of monitoring the dental environment to determine anesthetic gas leak sources during surgery

Real-Time Sampling

During each dental operation, N_2O was measured and recorded continuously The Miran 1A infrared gas analyzer (Foxboro Instruments, Inc , Foxboro, Massachusetts) was used to measure the anesthetic gas concentration levels The variable filter, variable path length infrared analyzer with 20 25 meter cell, was adjusted for N_2O The Miran 1A has direct-reading scales with a response time constant of approximately 15 seconds under continuous operation The lag time is caused by a combination of factors including transport of the gas to the analyzing chamber, mixing of gas in the chamber, and instrument response. Because of the time lag of 15 seconds or more, the peak and low exposures were averaged and do not report the instantaneous N_2O concentrations at the time of exposure However, the performance of this instrument for real-time sampling greatly outweighs this limitation in exposure averaging The Miran 1A sampling port was located approximately 7 to 15 inches above and behind the patient's breathing zone (the average distance of the dentist and dental assistant's breathing zones for each of the dental operations monitored) The following instrument settings were used wavelength of 4 48 micrometers, slit width of 0 50 millimeters, and a path length of 6 75 meters The Miran 1A has a detection range of approximately 1 to 1,000 parts of N_2O per million parts of contaminated air by volume (ppm) The Miran 1A was calibrated before and after each survey A lecture bottle of electronics-grade N_2O calibration gas was used to calibrate the Miran 1A for the detection range mentioned above Gas concentrations registered by the Miran 1A were recorded by a portable computer with a multifunction high speed analog/digital input/output expansion board (Metra Byte, Taunton, Massachusetts) The computer was programmed to accept and store data from the Miran 1A throughout the procedure The memory of the computer exceeded the length of time required to perform all dental operations Data was collected at 1-second intervals and averaged at 15-second intervals

Portable videotape recorders and camera ensembles (Panasonic Video Recorder/Player Model #2, NV 8400 Camera, Panasonic Video Camera, Model #3245) were used during the entire operation Motion and time measurement techniques were used to document activities of the dentist, the dental assistant, and the patient during the operation [50] The internal clock of the camera was synchronized with the computer, so that changes in N_2O concentration could be correlated with dental surgical activities Selected dental surgical activities were identified from the videotapes These activities were coded and inserted on a computer spreadsheet, along with the N_2O concentration data Statistical analysis of the N_2O concentration and changes in concentration were modeled as a function of these work elements from the spreadsheet Statistical analysis and modeling of real-time data to determine exposure sources is shown in Appendix A

There were nine dental operations in which real-time sampling of N_2O was sampled Seven of these operations were correlated with personal breathing zone samples from the dentist and dental assistant Operation #4 was not analyzed in detail, because of anesthesia equipment problems Two operations were monitored with the use of an infrared scanner (Thermovision™ 782 System) in order to visualize the N_2O escaping from the patient's breathing zone during surgery The infrared scanner was necessary to determine N_2O leak profiles from the patient during surgery This information is especially important in determining strategies for N_2O control around the mask and from the patient's mouth

Personal and Area Sampling

During the in-depth surveys, seven samples were taken in the breathing zone of the dentists and dental assistants During each of the seven operations, six general area samples were taken at the room air supply and exhaust vents and areas outside the room

Personal and general area air exposures to N_2O were collected in 30 liter bags and analyzed at the dental facility using a calibrated Miran 1A infrared gas analyzer Battery-powered universal flow sampling pumps (SKC 224-PCXR7, SKC Incorporated, 334 Valley View Road, Eighty Four, Pennsylvania) modified for bag filling were used to draw air through a section of tygon tubing (¼-inch diameter) into a Tedlar™ bag The sampling pumps were calibrated at a flow rate of 1 5 liters per minute (l/min) for both personal breathing zone samples and for general area samples In order to follow the NIOSH criteria of evaluating N_2O during the time of administration, the sampling pumps were turned on when the N_2O was turned on, and turned off when the N_2O was turned off General area sampling was conducted at the entry to the operatory, in the main hallway of the facility, at the room air supply and the room exhaust fixtures, and at the appointment desk (separate from the operatories) The floor plan and sampling areas at CHMC Dental facility are shown in Figure 1

Observation of Work Practices

Work practices of the dentists and dental assistants were evaluated to discern potential anesthetic gas exposure during surgery Dentists and dental assistants were videotaped during surgery Work analysis was conducted by running the videotapes at normal speed and "stop action" to determine work elements, which may increase or decrease anesthetic gas exposure Motion and time measurement techniques were used to catalog the work elements Work elements, which may influence changes in N_2O concentrations, were selected for detailed analysis (see section entitled "Real-Time Sampling")

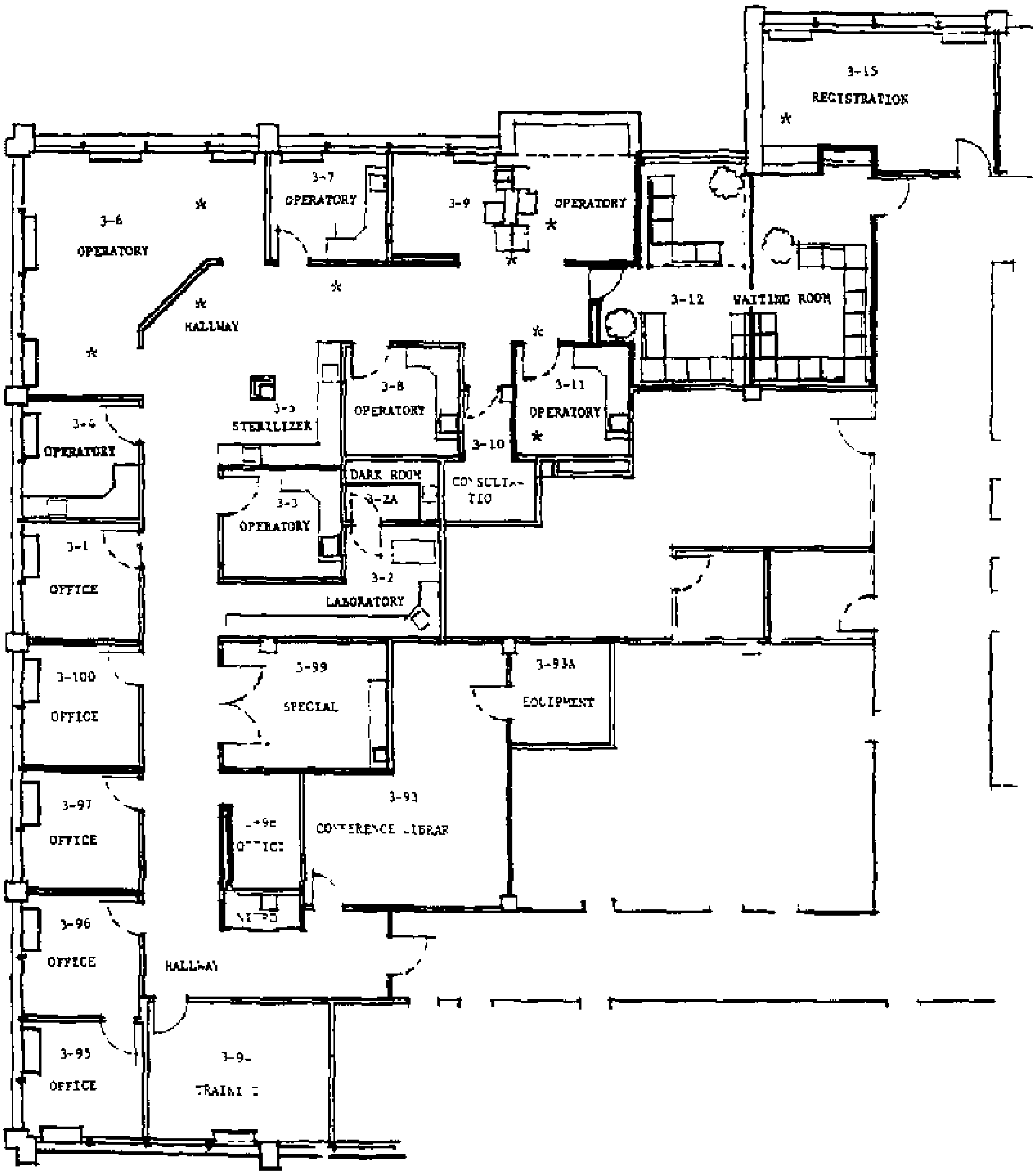
The real-time N_2O data were later synchronized with the videotapes to confirm observation of exposure sources, and to compare N_2O levels during the surgical operation The data acquisition system, used to integrate data from environmental sampling with work practices, is shown in the schematic in Figure 2

Evaluation of General Ventilation Systems

General ventilation measurements were taken for the dental operatories, laboratories, consultation room, equipment areas, dark rooms, sterilizer room, waiting room, offices, and the south and west halls For these areas, the Kurz

Figure 1

Floor Plan and Sampling Areas for NIOSH Surveys at Children's Dental Clinic

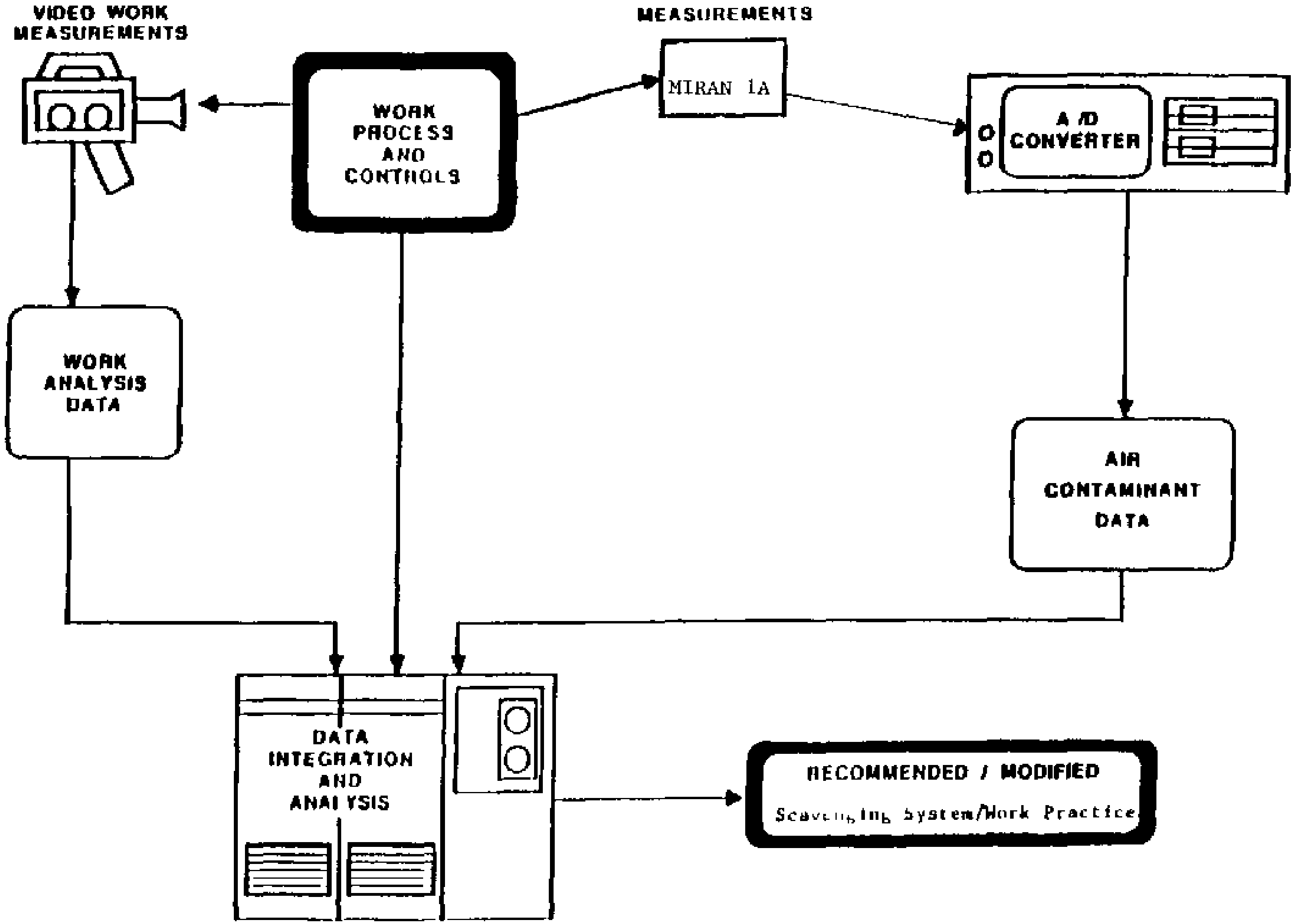


* Areas sampled for waste nitrous oxide by NIOSH researchers.

