

**Technical  
Report  
Control of  
Nitrous  
Oxide  
in Dental  
Operatories**



**U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES**

Public Health Service

Centers for Disease Control and Prevention

National Institute for Occupational Safety and Health

CONTROL OF NITROUS OXIDE IN DENTAL OPERATORIES

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September 1994

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REPORT NO.:  
ECTB 166-04

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DHHS (NIOSH) Publication No. 94-129

## ABSTRACT

Researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted four in-depth field evaluations, and one laboratory study to evaluate three commercial dental operator waste anesthetic gas scavenging systems for their effectiveness in reducing  $N_2O$ . Two of the scavenging systems were chosen for the field evaluations because of nationwide availability and differing nasal cone scavenging design. The other scavenging system was evaluated in the laboratory because of its unique design to capture  $N_2O$  due to patient mouth breathing. All scavenging systems, as designed, were found to be inadequate in consistently controlling the gas to the NIOSH REL. The NIOSH Recommended Exposure Limit (REL) for  $N_2O$  is 25 parts per million parts (ppm) of air or less during administration. The REL is based on avoidance of adverse reproductive and impaired psychomotor health effects. Infrared thermography, real-time sampling, and integrated personal and general area sampling were conducted to quantify exposures to dental personnel in the field studies. The fourth in-depth survey included a combination of laboratory and field work on two new local exhaust systems, intended primarily to control patient mouth emissions of  $N_2O$ . Laboratory testing on a head form in conjunction with the fourth field evaluation, established that mask leakage due to poor fit was the primary cause of  $N_2O$  emissions. An improved mask fit and the addition of a slotted skirt around the outer mask shell individually resulted in greatly reduced leakage rates in the laboratory tests. Also, exhaust systems placed on the chin, on the chest, or in the mouth, proved effective in capturing mouth emissions simulated by a breathing machine and head form. Based on these in-depth field surveys and laboratory tests, it was determined that  $N_2O$  concentrations may be consistently controlled to approximately 25 ppm or less by the following: (1) maintaining a leak free  $N_2O$  delivery system from the cylinder to the scavenging mask, (2) adjusting the system exhaust ventilation to recommended flow rates of approximately 45 liters per minute, (3) installing an air measuring device (such as a flowmeter) to assure that the exhaust rate is set properly, (4) redesigning the scavenging mask for better fit on the patient, and (5) using an auxiliary exhaust ventilation placed near the patient's mouth to capture excess  $N_2O$  from patient mouth breathing.

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## INTRODUCTION

The Occupational Safety and Health Act of 1970 has given the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), a number of responsibilities, including the identification of occupational safety and health hazards, evaluations of these hazards, and recommendations for standards to regulatory agencies for control of hazards. Located in the Department of Health and Human Services, NIOSH conducts occupational safety and health research to assist the standard setting function of 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 studies the engineering aspects of health hazard prevention and control in the workplace.

Currently, ECTB has been conducting an assessment of nitrous oxide exposures to dental personnel working in dental operatories. Nitrous oxide ( $N_2O$ ) mixed with oxygen has been used in dentistry as an analgesic and as a sedative for more than 100 years. Today more than 424,000 workers who practice dentistry (i.e., dentists, dental assistants, and dental hygienists) in the United States, are potentially exposed to  $N_2O$ .<sup>1,2</sup>

Research was initiated to provide specific information about consistently controlling waste  $N_2O$  in dental operatories below the NIOSH Recommended Exposure Limit (REL) of 25 parts  $N_2O$  per million parts (ppm) of air during dental surgery. There were three premises for this investigation. First, there were commercially available  $N_2O$  scavenging systems to control waste  $N_2O$  in dental operatories. Second, there was published information in the literature, indicating that such systems did not control waste  $N_2O$  to below the NIOSH REL. Third, there was insufficient evidence to indicate why such systems did not consistently control waste  $N_2O$  to below the NIOSH REL.

### RESEARCH OBJECTIVES

The objectives of this research were the following: (1) To determine why commercially available  $N_2O$  scavenging systems were not controlling concentrations of  $N_2O$  to below the NIOSH REL; (2) To determine whether the performance of commercially available systems could be improved to consistently reduce exposures to below the NIOSH REL; and (3) If the improved performance of commercially available scavenging systems could not consistently reduce exposures to below the NIOSH REL, to determine what further developments were needed to reach this goal.

### THE NEED FOR CONTROLS

The suspected long-term adverse health effects associated with exposure to low concentrations of  $N_2O$  have been demonstrated in a number of epidemiologic studies. These adverse health effects include irritability, headache, nausea, congenital abnormalities, spontaneous abortion, infertility, lymphoid malignancies, cervical cancer, hepatic and renal disease, and neurological disease.<sup>3,4,5,6</sup> Short-term adverse health effects of behavioral performance

decrements have also been reported when N<sub>2</sub>O was administered at 50 ppm in controlled laboratory settings.<sup>7</sup> The behavioral performance decrements are not present at 25 ppm. Based on the epidemiologic studies and the short-term health effects of performance problems, NIOSH recommends that exposures be limited to a time-weighted average (TWA) concentration of 25 ppm during the period of administration.<sup>8</sup>

Since the NIOSH recommendation was established, research efforts have focused on the mechanisms of N<sub>2</sub>O exposure and reproductive outcome. In the early 1980s, N<sub>2</sub>O concentrations at 1000 ppm were reported to inactivate the vitamin B<sub>12</sub> component of the enzyme methionine synthetase. It was theorized that the interference of the enzyme activity can impair deoxyribonucleic acid (DNA) synthesis and thus may partially explain the role of N<sub>2</sub>O in reproductive toxicity.<sup>9,10</sup> However, more recent research suggests that this is not well supported. What may be happening is a multifactorial etiology, which may involve changes in uterine blood flow.<sup>11,12</sup>

## OVERVIEW OF N<sub>2</sub>O

In the late 1980s, research demonstrated that rats exposed to 500 ppm N<sub>2</sub>O for eight hours per day for one or two months had reduced fertility.<sup>13</sup> These researchers hypothesized that N<sub>2</sub>O increases the fertility blocking secretion of luteinizing hormone reducing hormone in the hypothalamus, thus, disrupting ovulation. Most recently, a retrospective epidemiologic study of female dental assistants exposed to N<sub>2</sub>O showed significantly reduced fertility compared to unexposed females. In addition, those females with five or more hours of exposure per week had a 59 percent decrease in the probability of conception compared to unexposed females.<sup>14</sup>