Figure 2

DATA ACQUISITION SYSTEM

for Evaluating Nitrous Oxide Exposure in Dental Operatories



Model No 480, TSI Model No 1650, and Alnor (Balometer) were used to measure air-velocity and average flow rate, respectively Room air exchange rates were evaluated by determining dental operatory size with the amount of fresh air coming into the room Smoke tubes were used to assist in observation of general airflow patterns Building blueprints were used for locating air duct locations and comparing flow rates with building design specifications

Leak Testing Scavenging Equipment

Leak testing of low-pressure components of the anesthesia scavenging machine was determined by removing the breathing bag from the anesthesia machine, overfilling the breathing bag with O_2, corking the end of the bag, submerging it in water, and palpating the bag's surface to reveal leakage in the form of air bubbles Breathing holes and other low-pressure components were leak tested as a unit Preparations for this test included removing the hoses from the anesthetic machine and adapting a blood pressure gauge to fit the hoses The hoses were sealed at one end and supplied with air to a pressure of 30 mm Hg [5] The hoses were then submerged under water to reveal air bubble leakage For high-pressure leaks, soap solution and a swab applicator were applied around the valve connections of N_2O supply cylinders to check for leaks in the form of soap bubbles

During the surveys, NIOSH researchers noted selection of scavenging masks for proper anthropometric fit Mask selection may help reduce N_2O, if a good fit is made between the patient's nose and the mask size The Fraser-Harlake masks come in small, medium, and large sizes The small masks, or pedo masks as they are called, are designed for children, the medium and large masks for adolescents and adults, respectively If a large mask is used on a child, then there is a possibility that excess N_2O may escape into the dentist's and dental assistant's breathing zone

DATA ANALYSIS

Statistical comparisons were not performed between the personal and general area sampling results General area sampling was performed to determine if N_2O was present outside of the dental operatories, if the N_2O is being recirculated in the buildings ventilation system, and to what extent these areas were contaminated Because no gas cylinder leaks were found during the surveys and the N_2O levels were low relative to the dental operatories, no statistical tests appeared necessary for the general area samples

Paired student t-tests were used to compare differences in N_2O concentrations between the personal breathing zone results of the dentists and dental assistants Paired student t-tests were also performed for the real-time probe results and compared to the personal breathing zone results of the dentists, as well as the dental assistants [51]

Analysis of variance (ANOVA) was used to compare N_2O real-time sampling results for the three operatory configurations (i e , open bay, semi-open, and closed room) that were evaluated [51]

Mallows C_p statistic (which measures the sum of squared biases plus the squared random errors in Y at all N data points) was used to evaluate the contribution of the work activity as a function of changes in N_2O concentration for the dental operations mentioned above. Separate models were tested for each dental operation. The Statistical Analysis System (SAS) Procedure, General Linear Model SAS PROC GLM, was used for this analysis.[52] Note that because of the limited sample size, statistical significance may not be demonstrated for all variables encountered during this in-depth field study. A description of Mallows C_p statistic, as it was used to model the data and determine predictors of N_2O concentration as a function of work activities, is shown in Appendix A.

RESULTS

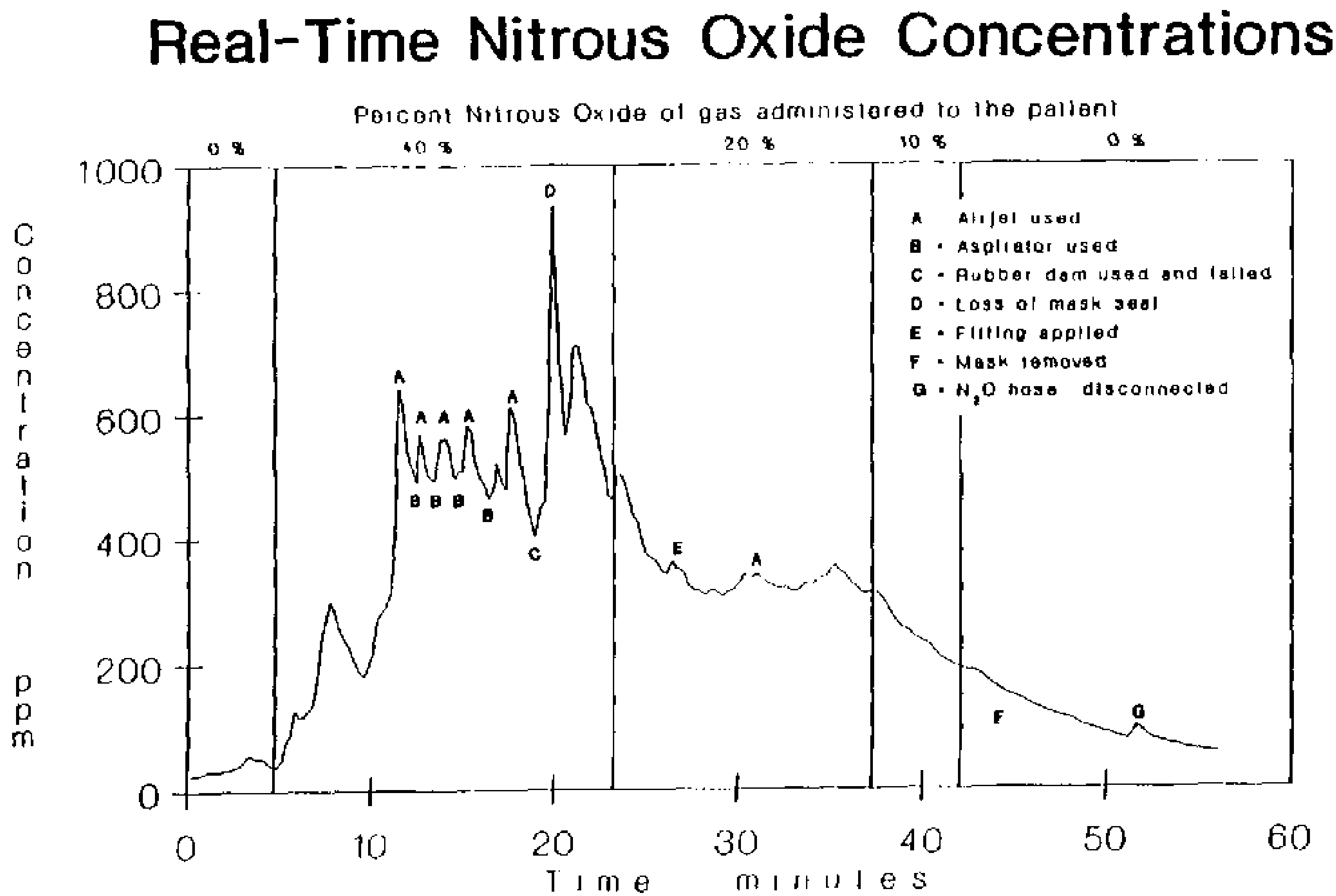
There were seven dental operations in which personal and general area air sampling was conducted for N_2O exposure One of the seven dental operations monitored for N_2O (Operation #4) had malfunctioning scavenging equipment and could not be evaluated for effective N_2O controls Preventive maintenance to avoid future episodes of exposure to N_2O due to equipment malfunction is addressed in the discussion and recommendation sections of this report Three additional runs were conducted without personal sampling one during the preliminary survey and two using an infrared camera to visualize N_2O leak sources during surgery The information which follows shows the N_2O results from all of the runs conducted However, detailed analysis of these data were for the six dental operations in which personal, general area, and real-time monitoring took place, and in which the equipment operated properly

PRELIMINARY FIELD SURVEY TO DETERMINE FEASIBILITY OF IN-DEPTH SURVEYS

On June 25, 1987, a preliminary field survey was conducted for the purpose of monitoring N_2O during dental surgery Anesthetic gas data were gathered with a direct-reading instrument (Miran 1A), work practices were recorded with a videotape recorder and camera ensemble, and general ventilation measurements were taken N_2O concentrations within the breathing zones of the dentist and dental assistant ranged from 25 ppm at the beginning of the operation to 950 ppm 20 minutes into the operation. Seven liters per minute (lpm) of gas was supplied to the patient's nasal mask throughout the operation N_2O was supplied at 2 5 lpm, while oxygen was supplied at 4 5 lpm The mixture provided the patient with 40 percent N_2O and 60 percent oxygen During the 45-minute operation, the dentist "stepped-down" the N_2O from 40 percent to 20 percent to 10 percent to 0 percent The general area concentration of N_2O subsequently decreased to 35 ppm 55 minutes after the operation began Work practices of the dentist and the dental assistant were videotaped and analyzed using traditional job analysis techniques [50] By combining direct N_2O readings with the videotape analysis, several work elements appeared to influence the concentration of N_2O during the course of surgery These elements included use of the scavenging unit, the regulation of N_2O concentration administered by the dentist, the use of a rubber dam (i e , a 6-by 6-inch rubber sheet inserted into the patient's mouth to isolate the operative site from oral fluids), and the dental assistant's use of the saliva aspirator It also appeared that the patient contributed to the dentist's and dental assistant's exposure through respiration of N_2O from the lungs by talking, coughing, and yawning A profile of the real-time sampling for N_2O during the operation is shown in Figure 3

This field survey showed that the use of a scavenging system does not guarantee a reduction in safe working levels of N_2O. During a NIOSH Health Hazard Evaluation and Technical Assistance (HETA) study of the same facility in 1979 (HETA 79-5), N_2O levels for personal exposure ranged from 90 to 3,500 ppm

Figure 3. Changes in Real Time Nitrous Oxide Exposure and Correlation of Dental Work Activities



without scavenging systems [47] While the scavenging system may have reduced N_2O to lower levels, based on these data it does not appear that scavenging alone decreased anesthetic gases to recommended levels Work practices including the regulation of N_2O by the dentist during the course of the operation, location of the dentist's breathing zone relative to the patient's, and the use of the saliva aspirator influences the amount of exposure dental personnel receive while working In addition, the general ventilation, air supply, exhaust, the amount of fresh makeup air, and room air changes per hour also influences exposure to dental personnel in the operating room and elsewhere Inadequate room ventilation also influences the time the N_2O stays in the work environment

IN-DEPTH SURVEY -- PERSONAL SAMPLING

N_2O exposures were generally lower in the open bay (Operatory 3-6) and semi-open bay (Operatory 3-9), compared to the closed room In Dental Operatory 3-6, the following N_2O concentrations were found Dental Operation #7, 160 ppm for the dentist, 113 ppm for the dental assistant, and 473 ppm for the real-time data collected approximately 6 to 13 inches above the patient's head The N_2O results for Dental Operatory 3-9 were Dental Operation #5 and #6, 225 ± 92 ppm for the dentist, 80 ± 47 ppm for the dental assistant, and 445 ± 40 ppm for the space above the patient's head N_2O concentrations were higher in Dental Operatory 3-11 compared to the two and three chair operatories mentioned above Dental Operatory 3-11 is a 10- by 10-foot enclosed room For the three operations monitored, this dental operatory showed a mean N_2O concentration of 709 ± 424 ppm for the dentists, 231 ± 174 for the dental assistants, and 493 ± 282 ppm for the space above the patient's head (Table 1) The mean N_2O concentration for dentists was 487 ± 366 ppm (excluding dental operation #4), for dental assistants, the mean N_2O exposure was 150 ± 144 ppm Paired student t-tests comparing N_2O personal sample results of dentists with dental assistants showed a significant difference (X=6, p< 03) The difference between the dentists' breathing zone results and the dental assistants' is attributed to the closer working proximity of the dentists to the patient compared to the dental assistants

GENERAL AREA SAMPLING

The general area sampling results showing concentrations above the NIOSH REL were observed at the entry to the operatory in five of six of the dental operatory runs and in the main hallway in three of six runs N_2O was not detected at the appointment desk on any of the sampling runs (Table 2)

The closed, semi-open, and open bay operatories were evaluated for N_2O concentrations in the dental operatory room air exhaust and the hallway Dental operatory room-supplied air did not show recirculation in the closed bay, but did show a substantial amount of N_2O recirculation from the Singer wall unit (Dental Operation #5, 49 ppm room exhaust versus 36 ppm room supply, Dental Operation #6, 73 ppm room exhaust versus 50 ppm room supply) The open bay also showed recirculation of N_2O from the Singer wall units, but with a much lower concentration 8 ppm room exhaust versus 4 for room supply These lower concentrations for the open bay may have been a function of (1) the larger area allowing for more dilution of the N_2O, (2) the amount of N_2O

Table 1. Summary of Personal and Real-Time Sampling Data for Nitrous Oxide during Administration

PROCEDURE ID	ROOM	PERSONAL		REAL-TIME MONITORING			
		DENTIST	DENTAL ASS'T	AVG	STD	MAX	MIN
Preliminary Survey	3-8	*	*	372	149	934	78
Dental Op. 1	3-11	223	120	206	125	511	1
Dental Op. 2	3-11	>1000	432	770	476	>1000	0
Dental Op. 3	3-11	904	142	502	503	>1000	0
Dental Op. 4	3-6A	133	88	295	161	638	2
Dental Op 5	3-9A	347	44	282	150	623	2
Dental Op. 6	3-9A	290	47	416	202	713	41
Dental Op. 7	3-6A	160	113	473	305	>1000	0
Dental Op. 8	3-6C	**	**	(473)	(605)	(>1000)	(4)
Dental Op. 9	3-6C	**	**	469	484	>1000	48

NOTES:
* = No personal sampling data was collected during the preliminary survey.
** = No personal sampling data was collected. These two runs were to assess the feasibility of IR thermography.
( ) = Nitrous oxide turned on prior to beginning of sampling period.