In 1977, NIOSH published a technical report entitled "Control of Occupational Exposure to N<sub>2</sub>O in the Dental Operator."<sup>15</sup> In this report, methods were recommended to control waste N<sub>2</sub>O to 50 ppm during administration, based on the technical feasibility of existing controls. Since then, several reports have shown that not only is N<sub>2</sub>O not being consistently controlled to 50 ppm, but also not to the NIOSH REL of 25 ppm during administration (based on health effects), when anesthetic gas control scavenging systems are used.<sup>15,17,18,19,20,21</sup>

## Physical Properties

N<sub>2</sub>O is an odorless, stable, noncombustible, colorless, tasteless gas that is approximately 1.5 times heavier than air. It is manufactured commercially by thermal decomposition of ammonium nitrate and purification of its byproducts.<sup>22</sup>

## Toxicological Properties

N<sub>2</sub>O does not combine with hemoglobin but is dissolved in the blood as a gas.<sup>23</sup> It is eliminated, virtually unchanged, from the body by way of the lungs; a slight amount may be excreted through the pores of the skin.<sup>24</sup> N<sub>2</sub>O is a weak anesthetic with rapid onset and rapid emergence,<sup>25</sup> most of it disappearing from the body in 17 to 35 minutes after being discontinued. N<sub>2</sub>O

can produce several changes in cardiovascular function. It may depress the myocardial action while stimulating the heart by central activation of the brain nuclei.<sup>26</sup> It decreases cardiac output, stroke volume, mean arterial pressure, stroke work, and minute volume.<sup>27</sup> Decreases are also seen in blood pressure, pulse rate, and respiration.<sup>28</sup> In 1979, Vein and King stated that N<sub>2</sub>O acted solely on the cerebral cortex, thus causing a mild depression and that N<sub>2</sub>O was not allergenic.<sup>29</sup> Amess et al. (1978) pointed out that N<sub>2</sub>O may interfere with the function of vitamin B<sub>12</sub>.<sup>30</sup> The toxic effects of N<sub>2</sub>O have been attributed to its ability to inactivate the enzyme methionine synthetase by oxidizing the enzyme's vitamin B<sub>12</sub> cofactor. Supporting documentation by Sweeney et al. (1985) provided evidence that occupational exposure to N<sub>2</sub>O may cause depression of vitamin B<sub>12</sub> activity, resulting in measurable changes in bone marrow secondary to impaired synthesis of DNA.<sup>31</sup> Other researchers have suggested that N<sub>2</sub>O may not depress vitamin B<sub>12</sub> activity, but that another mechanism may be causing the reproductive health effects.<sup>32,33</sup>

## Reproductive Effects

### Human Studies--

Exposure to N<sub>2</sub>O, along with other anesthetic agents including halogenated anesthetic compounds, has been identified by epidemiological studies to be a suspected reproductive health hazard. Vaisman published the first report in 1967 of adverse reproductive effects from working in operating theaters.<sup>34</sup> Dr. Vaisman noted that 18 of 31 female anesthesiologists who had been pregnant experienced at least one miscarriage. A number of studies in Sweden, the United Kingdom, and the United States have shown adverse reproductive effects in females working in operating rooms.<sup>5,6,35</sup> The most comprehensive epidemiological study of health dysfunction associated with work in the operating room was from research data obtained from 40,044 respondents.<sup>6</sup> Females working in the operating room showed an increased incidence of spontaneous abortion and carcinoma. The incidence of birth defects in their offspring was elevated, as well as in the offspring of nonoccupationally exposed wives of exposed male anesthetists. Spontaneous miscarriage and birth defects also were reported in a survey of female anesthetists in the United Kingdom.<sup>3</sup>

The findings of several epidemiologic surveys were summarized by James T. Purdham of the Occupational and Environmental Health Unit, University of Toronto.<sup>36</sup> Another study summarized the in vitro animal and retrospective studies from N<sub>2</sub>O exposure.<sup>37</sup> A consistent result in these summaries showed that women exposed to waste anesthetic gases had 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. A recent epidemiologic study of California female dental assistants found that women exposed to nonscavenged N<sub>2</sub>O were at significant risk of subfertility compared to unexposed women, and those with five or more hours of exposure per week had a 59 percent decrease in their probability of conception for any given menstrual cycle compared to unexposed female dental assistants.<sup>14</sup> This same study also reported that female dental assistants who worked with N<sub>2</sub>O had no evidence of reduced fertility when working with scavenged N<sub>2</sub>O systems compared to controls.

## Animal Studies--

Supporting evidence of the toxic effect of anesthetic agents is shown in laboratory studies. The evidence includes the following: teratogenic effects in various animal species upon exposure to a wide group of inhalation agents at anesthetic concentrations, decreased survival rate in various species, 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 two days exposure to 20 percent N<sub>2</sub>O.<sup>38,39</sup> Several animal studies have focused on anesthetic gases, principally N<sub>2</sub>O and halothane, as a cause of miscarriage or congenital abnormalities. When the animals were exposed to high concentrations of these anesthetics, spontaneous abortion (animal fetal resorption) and congenital abnormalities were observed. In one study by Viera et al. (1980), spontaneous abortion was observed in rats at 1000 ppm or more.<sup>40</sup> Similar concentrations of 1000 ppm have been found in operating rooms and in dental operatories not equipped with scavenging systems.

In a recent study, female rats were exposed to high concentrations (30 percent equal to 300,000 ppm) of N<sub>2</sub>O eight hours/day for four days to allow completion of one ovulatory cycle. All exposed rats exhibited abnormal ovulatory cycles. Rats exposed to oxygen and compressed air maintained a normal four-day estrous cycle.<sup>13</sup> More recent animal experiments suggest that the reproductive hazards may be related to decreased release of luteinizing hormone reducing hormone.<sup>41</sup> Other studies show that exposure to concentrations of 50 percent or more of N<sub>2</sub>O for 24 hours during early pregnancy result in high incidence of fetal wastage and skeletal and visceral abnormalities.<sup>32,42</sup> The mechanisms which result in the fetal wastage and skeletal and visceral abnormalities, as well as other teratogenic effects, are yet to be defined. As mentioned earlier, one popular opinion suggests that N<sub>2</sub>O reacts with the reduced form of vitamin B<sub>12</sub>, thereby inhibiting the action of methionine synthetase, and thus interfering with DNA synthesis.<sup>43</sup> However, this opinion has been challenged recently; an alternate theory suggests that N<sub>2</sub>O stimulation of alpha-1 adrenergic receptors may account for some of the adverse reproductive effects.<sup>33</sup> Fujinaga et al. (1991) suggest that two mechanisms can be postulated for linking adrenergic stimulation and adverse reproductive effects: reduced uterine blood flow, and/or overstimulation of G protein-dependent, membrane signal transduction pathways.<sup>33</sup> Both mechanisms are reported to be linked to teratogenic and tumorigenic effects. While the animal studies are not directly transferable to human studies, the reproductive effects warrant prudent use and control of N<sub>2</sub>O.