Table 2. Summary of General Area Data for Nitrous Oxide during Administration

	INIT CONC	ROOM SUPPLY	ROOM EXHAUST	ROOM DOOR	HALL	APPT DESK
Prelimin-ary Survey	25	#	#	#	#	#
Dental Op 1	4	0	21	##	##	0
Dental Op. 2	2	0	114	38	29	0
Dental Op. 3	0	0	33	38	10	0
Dental Op. 4	4	30	114	95	0	0
Dental Op. 5	2	36	49	45	64	0
Dental Op 6	45	50	73	48	50	1
Dental Op. 7	4	4	8	14	6	0
Dental Op. 8	5	###	###	###	###	###
Dental Op. 9	42	###	###	###	###	###

NOTE:
- # = No general area sampling data was collected during the preliminary survey.
- ## = Not all general sampling data was collected for Dental Op. 1
- ### = These runs were conducted to assess the feasibility of IR Thermography.

administered over time, (3) dental activity, and (4) proximity to the Singer wall units where the open bay chair was approximately 10 feet further away from the Singer air unit compared to the semi-open bay The reason the Singer wall units showed N_2O recirculation was because these units cannot be adjusted to bring in only outside air These wall unit dampers are usually closed during winter to outside air to conserve energy

REAL-TIME SAMPLING

Real-time sampling results for the ten operations ranged from an average N_2O concentration of 206 ppm in Operating Room 3-11 (Dental Operation #1) to 770 ppm in the same operating room (Dental Operation #2) (Table 1) N_2O levels exceeded 1,000 ppm in five of the ten operations monitored N_2O exposures were slightly, but not significantly, higher in the closed bay (493 ppm, Room 3-11) compared to the open bay (471 ppm, Room 3-6c) and the semi-open bay (349 ppm, Room 3-9A) The real-time sampling results followed the same N_2O concentration patterns as the personal sampling results Analysis of variance showed the means of these three sampled areas (i e , closed, semi-open, and open bay dental operatories) were not significantly different ($p= 69$) The nonsignificance may be attributed in part by the low sample size and high variance in N_2O concentrations for the different operatories that were monitored

When the averaged real-time sampling results (442 ppm) were compared to the averaged dentists' personal breathing zone results (487 ppm), there was no significant difference between the means ($p< 68$) However, there was a significant difference between the averaged real-time sampling results and the averaged breathing zone N_2O concentrations among dental assistants (150 ppm) ($p< 014$) Like the differences in personal sampling results between the dentists and dental assistants, the real-time probe results may be attributed to the closer placement of the sampling probe to the patient compared to the breathing zone of the dental assistant Based on the results of this survey, it may be assumed that the real-time sampling results may be more representative of the dentist's exposure than that of the dental assistants

INTEGRATION OF REAL-TIME DATA WITH WORK PRACTICES

Real-time sampling results and work activities were integrated to determine if changes in N_2O concentrations were related to these activities From the videotapes, the following dental activities were selected for analysis local anesthetic injection, instrumentation and extraction of teeth, filling teeth, use of aspirator, water and air syringe, and curing light for composite resin restorative material for teeth Other activities thought to be important for changing N_2O exposure were sampling probe distance, patient talking, when the N_2O was turned on, when the dentist changes N_2O concentrations during dental surgery, and when the N_2O was turned off Appendix B contains the graphs of sampling runs for Dental Operation #1 through Dental Operation #9 For the first seven runs selected, dental surgical activities (marked by vertical lines for activity start and stop times on the graphs) were observed to see if such activities influenced changes in N_2O concentrations Based on analysis of changes in N_2O concentration, it appears that the work activities, such as the use of the rubber dam, the aspirator, air and water syringes, dental work, and patient talking, did not have a significant influence on changes in N_2O exposure Activities which showed significant N_2O concentration changes were (a) when the dentist turned the N_2O gas on, (b) when the dentist adjusted the concentration over the course of the operation, and (c) when the dentist turned the N_2O gas off at the end of the operation

A detailed statistical analysis of N_2O changes over time was performed to confirm the observations made from these graphs Six of the data sets were analyzed Dental Operation #1, Dental Operation #2, Dental Operation #3, Dental Operation #5, Dental Operation #6, and Dental Operation #7 As mentioned earlier, Dental Operation #4 was not analyzed Due to an oversight, the anesthesia bag was accidently not attached to the anesthesia delivery unit during the sampling run because of anesthetic equipment problems The use of Mallows C_p statistic was used to model the exposure data as a function of the work practice variables which may act upon it More than 90 percent of all exposure data was predictable based on the concentration of N_2O in the previous interval (i e , 15 seconds) The changes in N_2O concentration were more predictable when longer time intervals were taken into consideration Up to 98 percent of the changes in N_2O exposure could be accounted for, based on the concentration of this gas delivered to the patient (see data modeling in Appendix A) The N_2O concentrations measured in the six data sets dominated all work activities which preceded and followed the surgical procedure, work activity appeared to have little, if any, influence on changes in N_2O concentration to which the dentist and dental assistant were exposed

This pattern was also evident in the preliminary survey conducted in June 1987 as well Note in Figure 3 that certain work activities could be observed to change N_2O concentrations However, the difference between the change observed in work activity was small and transient compared to the overall N_2O concentration as shown by the area under the graph curve This becomes more apparent when the dentist changes the amount of N_2O administered to the patient from 40 percent to 20 percent to 10 percent This demonstrates that the primary source of exposure for this scavenging system is from N_2O delivery and the inadequacy of scavenging system exhaust, and not from work practices of the dentists

GENERAL VENTILATION

On June 25, 1987, NIOSH researchers measured supply and exhaust airflows in the dental operatories and discovered that the ventilation system was not performing according to the design airflow rates contained in the construction drawings The deficient airflow was reported by NIOSH researchers to the Engineering Services Manager at CHMC Dental Facility The CHMC Dental Facility engineers later discovered breaks in the fiber-reinforced plastic ductwork in the plenum area above the operatory ceiling These breaks were corrected prior to the follow-up survey conducted on April 21, 1988 The airflow rates in the dental facility were measured by means of the Alnor™ balometer If the vent outlets were too large or were inaccessible for the Alnor instrument, a velocity traverse with a TSI hot wire anemometer was used The data is summarized in Table 3 A diagram of the dental facility layout is shown in Figure 1.

Table 3 General Ventilation Data for Children's Hospital Medical Center Dental Facility

Room Number Posted[a]	Plan[b]	Measured CFM Supply	Return	Specification CFM Supply	Return	Area ft^2	Function of Room
3-2	3-17	96	0**	150	40	78	Laboratory
3-2A	3-16	-	-	40	40	48	Dark room
3-3	3-10	65	0	120	*	112	Operatory
3-4	3-2	c	-	*	*	118	Operatory
3-5	3-9	-	37**	200	200	112	Sterilizer
3-6	3-1	c	-	*	*	384	Operatory
3-8	3-15	90	20	110	110	115	Operatory
3-10	3-23	160	-	140	*	106	Consultation
3-11	3-24	120	0	--	140	120	Operatory
3-12	3-30	95**	713**	700	500	500	Waiting Rm
3-93	3-18	70	-	260	260	311	Library
3-93A	3-21	75	50	70	70	95	Equipment
3-93A	3-21	120**	-	*	*	95	Equipment
3-98	3-12	35	-	60	60	80	Office
3-99	3-11	70	23**	130	130	163	Special
Hallway	3-7	70	-	100	*	--	South Hall
Hallway	3-14	-	-	*	375	--	West Hall
Total airflow		883	843	2080	1925	3260 ft^2	

* 163 No vents indicated on blueprints

** Flow measured by velocity traverse with TSI hot-wire anemometer

a Room numbers posted during the NIOSH survey

b Room numbers listed in blue print plans

c Ventilation by Singer™ wall units

The differences in the measured flow rates from the specification flow rates are accounted for in part by acceptable variations from design flows and by changes in the ventilation systems from the original blueprint specifications One example is Room 3-11, which originally was designated as a restroom area with two 70 cfm exhaust air vents This area was converted to a dental operatory and the ventilation system was changed accordingly This room has the dimensions 10 9 by 10 5 by 8 feet with a total volume of 915 cubic feet The ventilation to the room is 120 cfm supply air with no return air inlet This provides nine air changes per hour One dental procedure was monitored in this operatory on April 21, 1988, and two on April 22, 1988 Another example is Room 3-12, the waiting room It has a supply air outlet which was measured by velocity traverse to have a flow of 95 cfm, while the plan specifications call for 700 cfm This large difference was not accounted for by the plan specification

The periphery of the building was fitted with wall heating/air conditioning units manufactured by Singer Company and meeting American Refrigeration Institute (ARI) Standard 310-70 specifications for function EA15 These specifications call for a cooling blower capacity of 290 cfm, with 70 cfm (24 percent) maximum makeup air The heating mode specification calls for 280/60 cfm, which is a 21 percent maximum makeup air The airflow on two Singer units were measured during the April 1988 survey by traverse velocity measurements using the TSI hot-wire anemometer The calculated flow rates were 287 cfm and 320 cfm It is reasonable to assume that the specification flow rate of 290 cfm can be used

The measured supply and exhaust airflows did not balance In addition, some exhaust air ducts are dedicated to venting directly to the outside and it is difficult to determine from the plan specifications which vents they might be The differences between the supply and return air is the makeup air This makeup airflow is difficult to determine at any one time, because the Singer wall units, contributing up to 70 cfm of makeup air, operate on a demand basis

The makeup airflow percentage is an important factor in determining the building ventilation flow The makeup airflow is greatest during mild weather conditions, but few wall units may operate under these conditions For example, on the morning of April 21, 1988, there were six Singer units operating Assuming the maximum makeup airflow of 70 cfm, the makeup air from the peripheral units was 420 cfm During severe hot or cold weather conditions, the makeup airflow may be reduced to conserve energy

Room 3-9 has the dimensions of 10 24 by 22 6 by 8 feet with a total volume of 1,848 cubic feet The ventilation to the room is supplied by one Singer wall unit operated upon demand Since the area is open for 22 feet along the hallway, there appeared to be enough dilution air available from the general area, but the removal of the N_2O from the operatories is not predictable Two dental procedures were monitored in this operatory on April 25, 1988

Room 3-6 is the corner operatory area having the general dimensions of 22 by 22 by 8 feet, with a total volume of 3,872 cubic feet Ventilation is supplied to this open area by four Singer wall units, which are operated upon demand The potential ventilation supplied by these units is 280 cfm maximum of makeup air Since the area is open along the 16-foot wide entrance, there appears to be enough dilution ventilation available The removal rate of the N_2O from the operatory is not predictable One dental procedure was monitored in this operatory on April 22, 1988, and one on April 26, 1988

The third floor main risers for the south wing supply 6,400 cfm of air and exhaust 6,775 cfm, with a difference of 375 cfm This 375 cfm difference needs to be made up by infiltration of outside air and makeup from the Singer™ wall units The design flow balance between the supply and return air appears to consider the makeup air potential of the Singer™ wall units, which have a maximum makeup air rate of 55 to 70 cfm depending upon the operating mode

The 33 Singer units in this wing would need to supply an average of 11 cfm each to make up this difference While the system is operating, it adjusts to airflow changes and resistance changes in the system to be in dynamic balance at all times The outside air inlets were surveyed on June 25, 1987, to determine the air makeup flow rate The inlets measured 4 5 by 1 67 feet or 7 5 square feet The average velocities of the two inlets were 163 fpm and 125 fpm, giving flows of 1,223 cfm and 938 cfm This makeup air is for the four floors of the south wing of the building, or 540 cfm for each floor

SCAVENGING SYSTEM VENTILATION

The effectiveness of the capture capacity of the anesthetic gas from the scavenging nasal mask was evaluated by inserting a Dwyer™ rotameter in the exhaust ports of the scavenging mask tubing following Dental Operation #7 The exhaust valve for the scavenging mask was adjusted at the beginning of the operation by the dental assistant and not changed throughout the surgery For Dental Operation #7, this Dwyer flow meter showed the exhaust to be approximately 7 to 12 lpm It has been determined that scavenging of anesthetic gas from the nasal area of the patient should be 45 lpm when 4 to 7 lpm of N_2O and O_2 are mixed and delivered to the patient [5] Scavenging system ventilation was not evaluated for Dental Operations #1 to 6, because it was not discovered until later in the study that scavenging system flow rates were not automatically set at 45 lpm Vacuum systems which exhaust less than the recommended level may result in excessive exposure of N_2O to dental personnel

INFRARED SCANNING FOR NITROUS OXIDE

An infrared scanning camera was used during Dental Operations #8 and #9 to determine scavenging mask leakage, while the patient received N_2O during surgery NIOSH researchers found the scanner to be very useful in determining N_2O leakage around the patient's mask The scanner helped NIOSH researchers determine that the Fraser-Harlake mask did not fit the patient's face properly and that there was N_2O leakage between the mask and face seal However, patient mouth breathing also appeared to be a problem for these two operations It was observed that a sudden increase in N_2O exposure, observed from the real-time data (see graph tracings for Operations #8 and #9 in Appendix B), could be traced to the patient's expired breath, and when the patient would inspire, the N_2O levels would suddenly decrease This pattern of sudden changes in N_2O on the real-time data appear to indicate that patient breathing was a factor in exposure to the dentist and dental assistant Synchronization of the real-time data with the infrared scanner helped to confirm this source of exposure

DISCUSSION

Based on the results of these data, the major source of N_2O exposure for these dental personnel was caused by inadequate scavenging system ventilation to remove this gas from the dental operatory Poor scavenging system ventilation was caused by the dental assistants adjusting the vacuum exhaust valve to low levels prior to patient dental surgery These valve adjustments are subjectively set by the dental assistant according to the amount of noise generated by the air rushing through the nasal scavenger dome In addition, general ventilation was found to be inadequate to maintain low levels of N_2O in the dental environment This was evident as traces of N_2O were monitored from the real-time sampling before dental operations began (see initial concentrations of N_2O, Table 2)

PERSONAL SAMPLING

This in-depth survey showed that N_2O concentrations exceeded the NIOSH REL of 25 ppm during the time of administration for both personal and real-time sampling For the six dental operations monitored, the Time-Weighted Average (TWA) N_2O exposures of the dentists ranged from 160 ppm to over 1,000 ppm, and the TWA exposures of the dental assistants ranged from 44 to 432 ppm during the time of administration Dentists had an average of 487 ± 366 ppm N_2O exposure, while dental assistants had 149 ± 144 ppm Dentists had an average of 3 2 times higher N_2O exposure than dental assistants Dentists also had slightly higher exposures on average compared to the real-time sampling location (442 ± 197 ppm) However, due to small sample size and wide variance in concentrations, the difference between the dentists and real-time N_2O results was not significant The slightly higher exposure among dentists may be from their closer working proximity to the patient's breathing zone, where N_2O is delivered and respired