## Carcinogenicity and Mutagenicity

Excess cancer was found in a small group of nurse anesthetists in Michigan by Corbett in 1973.<sup>44</sup> However, Ferstandig evaluated Corbett's work and found that the high cancer rate occurred only for one year, and when all the data were considered, there was no significant difference between the nurse anesthetists and the control group.<sup>45</sup> Tests for mutagenicity (a test for screening carcinogenic agents in bacterial systems) are negative for N<sub>2</sub>O.<sup>46</sup>

## 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; kidney disease was less strongly associated with anesthetic exposure.<sup>47</sup> Studies supporting these conclusions were performed in England.<sup>48</sup> Because the workers were exposed to a mixture of anesthetic agents including nitrous oxide, halothane and methoxyflurane, it was not known what impact N<sub>2</sub>O alone had on liver and kidney dysfunction. In animal experiments N<sub>2</sub>O was shown to be without effects to the liver and kidneys.<sup>36</sup>

## Central Nervous System Effects

Human studies testing cognitive and motor skills show that exposure to trace concentrations of anesthetic gas mixtures, N<sub>2</sub>O/halothane or N<sub>2</sub>O/enflurane, and N<sub>2</sub>O by itself results in decreased ability to perform complex tasks.<sup>49, 4, 7</sup> However, experimental attempts to duplicate human performance decrements have not supported these earlier studies.<sup>50</sup> While habitual use of N<sub>2</sub>O has been linked to damage of the peripheral nervous system, the literature does not define a safe limit of occupational exposure that will not impair performance.

The epidemiologic and behavioral toxicity studies are not without controversy. The literature citing limitations of the research for long term, low concentration exposure to N<sub>2</sub>O is summarized by Yagiela (1991).<sup>43</sup> Yagiela concludes that there is evidence that a potential danger exists for adverse health effects to occur as a consequence of N<sub>2</sub>O exposure, and that there is a known mechanism by which N<sub>2</sub>O could induce deleterious health effects. In addition, some studies have not been able to duplicate the deficiencies in behavioral performance among test subjects reported in the literature.<sup>51, 52, 53</sup>

## EXPOSURE LIMITS

In May 1977, NIOSH published a criteria document entitled "Occupational Exposure to Waste Anesthetic Gases and Vapors."<sup>8</sup> This document recommended a N<sub>2</sub>O concentration no greater than 25 ppm during administration. This document also recommended the use of engineering and work practice controls and discussed health effects and methods for monitoring anesthetic waste gases and vapors. The NIOSH REL for N<sub>2</sub>O in the criteria document was based on several studies showing adverse health effects at higher anesthetic concentrations, including the following: irritability, headache, nausea, congenital abnormalities, spontaneous abortion, involuntary infertility, lymphoid malignancies, cervical cancer, hepatic and renal disease, and neurological disease compared to controls.<sup>3, 4, 7, 5, 6</sup> However, the recommendation for a 25 ppm maximum limit was based primarily on a NIOSH-sponsored study performed by Bruce and Bach<sup>4, 7</sup> and published by NIOSH in April 1977.<sup>15</sup> This study showed that human volunteers who were exposed to N<sub>2</sub>O at concentrations of 50 ppm had audiovisual decrements with delayed reaction times to audiovisual stimuli. No such decrements were observed at 25 ppm.<sup>8</sup> The criteria document concluded with the following recommendation: *"The adverse effects of prime concern involve decrements in performance, cognition, audiovisual ability, and in dexterity during exposures to nitrous oxide. Such effects have been observed*



at exposure levels to  $N_2O$  at 500 ppm. At levels as low as 50 ppm, audiovisual decrements were observed in exposed volunteers. This shows the potential for this substance to impair functional capacities of exposed workers. Similar decrements were not observed at 25 ppm nitrous oxide with 0.5 ppm halothane. Based on this information NIOSH recommends that where exposures are limited to  $N_2O$  alone, the permissible level of exposure should be a TWA concentration of 25 ppm during the period of administration."<sup>8</sup>

In April 1977, a NIOSH technical report was published which developed and evaluated controls for waste anesthetic gases in dental operatories.<sup>15</sup> Studies presented in this report and based on technical feasibility of existing controls demonstrated that in dental operatories it was possible to achieve a  $N_2O$  concentration of 50 ppm during administration. In October of that same year, an Ad Hoc Committee of the American Dental Association published a report entitled "Trace Anesthetics as a Potential Health Hazard in Dentistry."<sup>54</sup> The Committee recognized the potential that a health hazard could occur and urged that every effort be made to reduce the trace concentration of anesthetic/sedative agents in the dental environment to concentrations as low as possible using the existing technology.

In 1989, the American Conference of Governmental Industrial Hygienists (ACGIH) recommended a  $N_2O$  Threshold Limit Value (TLV)<sup>®</sup> of 50 ppm for an 8-hour day.<sup>55,56</sup> One problem with the 8-hour TWA is that it permits short-term exposures to high  $N_2O$  concentrations when the anesthetic is used intermittently. For example, if  $N_2O$  is administered for only one hour during the 8-hour day, then it may be interpreted by the dental community that an excursion of up to 400 ppm TWA is allowed under the ACGIH guidelines. However, in order to control for intermittent exposure, the ACGIH notes that exposure should not exceed three times the TWA (i.e., 150 ppm during administration of  $N_2O$ ).<sup>55</sup>

OSHA does not currently have a standard for  $N_2O$ . However, it has drafted guidelines for waste anesthetic gases and vapors. While the guidelines on anesthetic gases and vapors do not specify a limit, it provides information to employers and employees on the potential health risks, ways to reduce concentrations through engineering or work practice controls, means of implementing medical or training programs, procedures for monitoring gases and vapors in dental operatories, and implementation of preventive maintenance.