GENERAL AREA SAMPLING

The initial N_2O concentration in the rooms where N_2O was measured showed that some of this gas was present prior to the start of surgery in nine of ten operations monitored by NIOSH This initial concentration is probably a function of dental operations, which preceded the operation being monitored by NIOSH, and the poor scavenging system and dilution ventilation found in other dental operatories Room supply air sampling results, which includes the Singer wall units, were lower (17 ± 21 ppm) than the room exhaust sampling results (60 ± 42) These supply and exhaust air results suggest that N_2O concentration may be a function of dental room architecture and the ventilation supplied to these rooms (i e , lower in the open rooms, higher in the closed rooms) The reason for this difference is probably due to dilution of the N_2O in the open architecture rooms by diffusion and by random air currents Aspects of N_2O migration from the operatory environment was observed by taking room door (46 ± 27 ppm) and hallway measurements (32 ± 25 ppm) Also, recirculation of N_2O was observed with the Singer air conditioning units (30 ± 24 ppm) Despite the recirculation, the open architecture rooms had lower N_2O concentrations than the closed room (3-11). The closed room showed no recirculation of N_2O through the general air ventilation system. In addition, no N_2O was found at the appointment desk area This suggests that recirculation of N_2O is not occurring or that dilution of the gas reduces concentrations to nondetectable levels

SCAVENGING SYSTEM VENTILATION

The exhaust valve setting is subjectively adjusted by the dental assistant prior to surgery The scavenging system exhaust valve is attached to the corrugated breathing hose approximately 4 feet from the scavenging mask The valve adjustment is a function of the dental assistant's ability to hear a "hissing" sound created by the exhaust air flowing through the scavenging nasal inhaler The dental assistant will listen for the hissing sound either at the scavenging nasal inhaler or at the valve itself The hissing sound is kept to a minimum because it is distracting to the dentist The noise that is generated by the air rushing through the nasal dome of this scavenging system at recommended exhaust rates appears to be a design problem Redesign of the nasal dome to reduce the noise (created by a restricted air opening in the plastic dome) or acceptance of the noise by the dentist may significantly reduce N_2O, if the dentists choose to keep this scavenging system

GENERAL SYSTEM VENTILATION

On the days NIOSH researchers sampled, the highest exposure to N_2O occurred in Room 3-11, the operatory having dedicated ventilation from the building ventilation system The room is relatively small, 10 9 by 10 5 by 8 feet (915 cubic feet), which limits the effect of dilution The 120 cfm supply air provides nine air changes per hour, or one change each 7 minutes It may be that the release of N_2O during short periods of time overwhelms the system's ability to purge the room The operatories in the larger open areas without dedicated supply ventilation had lower exposures Because of the relatively high N_2O concentrations, purging the area of N_2O with low velocity convection currents may not be adequate If purging were possible, it might result in exposure to other persons in the general work area

Dilution ventilation and air mixing have obvious immediate benefits in any air pollution problem, but has never been accepted as the ultimate or desirable mechanism for removal This is because such ventilation can transport the problem to other areas

REAL-TIME SAMPLING AND WORK PRACTICES

Because of the low scavenging exhaust rates observed during dental surgery, the specific aspects of work practices on changing N_2O concentrations were not apparent for most of the operations monitored by the NIOSH researchers There were several work practice elements that were monitored such as local anesthetic injection, instrumentation or extraction of teeth, restoration of teeth, the use of aspirator, air and water syringes, and the use of rubber dams Also, patient elements were included such as respired N_2O from talking and yawning The most important predictive elements for N_2O concentration were when the dentist turned the N_2O on, adjusted the N_2O percentage during surgery, and when the dentist turned the N_2O off It is suggested that, if the scavenging system were operating according to recommended specifications of 45 lpm, the work practices such as use of the aspirator, air and water syringes, and patient talking may have been more prominent in N_2O exposure among dentists However, until scavenging flow rates are adjusted to proper exhaust rates and the general ventilation is improved to design specifications, the impact of these work practices cannot be evaluated

INFRARED SCANNING FOR NITROUS OXIDE

The infrared scanner proved to be a valuable tool in determining N_2O leakage from the patient's mask, as well as the amount of N_2O from patient mouth breathing By following the real-time data patterns, NIOSH researchers could discern when there was a mask leak, when the patient was mouth breathing, or both This ability to determine these exposure sources may be helpful in providing recommendations in reducing overall exposure However, because of the major impact of the inadequate ventilation from the scavenging system exhaust for this in-depth survey, the contributions to N_2O exposure from patient mouth breathing were relatively small Therefore, it cannot be determined that if the Fraser-Harlake Scavenging System ventilation were increased to the recommended flow rate of 45 lpm, N_2O would be reduced to 25 ppm during the time of administration

MAINTENANCE

During these surveys, NIOSH researchers observed that the N_2O scavenging equipment was in good repair including the gas cylinder delivery area, the gas delivery system, and the high to low pressure connectors at the dental bays It was also observed that enough scavenging equipment was available for each dental unit which used N_2O, and the equipment was in good repair It is recommended that periodic preventive maintenance of equipment be a major part of the maintenance program to avoid exposure to N_2O Equipment malfunctions such as improper connections of anesthesia hoses, rebreathing bags, and scavenging masks should be inspected by the dentist and dental assistant prior to each dental surgery The dentist and dental assistant should also inspect the connection fittings, bags, and masks for cracks and tears due to general wear and degradation, and replace these items as needed

EDUCATION AND TRAINING OF DENTAL PERSONNEL ON THE USE OF NITROUS OXIDE SCAVENGING EQUIPMENT

In discussions with the dentists and dental assistants during the present survey, it was determined that there is very little instruction on the proper use of scavenging equipment This may be a problem between the manufacturer, the seller, and the user NIOSH researchers observed that instruction on how to operate the scavenging units appeared to be word-of-mouth, with each dentist and dental assistant having their own style in using the scavenging equipment For example, different dental assistants would adjust the scavenging system vacuum flow rate by listening to the "hissing" sound at the nasal dome or at the valve This difference in listening location between dental assistants was by personal preference As for the dentists, they should be prudent in their use of N_2O and should inspect the anesthesia delivery and scavenging system prior to use to make sure all parts are in place and the fittings secure

CONCLUSIONS

Dentists and dental assistants were overexposed to N_2O anesthetic during dental surgery in all of the sampling runs that were evaluated The major source of exposure was during delivery of the N_2O to the patient It appears that the delivery of this anesthetic overwhelms the scavenging system exhaust valve settings and general ventilation of the operatories Because of the scavenging system and general ventilation deficiencies, the N_2O decreased slowly when the N_2O was adjusted down by the dentist following dental surgery Work practices such as the use of the aspirator, air syringe, water syringe, rubber dam, etc , played a very minor role in excess exposure to the dental personnel During the NIOSH study, it was discovered that the dental assistants subjectively adjusted the scavenging vacuum system according to the "hiss" sound emitted by the nasal hood A loud "hiss" was undesirable by the dentist, and the dental assistants were encouraged to adjust the vacuum control valve to reduce this noise The hissing sound is caused by the outside air rushing through the small air gap in the nasal hood When NIOSH researchers measured the vacuum unit flow rate, the vacuum was found to be exhausting only 7 to 12 liters per minute as set by the dental assistant prior to surgery The recommended flow rate is 45 liters per minute when the anesthetic gas machine is delivering a mixture of N_2O and oxygen to the patient [5]

RECOMMENDATIONS

To reduce the major source of N_2O exposure to dental personnel, it is recommended that (1) a Fraser-Harlake representative be contacted to discuss these sampling results, (2) a request be made to the manufacturer to install a rotameter to the Fraser-Harlake vacuum system, so that dental assistants can adjust the exhaust valve and monitor the air exhaust of 45 liters per minute from the scavenging mask of the patient, and (3) if the noise generated by the Fraser-Harlake hood is undesirable at the higher flow rate, then the user should request that the hood be redesigned to reduce this noise If the manufacturer cannot supply a retrofit rotameter device to monitor proper exhaust of this anesthetic, and/or redesign the nasal hood to reduce noise, it is recommended that another, quieter nasal hood and scavenging system which offers an exhaust monitoring device be purchased Additional precautions to reduce unnecessary N_2O exposure include improved general ventilation, good work practices (including checking the scavenging system for proper connections), and prudent use of this anesthetic

Additional recommendations for controlling N_2O fall into several categories including General Equipment Maintenance, the Scavenging System, Work Practices, Ventilation, Environmental Monitoring, and Administrative Controls Listed below are specific recommendations for controlling N_2O inhalation by dental personnel during patient surgery

GENERAL EQUIPMENT MAINTENANCE

The analgesia equipment is composed of several rubber components, which may be degraded by the N_2O as well as through repeated sterilization for infection control It is recommended that all rubber hoses, connections, tubing, and the breathing bag be frequently checked to assure that this equipment is in good working order Leak testing can be performed according to the manufacturer's recommendations or by the procedures outlined in the "Leak Testing Scavenging Equipment" section of this report For gas cylinders, Teflon® tape is recommended for all metal-threaded connections through which N_2O flows High to low pressure connections should also be checked regularly, as the o-rings may become worn and may become a N_2O leak source

THE SCAVENGING SYSTEM

As this survey has shown, scavenging exhaust systems which do not have proper exhaust flow rates do not work effectively It is recommended that a flow metering device such as a rotameter be used to monitor the proper exhaust flow rates A bypass rotameter may have an advantage over an in-line rotameter, because it avoids moisture problems in the vacuum line and possible false readings by the rotameter ball and airflow scale

For the scavenging mask, leaks around the mask may be kept to a minimum if the proper anthropometric size is selected Also, the mask can be more securely fastened by using the slip clamp connected to the analgesia hoses near the back of the patient's head and dental chair headrest

It is recommended that a mask be selected that can collect air from all around the mask The mask should also be free of noise when the proper flow rate is selected (i e , 45 lpm)

Suction pumps should have enough power to maintain scavenging flow at the nasal mask to 45 liters per minute Suction pumps should also have enough power to overcome the static pressure drop associated with several in-line scavenging units operating at the same time, in order to maintain the recommended scavenging flow rates

All suction pumps aspirating air from the patient's mouth or from the mask should be vented outside the building and away from fresh air inlets

WORK PRACTICES

Dentists and dental assistants should inspect the anesthesia machines and all connections prior to starting anesthetic gas administration Breathing bags should be attached to the anesthesia machine and that hoses and clamps are in place prior to turning on the anesthetic gas

Make sure the scavenging mask is properly connected to the the gas delivery hose and the vacuum system The scavenging mask in use by this facility (called the scavenging nasal inhaler system) can easily be connected incorrectly The y-connector leading from the scavenging "dome" to the vacuum hose should be on the patient's left side with the open portion of the y-connector inserted directly into the nasal "dome" connection port The other end of the y-connector, which is closed, should be inserted into the nasal "hood" connection port The N_2O and oxygen gas is delivered through the hose and into the nasal hood on the right side of the patient

It is recommended that the N_2O not be turned on until (1) the vacuum system scavenging unit is turned on to the recommended flow rate of 45 lpm, and (2) the scavenging nasal cone is placed over the patient's nose prior to surgery

To reduce leaks around the nasal cone during gas delivery, use the slip clamp which is attached to the scavenging nasal inhaler hoses to seat the mask more securely on the patient's nose

Flush oxygen through the analgesia equipment following dental surgery, especially the breathing bag, prior to disconnecting the gas delivery system, and prior to turning the scavenging system vacuum off

VENTILATION

Where air conditioners are used, a minimum of two outside air changes per hour is recommended A minimum of ten total air changes per hour is recommended for dental operatories which use N_2O Recirculating room air is not recommended, and should be exhausted outdoors and away from air intake vents The Department of Health and Human Services publication entitled "Guidelines for the Construction and Equipment of Hospital and Medical Facilities" [Publication No (HRS-M-HF) 84-1, 1984] lists more detailed information regarding ventilation guidelines [53]

Install sweep fans where general ventilation is inadequate or where supplemental ventilation is needed An air velocity of approximately 25 cfm at a distance of 3 feet from the patient's head is recommended [5]

ADMINISTRATIVE CONTROLS AND ENVIRONMENTAL MONITORING

When N_2O is used, the waste gas should be reduced to the lowest achievable level NIOSH recommends that N_2O exposures should be no greater than 25 ppm during administration [54]

It is recommended that annual reviews of N_2O use be evaluated as well as reviews of waste gas reduction program The annual review should include environmental air monitoring, leak testing of equipment, and personal and environmental monitoring Air monitoring may be performed either by gas bag sampling, real-time sampling, and/or by passive dosimetry

Dentists should request information from dental equipment suppliers on the proper use of the equipment and its effectiveness in reducing N_2O prior to purchase

FOLLOW-UP EVALUATION

Sampling to confirm the efficiency of the controls should be conducted after the above recommendations have been implemented, especially after the scavenging system vacuum flow rates are adjusted to 45 lpm

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APPENDICES

APPENDIX A

MODELING OF REAL-TIME DATA TO DETERMINE EXPOSURE SOURCES

The six data sets have been analyzed to determine factors which appear most important as predictors of N_2O concentration at a given time Since the concentrations of N_2O at a given time represents the concentration in the preceding time interval plus change, the heart of the problem is prediction of change Also, it should not be surprising that concentration at the previous interval is the major predictor at a given time

Accomplishing this task requires determination of a reasonably good model to explain the data If the model is inadequate, the effects of the factors it includes are distorted Many questions have not been resolved concerning the effects of

the sequence in which events occurred
in what ways the effects of various factors were interrelated, e g , potential nesting of effects
the effects of serial dependencies of the observations which were not analyzed
the interrelationships, i e , colinearities, among the factors and the extent of confounding this produced
the factors coded in the proper manner
All models had large outliers which were influential did these distort the results?
in all cases the residuals were clearly and definitely nonnormal which implications does this have about the adequacy of the models?
most of the partial regression residual plots appeared to indicate that the relationship of the event or practice variables depended upon a few influential points rather than an overall trend