Presently there are few specific state regulations governing the handling and administration of  $N_2O$  by dentists. The Boards of Registration in Dentistry of 24 states have rules that regulate the use of  $N_2O$ . Massachusetts, Tennessee, Utah, and Wisconsin have implemented more detailed regulatory language regarding the use of  $N_2O$ ; Massachusetts and Wisconsin also have implemented laws to control  $N_2O$  by using scavenging systems.

## DENTAL PRACTICES AND ANESTHESIA EXPOSURES

### Analgesic/Anesthetic Dental Practices

Dental practices may vary according to the type of dental setting, dental operation, and patient needs. Certain basic practices performed by the

dentist when using  $N_2O$  are similar. Before  $N_2O$  is administered, the dental assistant may position the patient in a dental chair and perform various other functions needed before the dentist begins work. These may include organizing the dental tools, setting up the mask for  $N_2O$  delivery to the patient, and arranging intravenous sedation (if needed). Following preparation procedures, the dentist positions himself next to the patient and begins the operation. The dentist or assistant places the mask over the patient's nose, turns on the oxygen and  $N_2O$ , and waits a few minutes, possibly five to ten minutes, for the  $N_2O$  to take effect.  $N_2O$  can be administered to the patient from a range of 1 to 70 percent; the usual range is 30 to 50 percent  $N_2O$ . For safety reasons, certain anesthesia machines are designed so that no more than 70 percent  $N_2O$  and no less than 30 percent  $O_2$  can be delivered to the patient. The amount of  $N_2O$  administered is based on patient needs as determined by the dentist. Some dentists administer  $N_2O$  at higher concentrations at the beginning of the operation, then decrease the amount as the operation progresses. Others administer the same amount of  $N_2O$  throughout the operation. When the operation is completed,  $N_2O$  is turned off. Oxygen may be continued for a few minutes, after which the mask is removed from the patient. Some dentists turn the  $N_2O$  on only at the beginning of the operation, using  $N_2O$  as a sedative during the administration of local anesthesia, and turn it off before operating procedures. Based on variations in dental practices and other factors in room air,  $N_2O$  concentrations can vary considerably for each operation and also vary over the course of the operation.<sup>57</sup>

#### Nitrous Oxide Exposure During The Dental Procedure

When  $N_2O$  equipment leakage is prevented, gas concentrations will be highest around the breathing zone of the patient, especially the nosepiece where the anesthetic is administered. The anesthetic gas mixture is exhaled by the patient, either from the nose or from both the nose and mouth, and is 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 vary according to the amount of fresh air supplied to the dental room and the room configuration (i.e., open or closed architecture).<sup>57</sup> Personal exposure of the dentist and dental assistant to the anesthetic will vary according to their proximity to the breathing zone of the patient and the general room concentration. Previous survey observations have shown that the dentist usually works from 6 to 12 inches above the patient's breathing zone, while the dental assistant works from 12 to 24 inches of this zone.<sup>57</sup> In an environment where there is little air movement, high concentrations of  $N_2O$  may occur between the working level of the dental personnel and the patient. If the room is not well ventilated, gas concentrations may be very high at times and not return to baseline levels. Over time, 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 3,500 ppm.<sup>21</sup> Table 1 shows the results of NIOSH Hazard Evaluation and Technical Assistance (HETA) evaluations for non-scavenged occupational exposure to nitrous oxide in dental operatories.

The NIOSH findings are consistent with other studies showing high concentrations of N<sub>2</sub>O in dental operatories. As Table 1 shows, there is a large range of N<sub>2</sub>O concentrations for nonscavenged delivery systems. Scheidt et al. showed that the concentration of waste gas in the ambient air during administration of N<sub>2</sub>O/O<sub>2</sub> is dependent upon three primary factors: (1) the distance from the nosepiece escape valve; (2) the position in relation to the direct line of waste gas dissemination; and (3) the changes in concentration of analgesia.<sup>58</sup>

Table 1. NIOSH Hazard Evaluation & Technical Assistance (HETA) results for N<sub>2</sub>O in nonscavenged dental operatories.

HETA # Report Number	General Area Sampling Range, (ppm)	Personal Sampling Range, (ppm)
78-9 <sup>59</sup>	10 - 170	150 - >1400
79-5-554 <sup>60</sup>	75 - 3000	90 - 3500
79-43 <sup>61</sup>	170 - > 1000	180 - >1000
79-59 <sup>62</sup>	54 - 500	258 - 2650
80-16 <sup>63</sup>	100 - 210	25 - 300
81-200-999 <sup>64</sup>	150 - >1000	200 - 700
81-342-1005 <sup>65</sup>	4 - >250	175 - >250
84-126-1555 <sup>66</sup>	20 - 350	---
84-204-1600 <sup>67</sup>	100 - 750	670 - 2270
84-412-1612 <sup>68</sup>	70 - 315	2400
85-408-1666 <sup>69</sup>	100	150 - >1000
86-157-1678 <sup>70</sup>	50 - 800	700 - >1000

Angle of position in relation to the direction of waste gas dissemination was shown to be the most dominant factor. These findings may explain the large variation reported in the literature with regard to concentrations from nonscavenged systems.

#### CONTROL PRINCIPLES

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 the following activities: (1) effective scavenging devices that remove excess anesthetic gas at the point of origin (e.g., from the proximity of the mask); (2) good work practices on the part of the dentist and dental assistant, including the proper use of controls; (3) proper maintenance of equipment to prevent leaks; and (4) regular monitoring of environmental exposure for leaks in the anesthesia equipment delivery systems and to assure the effectiveness of equipment and controls. Additional controls that may be applied include dilution, general ventilation, and good housekeeping.

In general, a system comprised of the above control measures is required to provide worker protection under normal operating conditions. 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 and training of dental personnel to reduce and eliminate occupational health problems are also important elements for a complete, effective, and durable control system.

The sections that follow briefly examine the existing guidelines and current controls that are used to reduce sources of  $N_2O$  in the dental operatory. Appendix A provides additional information on controls that are used for  $N_2O$  at various points in the analgesia delivery system.

## Engineering Controls

### Substitution--

The substitution of  $N_2O$  with a nontoxic analgesic gas, which can perform to the specifications required by this profession, would eliminate the hazards to the dental personnel from exposure to  $N_2O$ . Currently no such analgesic gas is available. Although  $N_2O$  is routinely used in dental practice, many dental schools are training their students to use local anesthetics in combination with injectable drugs to get the same results. However, many dentists continue to prefer  $N_2O$  because of its relative safety.<sup>11</sup>

### Isolation--

Isolating dental personnel from  $N_2O$  emissions by a physical barrier or by increasing the distance between the dentist and the patient while  $N_2O$  is in use is a potential control method to reduce exposure. However, physical separation with a clear plastic barrier placed between the patient and dentist may not be practical because of the awkwardness and distance constraints of such a barrier. If barriers such as clear plexiglass are used, then functional design elements, such as size, distance, and effects on lighting, need to be considered. Consultation with dental practitioners will help with design, as well as acceptability of such control devices in the dental profession. It has been reported that a "rubber dam," a plastic 6X6 inch sheet placed in the patient's mouth during  $N_2O$  administration, serves to

reduce waste N<sub>2</sub>O by trapping this gas in the patient's mouth. However, as discussed later in this report, N<sub>2</sub>O emissions may not be reduced by the use of rubber dams. The use of infrared thermography indicated that N<sub>2</sub>O was not trapped in the patient's mouth but was redirected through the left and right sides of the mouth where the rubber dam was not fastened.<sup>57</sup>

### Respiratory Protection--

Workers should wear respiratory protection when N<sub>2</sub>O concentrations are not consistently below 25 ppm; however, practical considerations may prevent them from wearing such protection. Therefore, it is essential that employers use the engineering controls and work practices to reduce N<sub>2</sub>O concentrations below 25 ppm.

When N<sub>2</sub>O concentrations are not consistently below 25 ppm, workers should take the following steps to protect themselves:

Wear air-supplied respirators. Air-purifying respirators (that is, respirators that remove N<sub>2</sub>O from the air rather than supply air from a clean source) should not be used because respirator filters do not efficiently remove N<sub>2</sub>O.

As specified by the NIOSH Respirator Decision Logic, minimal protection for an air-supplied respirator is provided by a half-mask respirator operated in the demand or continuous-flow mode. [Note: the assigned protection factor (APF) for this class of respirator is 10. The APF indicates the amount of protection provided by a class of respirator. An APF of 10 means that the respirator should reduce the air concentration of N<sub>2</sub>O for the wearer by a factor of 10 (or to 10% of the concentration without respiratory protection).] More protective air-supplied respirators are described in the NIOSH Respirator Decision Logic.<sup>72</sup>

When respirators are used, the employer must establish a comprehensive respiratory protection program, as outlined in the NIOSH Guide to Industrial Respiratory Protection, and as required by the OSHA respiratory protection standard [29 CFR 1910.134]. Important elements of this standard are (1) an evaluation of the worker's ability to perform the work while wearing a respirator, (2) regular training of personnel, (3) periodic environmental monitoring, (4) respirator fit testing, (5) maintenance, inspection, cleaning, and storage, and (6) selection of proper NIOSH-approved respirators. The respiratory protection program should be evaluated regularly by the employer.

### Scavenging Systems--

The NIOSH technical report entitled "Control of Occupational Exposure to N<sub>2</sub>O in the Dental Operatory," published in 1977, presented information on the development of engineering controls to consistently control waste N<sub>2</sub>O to 50 ppm during administration. The main engineering control was the design and development of a nasal scavenging mask. This scavenging mask consists of an inner and a slightly larger outer nasal mask. The inner mask has two

3/8 inches hoses connected which supply anesthetic gas to the patient. A relief-valve is attached to the inner mask to release excess N<sub>2</sub>O into the outer mask. The outer mask has two smaller hoses connected to a vacuum system to capture excess gases from the patient and from the analgesia machine. A flow rate of approximately 45 liters per minute (lpm) is the optimal flow necessary to prevent significant N<sub>2</sub>O leakage into the room air.

In addition to scavenging masks, other engineering controls were developed to control N<sub>2</sub>O, such as a suction hook and evacuated plastic hood which fit over the patient's head.<sup>15</sup> Researchers found the hood and suction hook were compatible with a conventional nasal mask; however, it was inconvenient to the dentist and unacceptable to the unanesthetized patient. The three-stage industrial scrubber, which contained a water spray, a calcium sulfate (CaSO<sub>4</sub>) absorber, and a high efficiency filter did not significantly reduce N<sub>2</sub>O concentrations. The authors concluded that optimal control of N<sub>2</sub>O could not be achieved by any single control system, and that the primary systems should include a regular maintenance program of the anesthetic equipment to reduce leakage, ventilation of the waste N<sub>2</sub>O to a safe disposal site, and use of a scavenging nasal mask.<sup>15</sup>

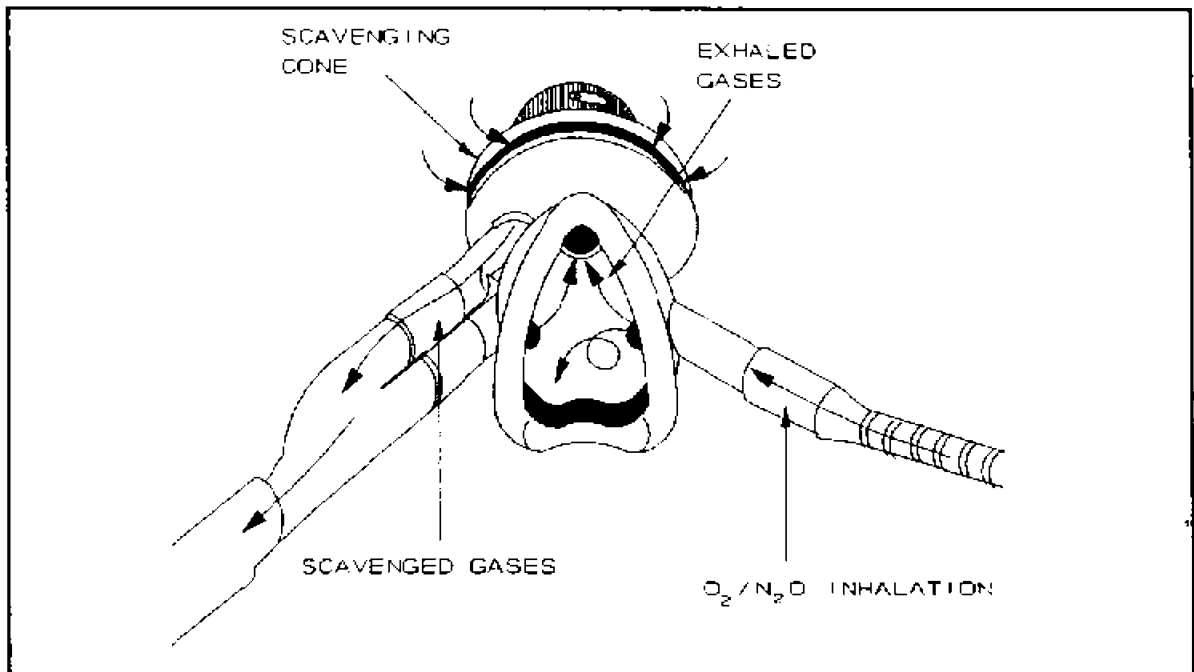
The usual analgesia equipment used by the dentist includes a N<sub>2</sub>O and O<sub>2</sub> delivery system, a gas mixing bag, and a nasal mask with a positive pressure relief valve.<sup>73</sup> The analgesia machine is usually adjusted to deliver more of the analgesic gas mixture than the patient can use.