In each case, several models with somewhat different sets of factors were almost equally good fitting Three factors appeared most important in almost all models N_2O concentration in the preceding time interval (which suggests the validity of the concentration model), N_2O concentration of two intervals prior to the current, and the source concentration of N_2O in intervals preceding the current, where n was determined by examining the data and determining how many intervals elapsed before a sizable jump in current concentration occurred after N_2O was first turned up

The gas generation model can be restated as predicting that the concentration of N_2O equals a constant, plus a second constant, times the concentration of N_2O in the previous interval The first constant depends on gas generation or input to the system In this case, this "constant" is replaced by a linear combination of all factors in the model that may reflect generation of the gas as well as escape of the gas from the patient's mouth this varies with different events or practices The fact that concentration was a predictor not only in the previous time interval, but in one or more previous time intervals is related to current concentration probably reflects the fact that concentration levels were changing fairly rapidly This means that the reading for concentration in both the current and the previous intervals are locally generated levels and not levels for the entire system In the simplist of terms, it appeared that changes in N_2O concentrations were primarily a function of turning the anesthesia machine on, delivering the anesthetic to the patient, and turning the anesthetic off Because of the relatively high concentrations of waste N_2O, work practices were not a factor with regard to significantly changing these concentrations

* NOTES on Statistical Analysis Symbols
(see table which follows)

INTERCEPT The intercept is nonzero (i e , low background concentrations of N_2O present) This row indicates the hypothesis that the intercept is zero can be rejected This was observed after the fact for Dental Operation #1 data and then applied to the remaining data sets

C(p) is the statistic by Mallows[51] to estimate the total error of the regression, both those sources of randomized error represented by the standard error of regression, and the bias of the fitted model It is a useful criterion for selection of models If $C(p) > p$, where p = the number of factors in the model, then the model may be biased C(p) is probably biased if there are serial correlations

R-SQUARE is the square of the estimated multiple correlation of the concentration of N_2O on the factors in the model This may be an overestimate if the observations are serially correlated

Adjusted R-SQU is an adjustment of R-SQUARE to allow for the number of factors in the model This may be an overestimate if the observations are serially correlated

% of CHG VAR EXPLAIN is the square of the adjusted estimate of multiple correlation when the dependent variable is current concentration of N_2O minus the concentration in the previous time interval, i e , the change in concentration This may be an overestimate if the observations are serially correlated

MSE is the sum of squares of residuals divided by the degrees of freedom for error, it is termed the mean square error and is, when the model is valid, an unbiased estimate of the variance about the regression line, i e , the variance of Y(x) about E{Y(x)} where x is the vector of the particular values of the independent factors and Y is concentration of N_2O This is likely an underestimate if the observations are serially correlated

ROOT MSE is the square root of MSE and estimates the standard error of regression This is likely an underestimate if the observations are serially correlated

DF for ERROR is the degrees of freedom for error which equals the number of observations minus the number of factors, p

LAG for N_2O is the maximum lag considered for all factors based on observing how many intervals after N_2O was first turned on before a sizable increase in concentration occurred The average time or lag interval was 15 seconds A lag is the number of time intervals after the occurrence of an event that a response in the concentration of N_2O is measured For example, a lag of 14 means that the reading of N_2O was related to factors levels 14 time intervals (210 seconds or 3 5 minutes) before

OUTLIERS An outlier is an observation that appears unusual However, the real question is neither how to identify them (I tend to be somewhat liberal) nor whether such observations should be adjusted or deleted, etc , but rather what effect such observations have on our conclusions

If the conclusions with or without a few outliers remains basically the same, our confidence in the conclusions is maintained or strengthened and we care little about them On the other hand, if the conclusions are sensitive to observations which appear unusual, then confidence in the conclusions is weakened In this case, observations associated with residuals more than 3 5 times their estimated standard errors are noted Most of these are readily apparent in various graphical plots and are associated with disproportionate influence and other diagnostics However, no analysis has been done to determine how these observations affect conclusions, except in the case of Dental Operation #2 In this case, after removing residuals the apparent best model contained only 4 factors, down from 7 Two factors - CONC lag time (L1) and N_2O lag time (L17) - remained in the revised model while the other two had appeared in the first model but with different lag times The revised model, however, has a new set of outliers and several of the problems with the first model remained

RESIDUALS NORMAL Lack of normality of the residuals may suggest that some important factors were not included in the fitted model.

RESIDUALS PATTERN The residuals should be nearly independent and patterns suggest the influence of other factors, such as time, not accommodated by the model fitted In this case, the presence of a pattern was determined by "eyeballing" the data Usually, the pattern appeared to be a succession of positive residuals followed by negative residuals

MODEL BIASED The answer was determined mostly by reference to C(p) and whether that statistic is greater than p, the number of factors

DURBIN-WATSON STAT is a measure of one type of serial dependence among data points The values shown above appear not to be statistically significant

1ST ORDER AUTOCORR is the simple correlation of the concentration of N_2O with the concentration in the previous interval This should be as low as the latter included in the model

FACTOR refers to the code for a factor included in the model These are arranged so that factors appearing in several models are apparent whether or not the relationship involves the same number of lagged intervals A factor with no "Ln", where n is an integer, means that it is value of the factor in the current time interval while otherwise n refers to the number of lagged intervals

STAND EST SLOPE This is the standardized estimate of the slope of the factor in the regression equation which estimates the number of standard deviations of change in N_2O is produced by one standard deviation increase in the factor This removes distortions caused by differences in the scale of various factors

% VAR This is a rough estimate of the percentage of the variance of the concentration of N_2O which is explained by the factor This is a tricky matter as the effect of one may be to increase or decrease the effect of other factors

STATISTICAL REPORT - APPARENT "GOOD" MODELS

CHARACTERISTIC	DENTAL OPER.#1	DENTAL OPER.#2	DENTAL OPER.#3	DENTAL OPER.#5	DENTAL OPER.#6	DENTAL OPER.#7
NO. OBSERVATIONS	131	237	106	208	127	181
NO. FACTORS	10	7	10	16	9	4
INTERCEPT	NO	NO	NO	NO	0 05	NO
C(p)	12 45	7 63	16 2	14 6	8 07	3 13
R-SQUARE	0 987	0 984	0 976	0 991	0 978	0 94
ADJ R SQR	0 986	0 983	0 974	0 99	0 9767	0 938
% CHG VAR EXPLAIN	41 9	31 9	50	42 8	32 4	17 7
MSE	780 47	11024	5065	897	3444	11559
ROOT MSE	27 9	105	71 2	29 9	58 7	107 5
DF FOR ERROR	121	230	96	192	118	177
LAG FOR N20	14	17	14	5	8	8
OUTLIERS	3	5	2	6	2	1
OVER 4 SE'S	2	2	1	3	2	1
OVER 5 SE'S	1	2	1	2	1	1
OVER 6 SE'S	1	1	1	0	1	1
LARGEST	6 64	11 308	-8 184	5 98	-6 216	11 142
RESIDUALS NORMAL	NO	NO	NO	NO	NO	NO
RISIDUALS PATTERN	RUN	RUN	RUN	RUN	RUN	RUN
IS MODEL BIASED	PROBABLY	PROBABLY	PROBABLY	MAY NOT BE	MAY NOT BE	MAY NOT BE
DURBIN-WATSON STAT	2 11	1 97	1 97	1 88	2 075	1 799
FRST ORDER AUTOCORR	-0 056	0 015	0 015	0 059	-0 038	0 101
FACTOR	CONC L1	CONC L1	CONC L1	CONC L1	CONC L1	CONC L1
STAND EST SLOPE	1 15	1 21	0 95	1 13	1 17	0 819
% VAR	97 8	97 7	94 9	98 4	97 7	92 8
FACTOR	CONC L2	CONC L2		CONC L2	CONC L2	
STAND EST SLOPE	-0 33	-0 32		-0 2	-0 42	
% VAR	0 4	0 34		0 1	0 3	
FACTOR			CONC L3		CONC L3	
STAND EST. SLOPE			-0 129		0 119	
% VAR			0 42		0 07	
FACTOR			CONC L14			CONC L8
STAND EST SLOPE			-0 098			-0 128
% VAR			0 02			0 5
FACTOR				N20		
STAND EST. SLOPE				-0 23		
% VAR				0 1		

STATISTICAL REPORT - APPARENT "GOOD" MODELS

CHARACTERISTIC	DENTAL OPER.#1	DENTAL OPER #2	DENTAL OPER.#3	DENTAL OPER #5	DENTAL OPER.#6	DENTAL OPER.#7
FACTOR				N20 L1		
STAND EST. SLOPE				0 25		
% VAR				0 1		
FACTOR		INJCT				
STAND EST SLOPE		0 038				
% VAR		0 02				
FACTOR		INJCT L1		INJCT L1		
STAND EST SLOPE		0 04		0 02		
% VAR		0 09		0 01		
FACTOR	INJCT L2	INJCT L2		INJCT L2	INJCT L2	
STAND EST SLOPE	-0 03	-0 05		-0 02	0 039	
% VAR	0 05	0 04		0	0 03	
FACTOR				INJCT L5		
STAND EST SLOPE				0 02		
% VAR				0 03		
FACTOR	LIGHT L2		LIGHT L2	LIGHT L5		
STAND EST SLOPE	0 04		0 057	0 02		
% VAR	0 1		0 35	0 03		
FACTOR	OTHER L2		OTHER L14	OTHER L5	OTHER L2	
STAND EST. SLOPE	-0 021		0 053	0 01	0 051	
% VAR	0 05		0 23	0 01	0 11	
FACTOR				WATER	WATER	
STAND EST SLOPE				0 02	0 038	
% VAR				0 08	0 07	
FACTOR				WATER L1	WATER L1	
STAND EST. SLOPE				0 04	0 026	
% VAR				0 05	0 02	
FACTOR	WATER L14					
STAND EST SLOPE	0 018					
% VAR	0 02					
FACTOR				PULL L2		
STAND EST. SLOPE				0 02		
% VAR				0 02		

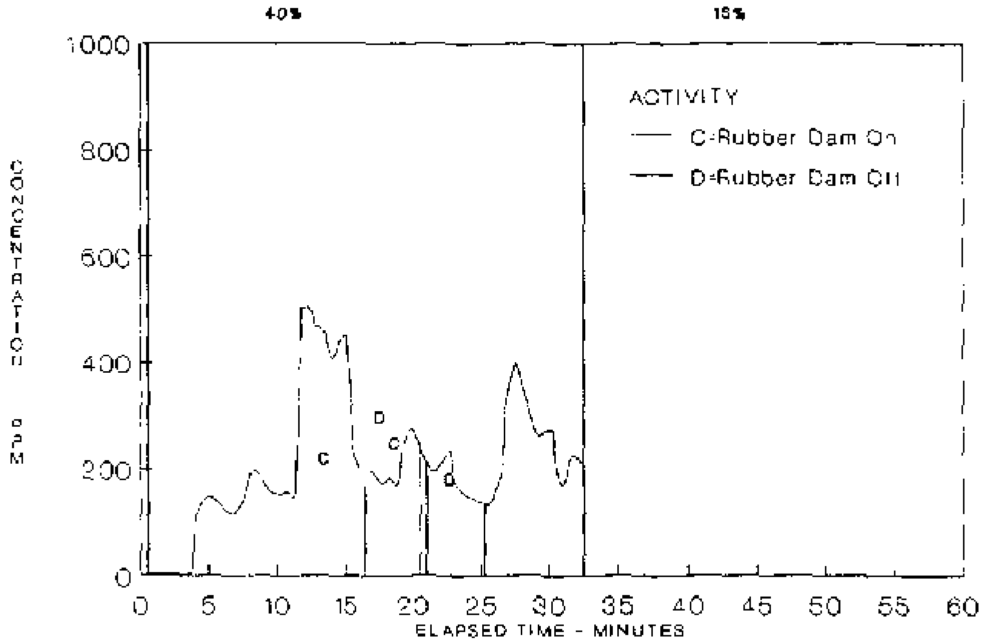
STATISTICAL REPORT – APPARENT "GOOD" MODELS

CHARACTERISTIC	DENTAL OPER.#1	DENTAL OPER.#2	DENTAL OPER.#3	DENTAL OPER.#5	DENTAL OPER.#6	DENTAL OPER.#7
FACTOR			ASPIR			
STAND EST SLOPE			0 045			
% VAR			0 15			
FACTOR			N20 L2			
STAND EST SLOPE			0 071			
% VAR			0 23			
FACTOR	N20 L14	N20 L17				N20 L8
STAND EST. SLOPE	0 18	0 08				0 24
% VAR	0 1	0 18				0 5
FACTOR	FILL			FILL		FILL
STAND EST. SLOPE	0 051			0 01		0 049
% VAR	0 1			0 01		0 15
FACTOR	FILL L2			FILL L5		
STAND EST SLOPE	0 041			0 02		
% VAR	0 1			0 02		
FACTOR			RUBDAM			
STAND EST. SLOPE			0 381			
% VAR			0 81			
FACTOR	RUBDAM L2		RUBDAM L2			
STAND EST SLOPE	-0 093		-0 28			
% VAR	0 1		0 37			
FACTOR			DRILL			
STAND EST SLOPE			0 04			
% VAR			0 11			
FACTOR				DRILL L5		
STAND EST. SLOPE				-0 04		
% VAR				0 02		
FACTOR						
STAND EST SLOPE						
% VAR						
FACTOR		PATNT L2		PATNT L2	PATNT L8	
STAND EST. SLOPE		0 02		0 02	0 035	
% VAR		0 04		0 03	0 32	