A scavenging system, simply defined, is a means to collect and remove excess gases to prevent them from being vented back into the operating room. Installation of an efficient scavenging system is the most important step in reducing trace gas concentrations. It has been demonstrated that ambient concentrations have been lowered by 90 percent through the use of an efficient system.<sup>74,75,76</sup>

A scavenging system has five basic components: (1) a gas collection assembly, which captures excess anesthetic N<sub>2</sub>O at the site of emission, then delivers it to the transfer tubing; (2) transfer tubing, which conveys the N<sub>2</sub>O to the interface; (3) the interface, which provides pressure relief and may provide reservoir capacity; (4) gas disposal assembly tubing, which conducts the N<sub>2</sub>O from the interface to the disposal assembly; and (5) the gas disposal assembly. Some or all of these components may be combined into a single device.

The first prototype vacuum connected scavenging system was developed and tested in the middle 1970s. There are currently several commercially available scavenging systems; however, several studies have shown that these systems cannot consistently meet the NIOSH REL.<sup>16,17,18,19,20,77,78,79</sup> The most common scavenging system design includes a scavenging circuit (Mapelson D), a nasal mask, and a vacuum system. Figure 1 is a simplified schematic of a common anesthetic nasal mask that is retrofitted with scavenging equipment (a plastic dome with an exhaust tube is attached to the nasal exhaust port to reduce ambient N<sub>2</sub>O concentrations). Another 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 is

Figure 1 Schematic of an anesthetic nasal mask retrofitted with a plastic scavenging dome and exhaust port.



attached to the outer space of the mask to provide exhaust.<sup>15</sup> This shape allows for scavenging of excess gas supplied to the patient, as well as excess gas that may escape around the edges of the mask. Figure 2 is a simplified schematic of the principal components of this common scavenging nasal mask. Figure 3 is a schematic of the anesthetic gas delivery and scavenging system with a detail of the Porter-Brown Scavenging Mask.

#### Nitrous Oxide Concentrations in Dental Operatories with Scavenging Systems

Table 2 shows NIOSH HETA results for scavenged occupational exposure to N<sub>2</sub>O in dental operatories. These data show that scavenged dental operatories have lower N<sub>2</sub>O concentrations compared to non-scavenged dental operatories. However, such systems do not consistently reduce N<sub>2</sub>O to the NIOSH REL. Similar results have been reported by other researchers.<sup>18,80</sup> A recently published article showed high concentrations of N<sub>2</sub>O for both scavenged and non-scavenged systems when used during pediatric sedation.<sup>16</sup> This study was performed on 20 uncooperative 2 to 4 year old children, randomly assigned to a scavenged versus non-scavenged dental operatoriy. The results showed the N<sub>2</sub>O concentrations exceeded the NIOSH REL by more than ten times, regardless of whether a scavenging system was employed or not (mean concentration 300 ppm for scavenged versus 375 ppm for non-scavenged dental operatoriy).<sup>18</sup>

Figure 2 Schematic of the principal components of a common scavenging nasal mask.

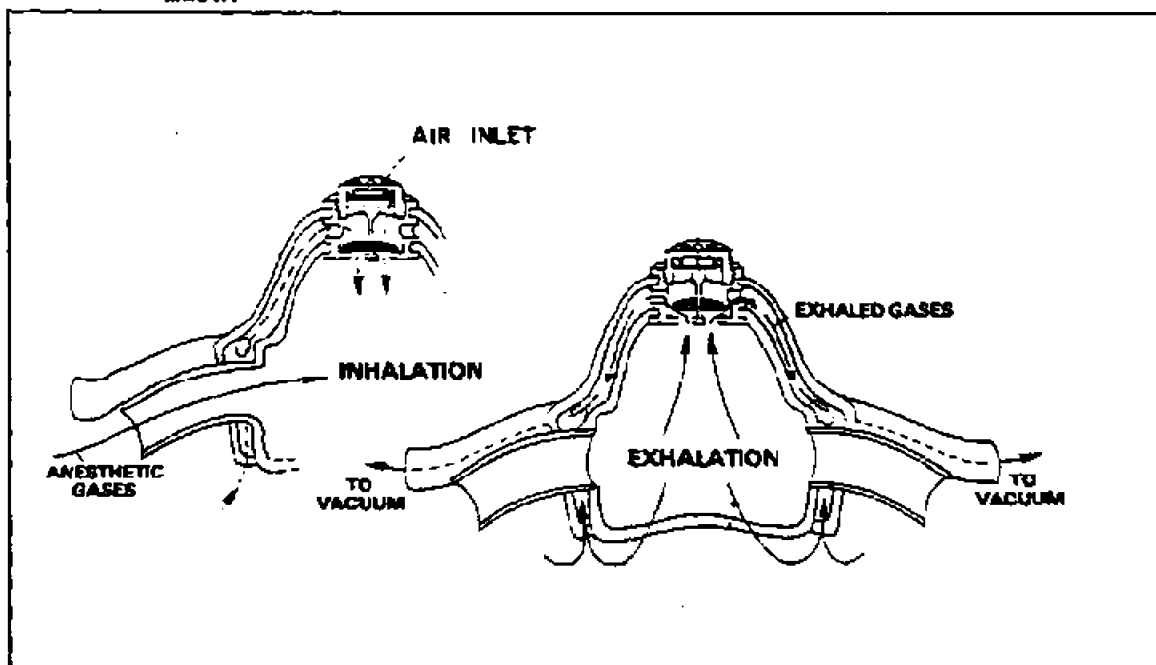
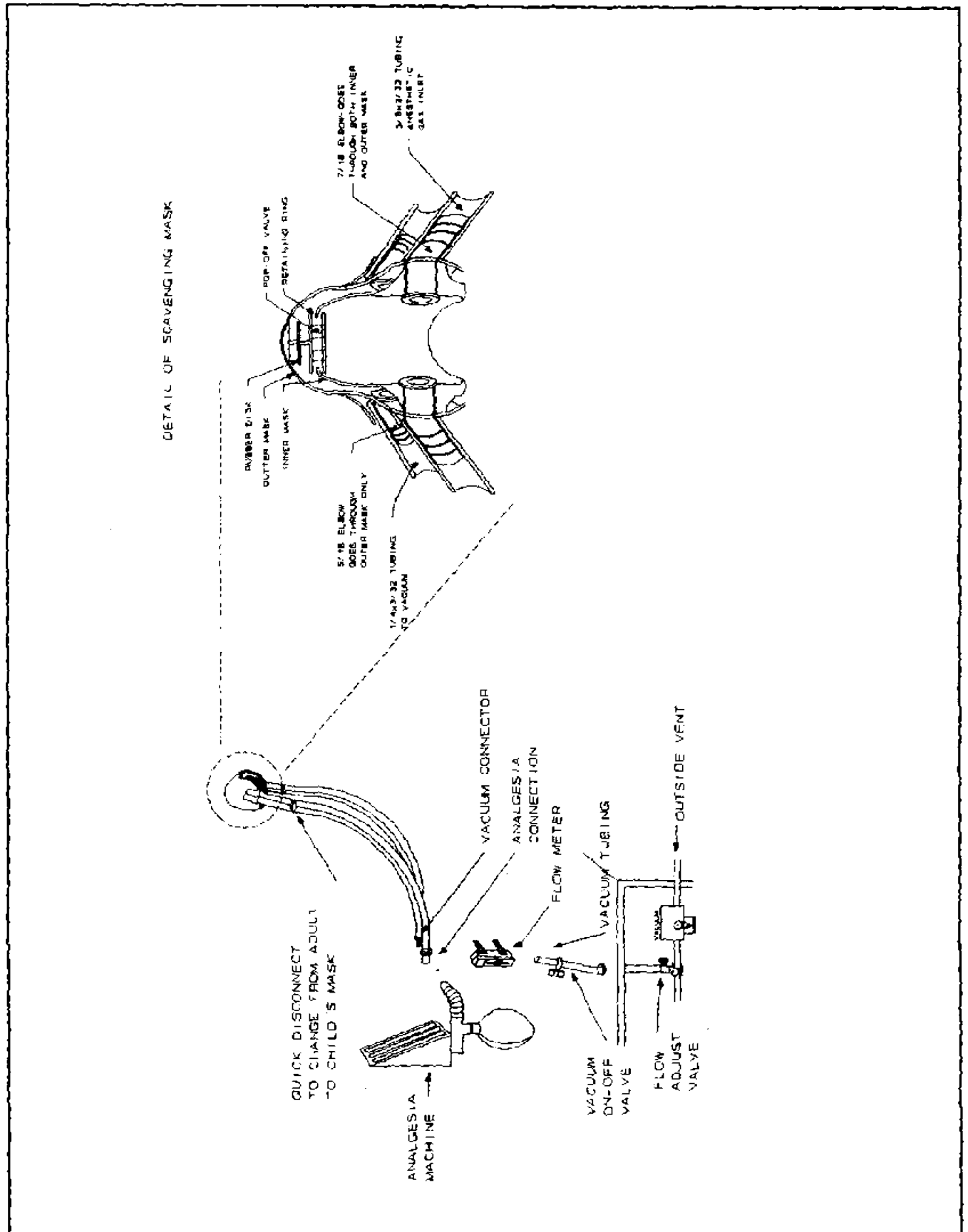


Table 2. NIOSH Hazard Evaluation and Technical Assistance (HETA) results for  $N_2O$  concentrations in dental operatories using nasal scavenging masks.

HETA Report Number	General Area Sampling Range, (ppm)	Personal Sampling Range, (ppm)
78-62 <sup>81</sup>	TRACE	38 - 171
78-129-544 <sup>82</sup>	10 - >160	40 - 430
79-107-632 <sup>83</sup>	10 - 60	10 - 300
80-102-764 <sup>84</sup>	3 - 36	16 - >250
80-113-813 <sup>85</sup>	25	400 - 500
80-249-833 <sup>86</sup>	200	250 - >1000
81-111-1471 <sup>87</sup>	40 - >250	30 - >1000
82-070-1148 <sup>88</sup>	500 - 650	650 - >1000
84-126-1555 <sup>86</sup>	7 - 182	130 - 1300
84-412-1612 <sup>88</sup>	30 - 270	830
86-179-1699 <sup>89</sup>	0 - 500	200 - 1000
87-281-1854 <sup>90</sup>	65 - 140	30 - 220



Figure 3. Schematic of the principal components of a scavenging system with nasal mask.