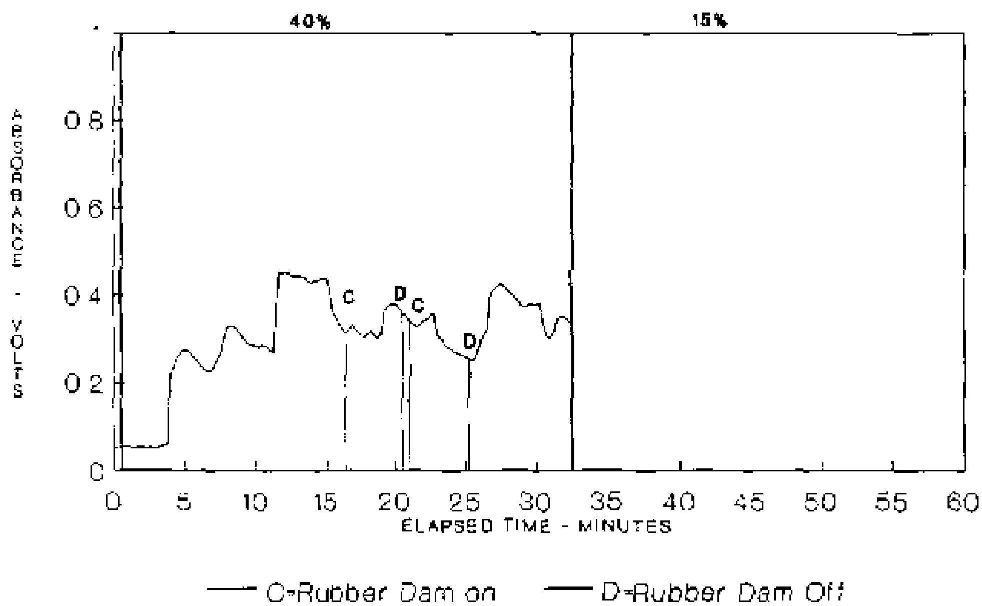
APPENDIX B

NITROUS OXIDE CONCENTRATION VERSUS ELAPSED TIME FOR DENTAL OPERATIONS 1 THROUGH 9 AT CHILDREN'S HOSPITAL MEDICAL CENTER DENTAL FACILITY

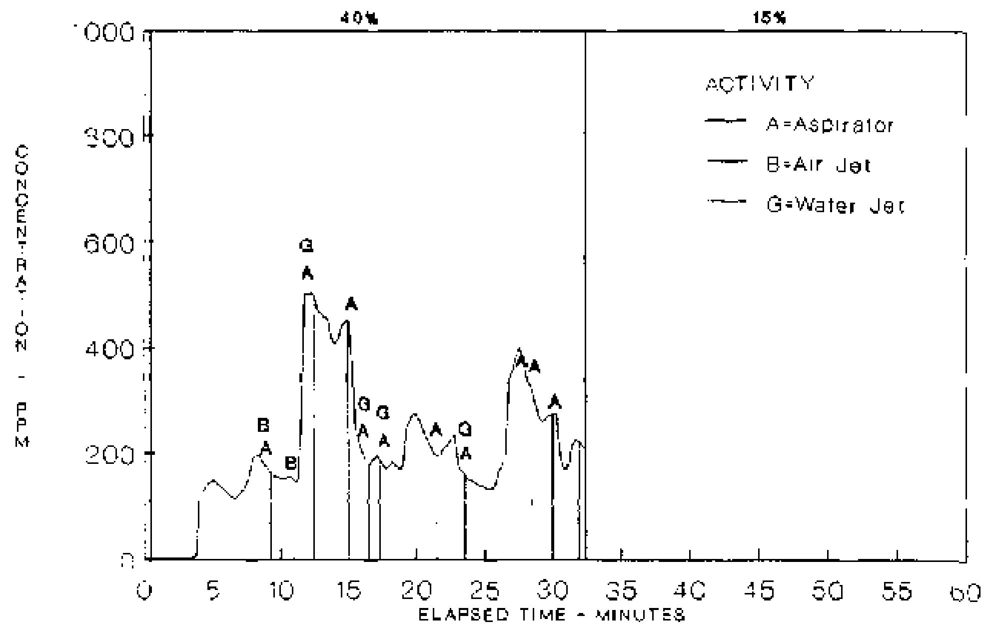
N_2O CONCENTRATION VERSUS ELAPSED TIME
Dental Operation #1 - 21 APRIL 1988
Rubber Dam Use



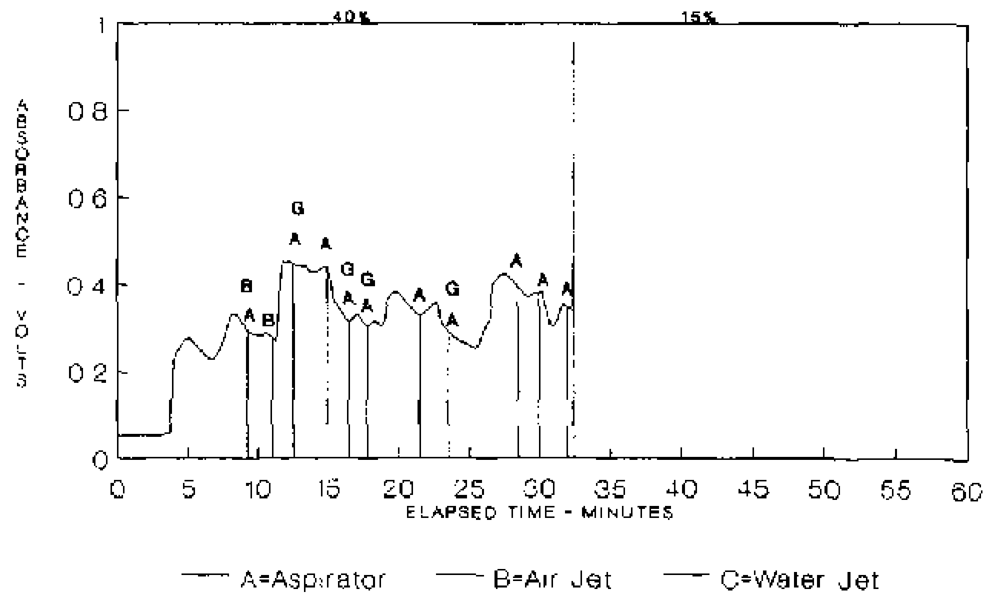
ABSORBANCE VERSUS ELAPSED TIME
DENTAL OPERATION #1 - 21 APRIL 1988
Rubber Dam Use



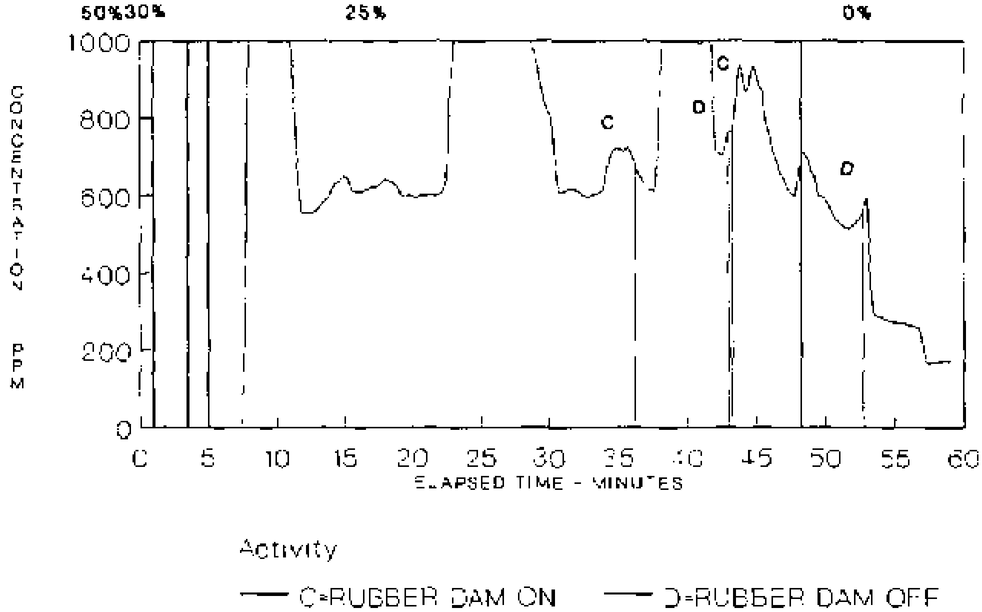
N_2O CONCENTRATION VERSUS ELAPSED TIME
DENTAL OPERATION #1 - 21 APRIL 1988
Aspirator Use



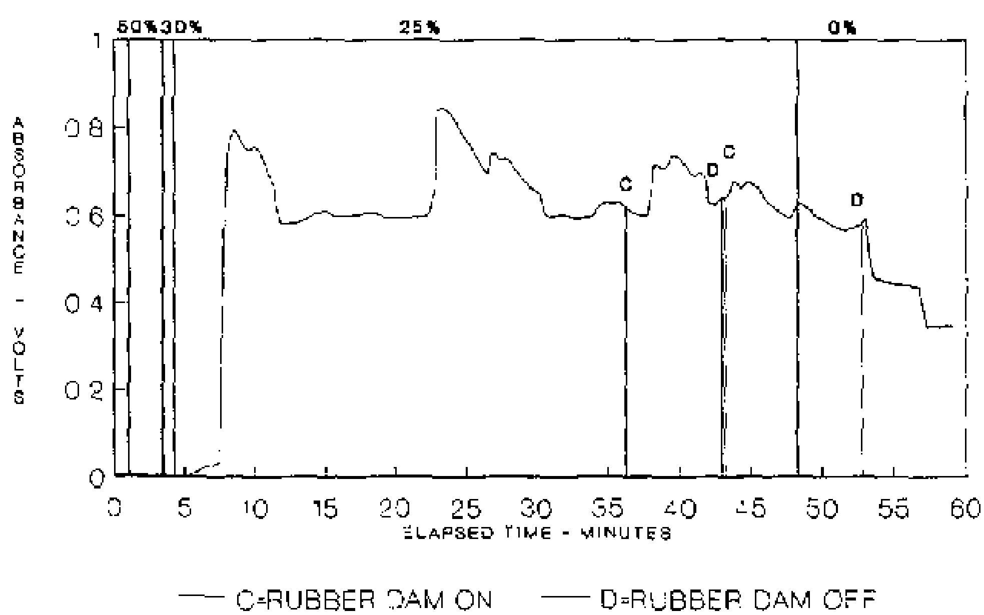
ABSORBANCE VERSUS ELAPSED TIME
DENTAL OPERATION #1 - 21 APRIL 1988
Aspirator Use



N_2O CONCENTRATION VERSUS ELAPSED TIME
DENTAL OPERATION #2 - 22 APRIL 1988
Rubber Dam Use



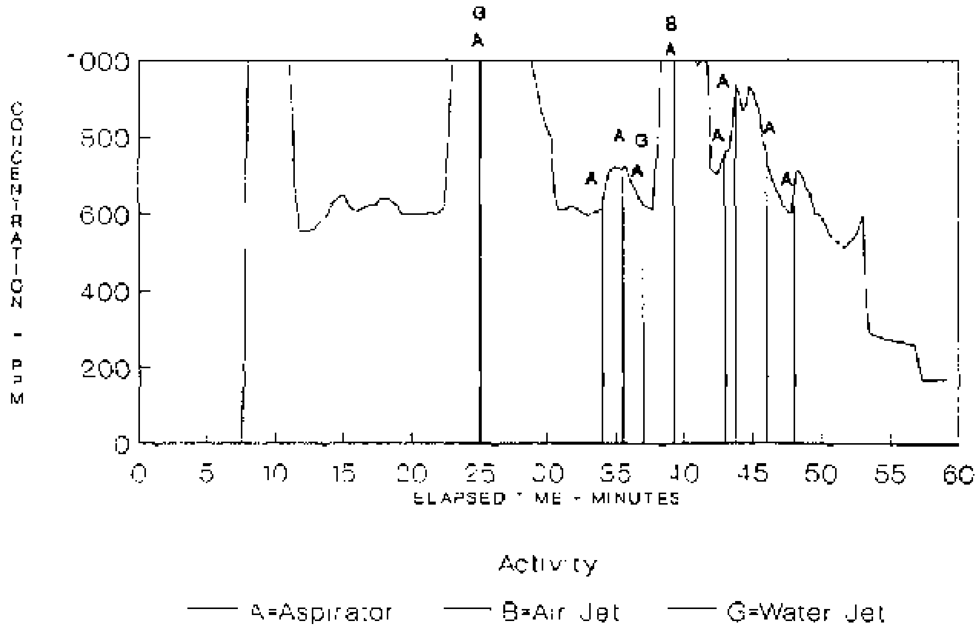
ABSORBANCE VERSUS ELAPSED TIME
DENTAL OPERATION #2 - 22 APRIL 1988
Rubber Dam Use



N_2O CONCENTRATION VERSUS ELAPSED TIME

DENTAL OPERATION #2 - 22 APRIL 1988

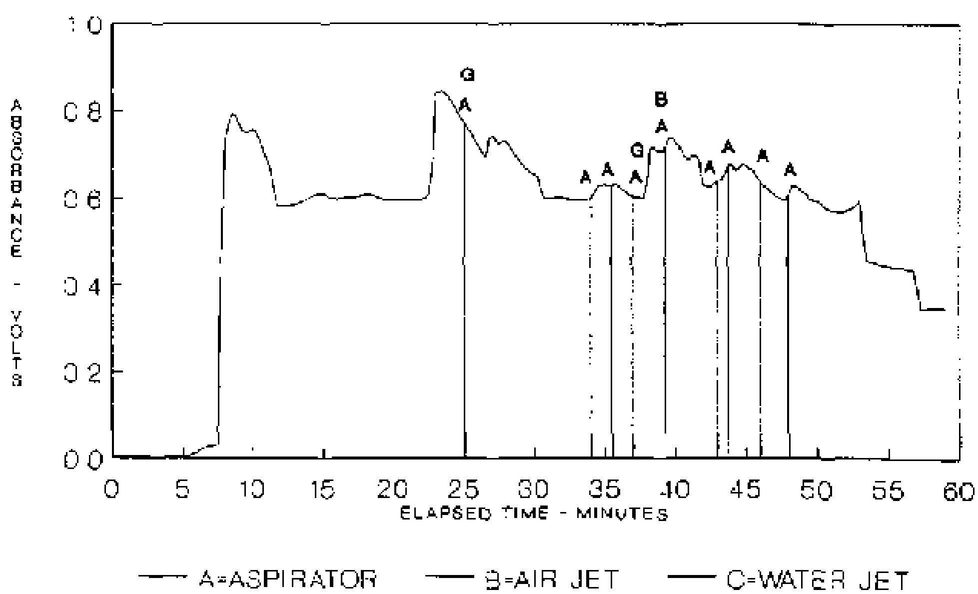
Aspirator Use



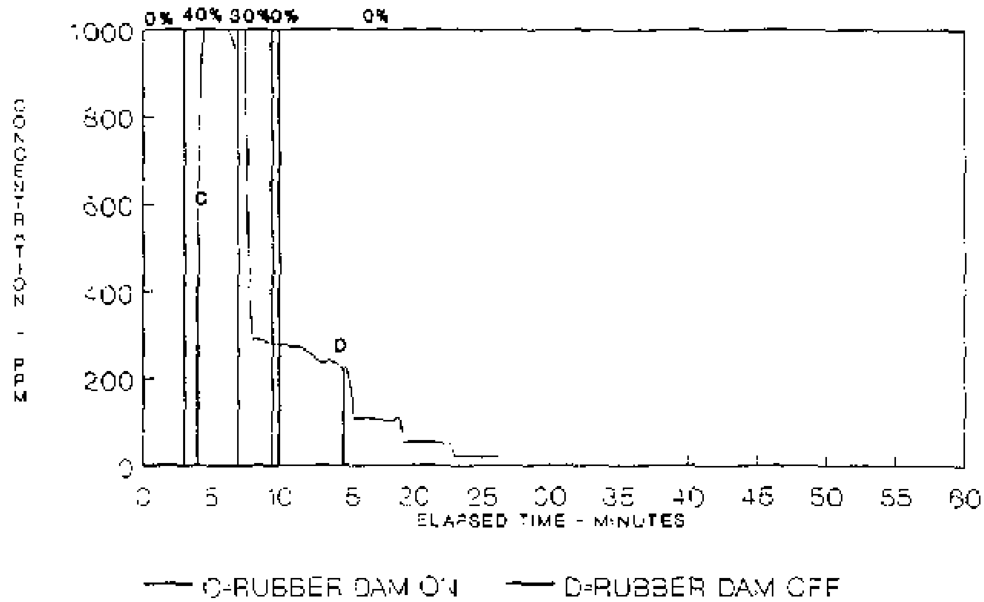
ABSORBANCE VERSUS ELAPSED TIME

DENTAL OPERATION #2 - 22 APRIL 1988

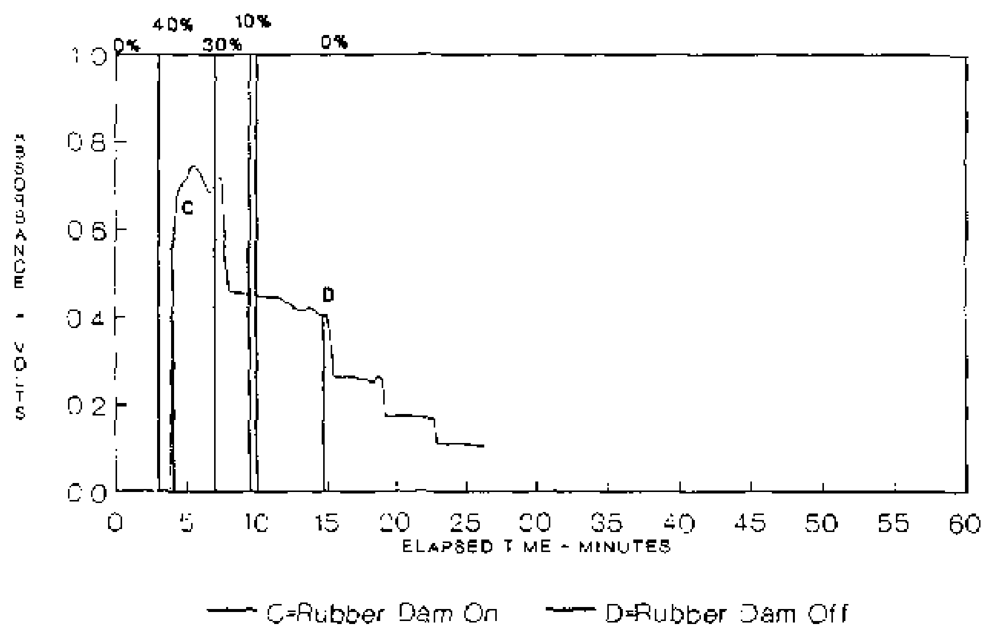
Aspirator Use



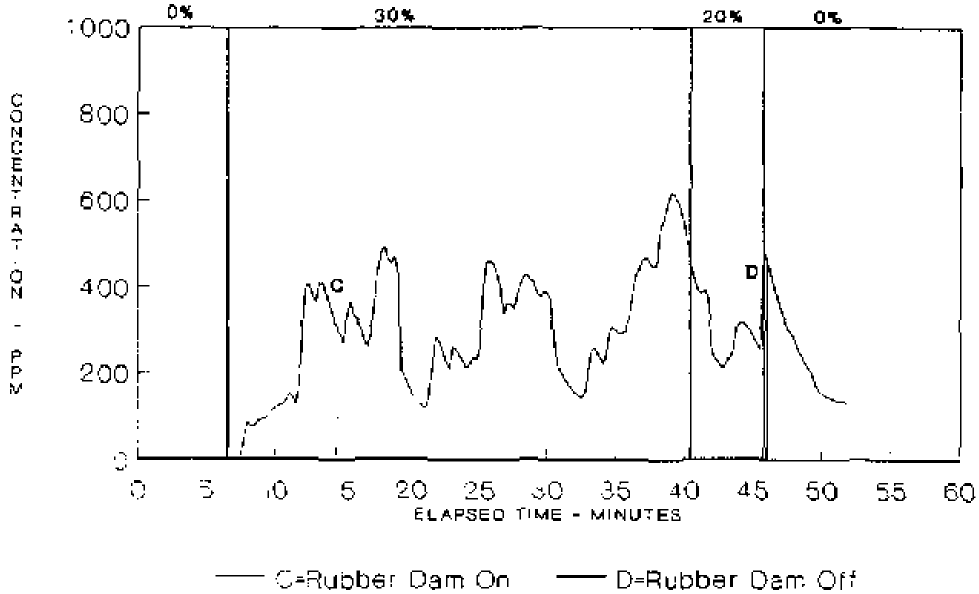
N_2O CONCENTRATION VERSUS ELAPSED TIME
DENTAL OPERATION #3 - 22 APRIL 1988
Rubber Dam Use



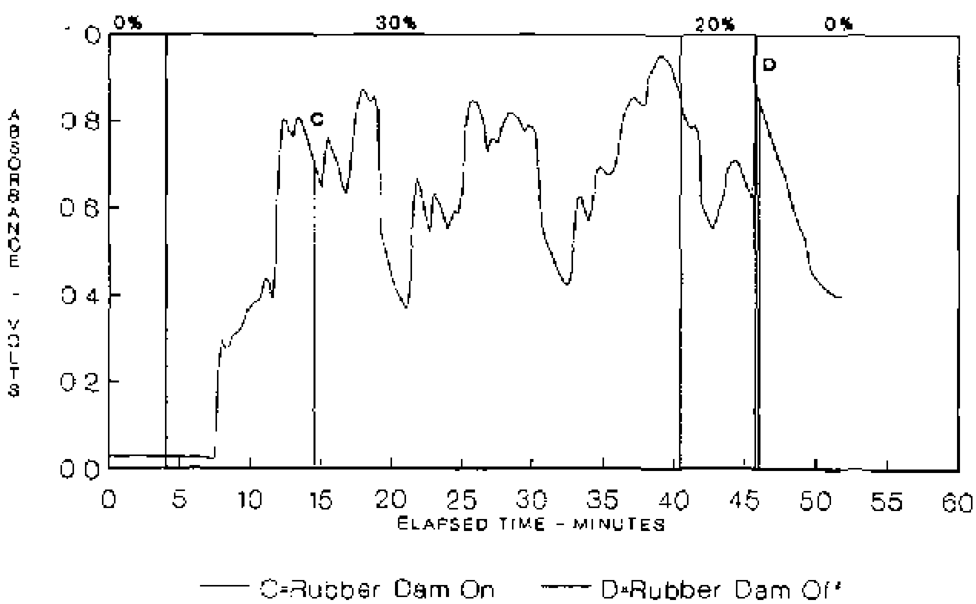
ABSORBANCE VERSUS ELAPSED TIME
DENTAL OPERATION #3 - 22 APRIL 1988
Rubber Dam Use



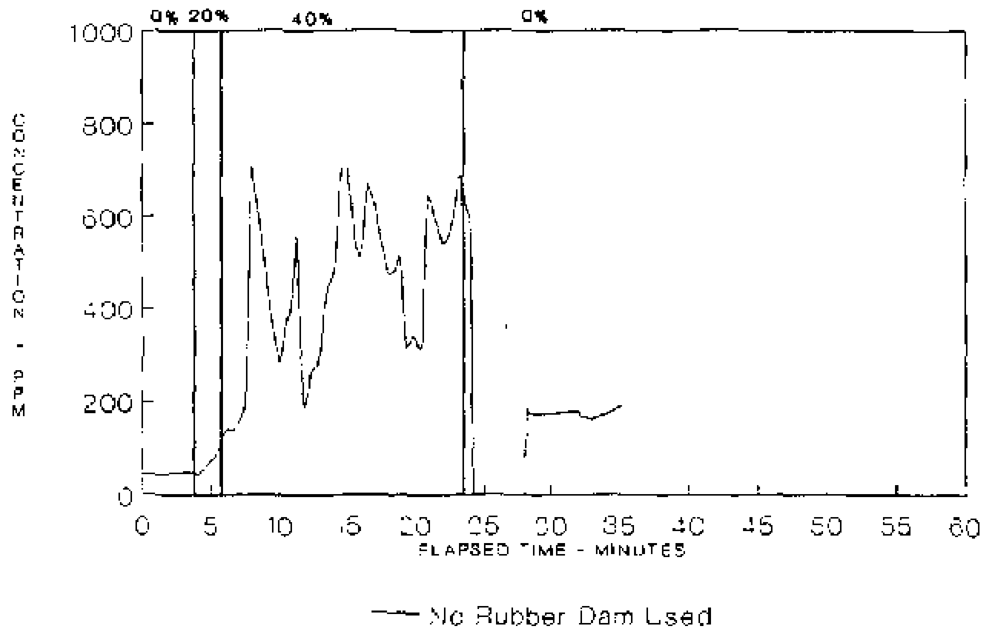
N_2O CONCENTRATION VERSUS ELAPSED TIME
DENTAL OPERATION #5 - 25 APRIL 1988
Rubber Dam Use



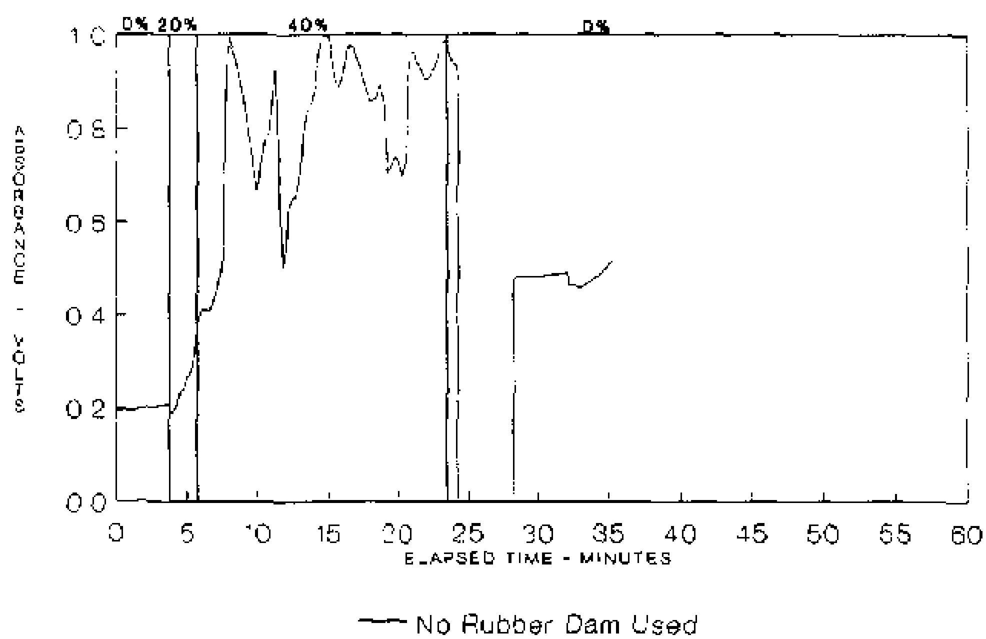
ABSORBANCE VERSUS ELAPSED TIME
DENTAL OPERATION #5 - 25 APRIL 1988
Rubber Dam Use



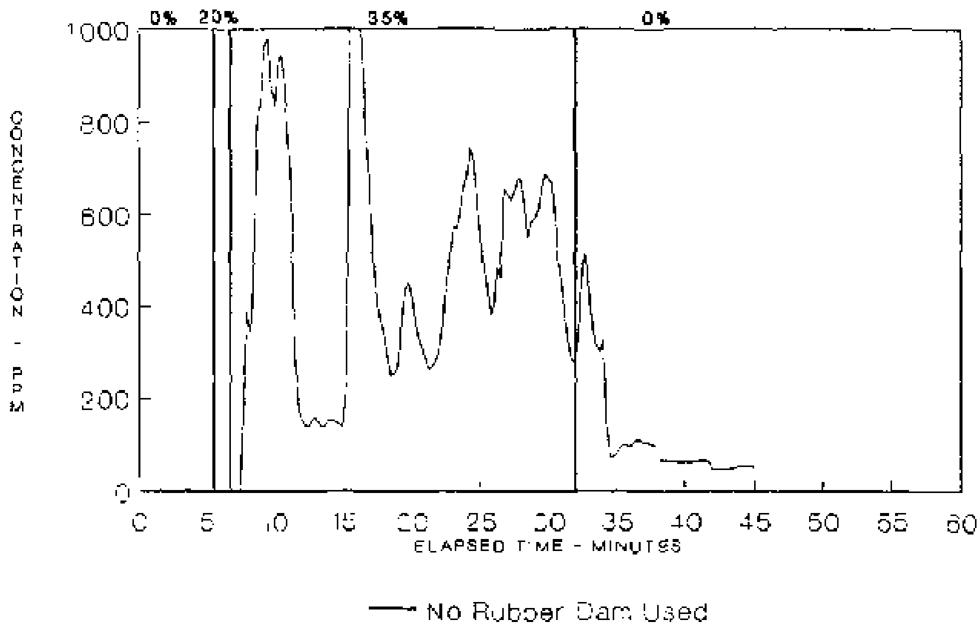
N_2O CONCENTRATION VERSUS ELAPSED TIME
DENTAL OPERATION #6 - 25 APRIL 1988



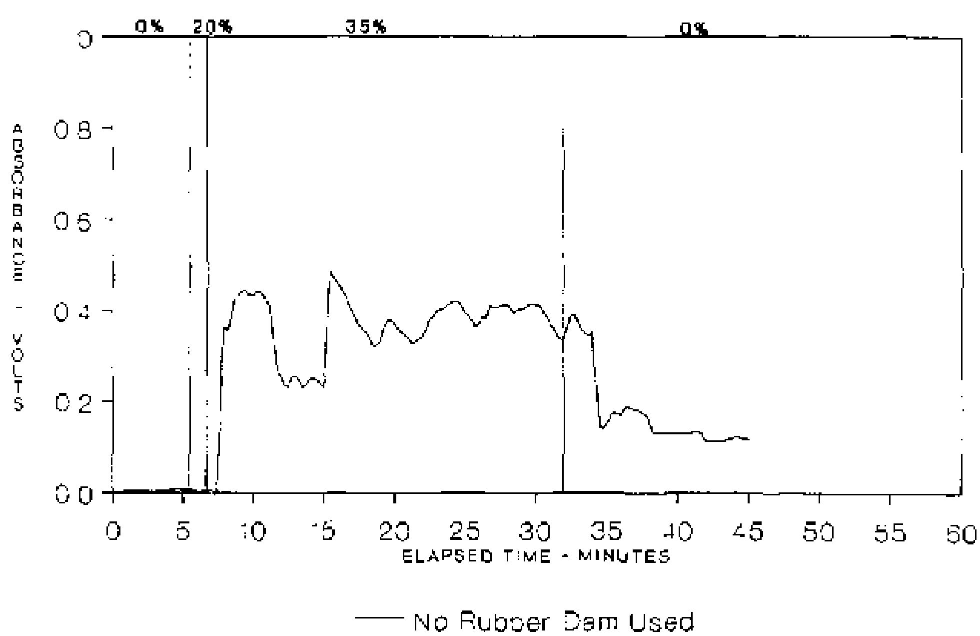
ABSORBANCE VERSUS ELAPSED TIME
DENTAL OPERATION #6 - 25 APRIL 1988



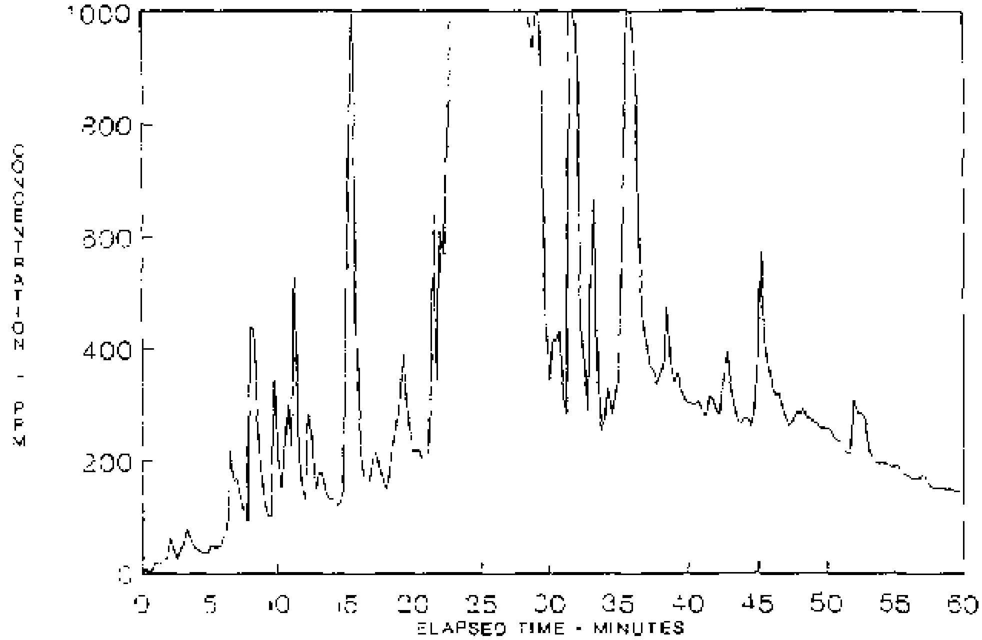
N_2O CONCENTRATION VERSUS ELAPSED TIME
DENATAL OPERATION #7 - 26 APRIL 1988



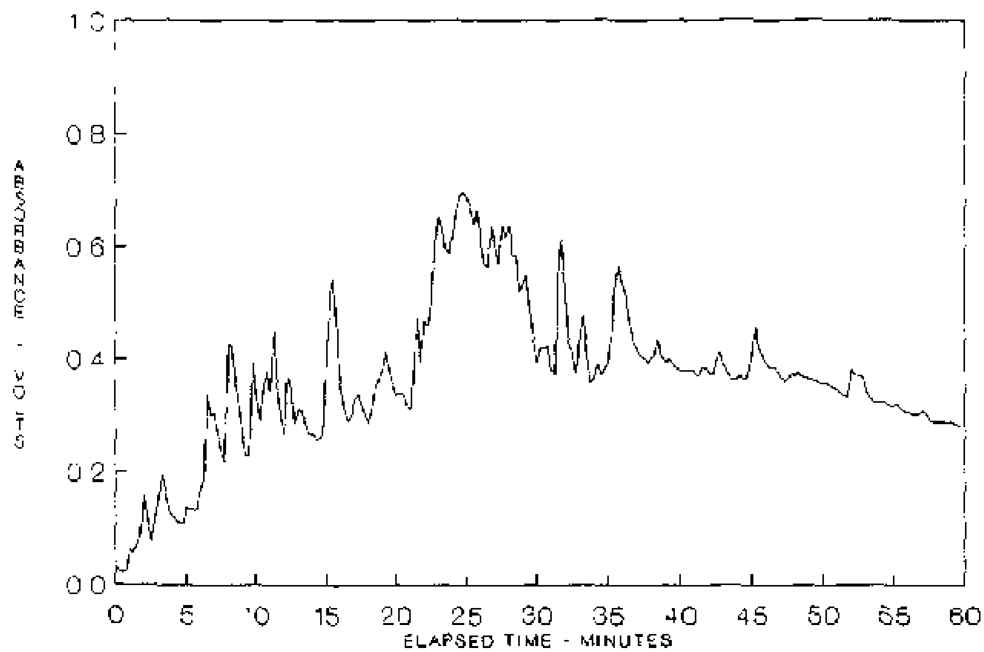
ABSORBANCE VERSUS ELAPSED TIME
DENTAL OPERATION #7 - 26 APRIL 1988

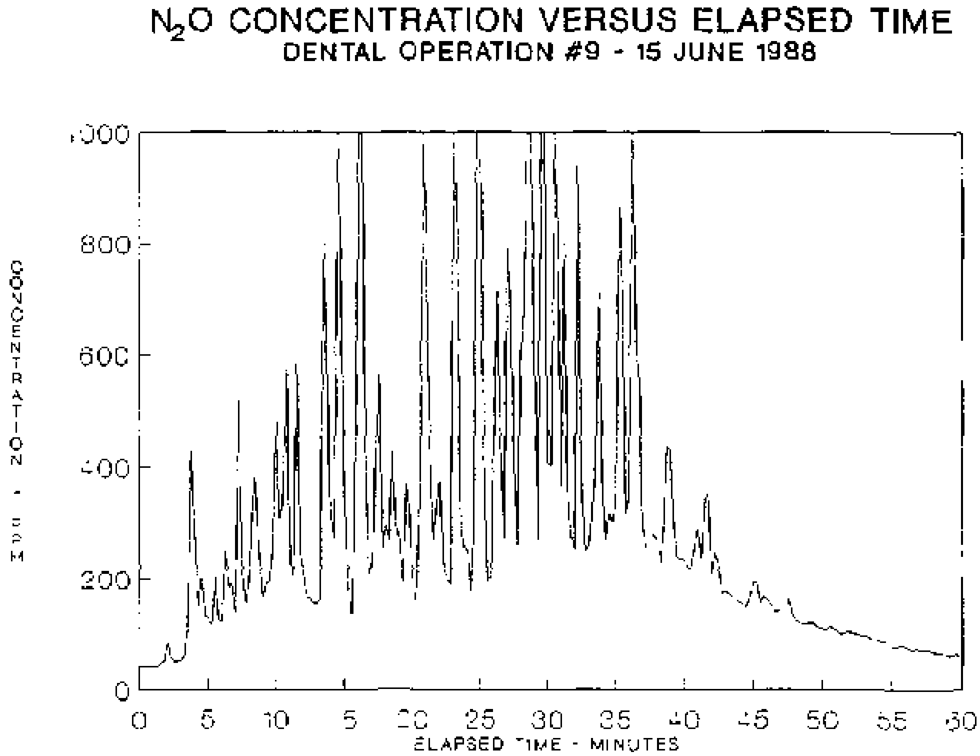


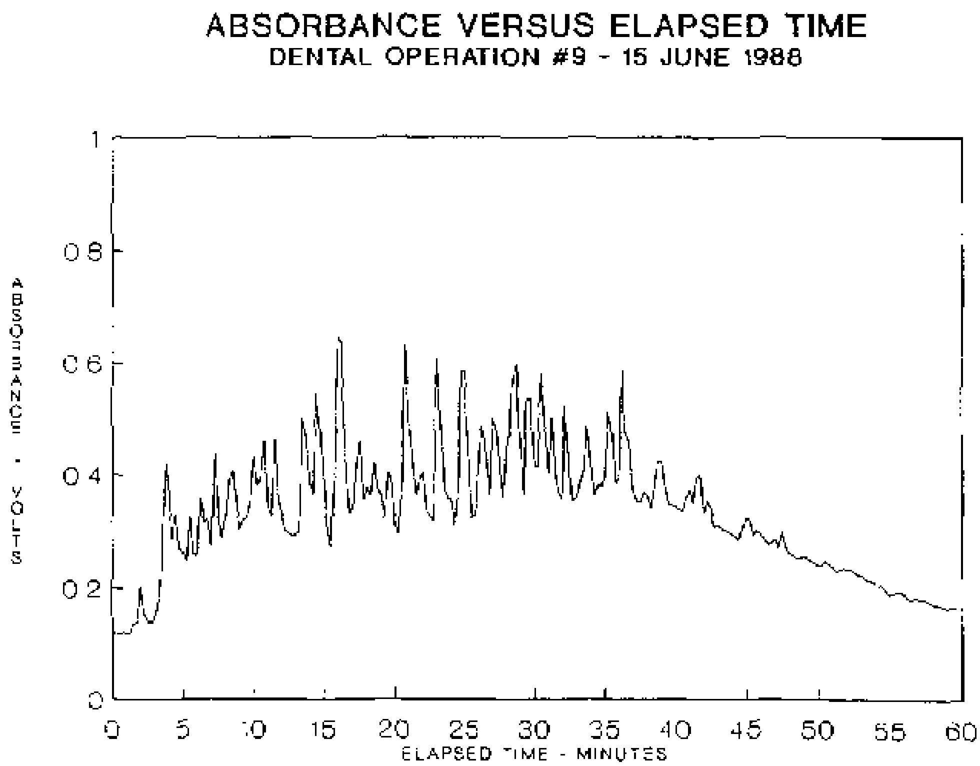
N_2O CONCENTRATION VERSUS ELAPSED TIME
DENTAL OPERATION #8 - 15 JUNE 1988



ABSORBANCE VERSUS ELAPSED TIME
DENTAL OPERATION #8 - 15 JUNE 1988




N2O CONCENTRATION VERSUS ELAPSED TIME
DENTAL OPERATION #9 - 15 JUNE 1988
CONCENTRATION - PPM
ELAPSED TIME - MINUTES


ABSORBANCE VERSUS ELAPSED TIME
DENTAL OPERATION #9 - 15 JUNE 1988
ABSORBANCE - VOLTS
ELAPSED TIME - MINUTES