## Efficiency of Different Scavenging Systems

A study to determine the efficiency of scavenging devices by a standardized experimental model was conducted by Hollonsten in 1982.<sup>16</sup> Eight different masks were tested using well-controlled sedation techniques. Efforts were made to reduce N<sub>2</sub>O leakage by employing leak-proof equipment and carefully positioning the nose mask. The breathing zone N<sub>2</sub>O concentrations for the dentists varied from 4 to 385 ppm and the ambient air concentrations (i.e., in the dental operatory, but not in the dentist's breathing zone) ranged from 0 to 55 ppm. These results are consistent with the NIOSH studies cited above, which show that operatories using scavenging systems have a range of 10 ppm to 1,300 ppm for personal sampling, and from 0 to 800 ppm for ambient air, or general air concentrations. Researchers comparing other scavenging systems have reported similar results.<sup>16,17,18,91</sup> In a study performed by Hollonsten, seven commercially available scavenging systems were evaluated: Blue™, Brown™, Porter™ #1, Porter™ #2, two conventional masks fabricated in Denmark, and the Fraser-Harlake™. Sampling results for the Blue Mask showed a mean concentration of 4 ppm (2-65 ppm) for 12 experiments; the Brown mask showed a mean concentration of 5 ppm (2-178 ppm) for 13 experiments. The other masks ranged from a mean concentration of 17 to 53 ppm and met the Swedish standards of occupational exposure of 100 ppm. The Fraser-Harlake system did not perform as well as the others tested with a mean concentration of 385 ppm (110-1400 ppm).<sup>16</sup>

Donaldson et al. published information in which the mechanisms, testing, and effectiveness of various scavenging systems were evaluated.<sup>20</sup> Donaldson was able to show differences in mask performance under controlled conditions. Six scavenging masks were evaluated: Brown, Porter, Parkell™, Dupaco™, and Fraser-Harlake. The Brown mask performed best with a mean concentration of 43.4 ppm for 35 trials in eight different dental offices; the Fraser-Harlake performed worst with a mean concentration of 62.7 ppm for 35 trials in eight dental operatories. Reasons for leakage ranged from talking (48%), movement (48%), poor mask fit (36%), restlessness (12.4%), technical problem (9.5%), mouth breathing (2.8%), mask movement (4%), and moustache (3%). Donaldson concluded that (1) the scavenging systems did not perform as well under actual conditions of dental surgery when compared to controlled experimental conditions and (2) that the scavenging systems appeared to perform best when used with nitrous oxide delivery systems designed for the mask. Mixing and matching different anesthesia delivery and scavenging components produced poorer results.

The state of Wisconsin Department of Health and Social Services, Occupational Health Section, has performed over 300 dental surveys dating from 1978. Analysis of data from dental operatories where the scavenging system and vacuum exhaust rate information was collected showed that these operatories had significantly lower waste N<sub>2</sub>O concentrations than dental operatories without scavenging systems and masks (scavenging: [N=101 dental sites] mean N<sub>2</sub>O concentration 686/median 265; no scavenging: [N=64 dental sites] mean N<sub>2</sub>O concentration 2031/median 658). Table 3 shows the immediate work area N<sub>2</sub>O concentration results from different scavenging systems in dental operatories for the state of Wisconsin.

Table 3. Mean and standard deviation of N<sub>2</sub>O concentrations in dental operatories for scavenging masks evaluated in Wisconsin.

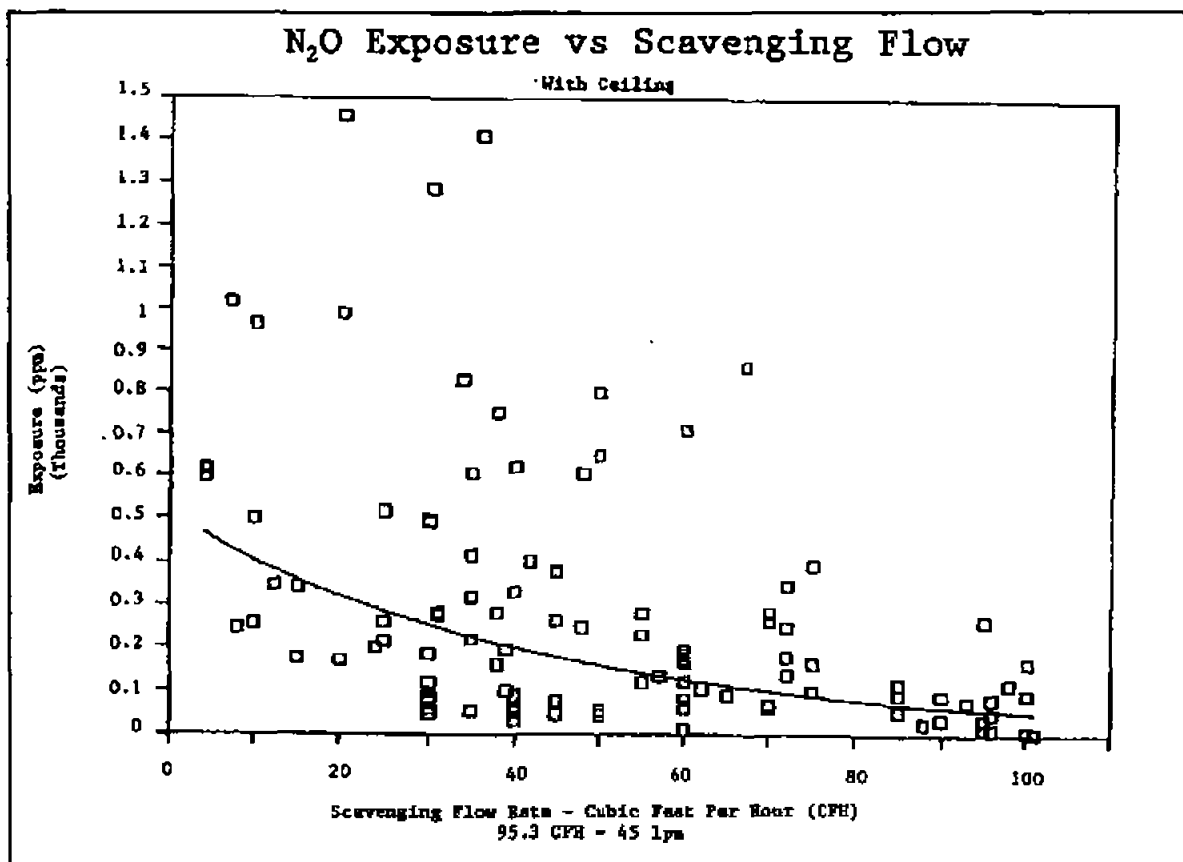
Scavenging Masks	Dental Sites Surveyed	Mean N <sub>2</sub> O Concentration	Standard Deviation
Porter	33	636	650
Brown	20	325	357
Porter-Brown™	1	223	---
Blue	2	53	10
MDT-McKessen™	3	257	67
Fraser-Harlake	16	1105	2203
Comfort Cushion™	3	112	50
Other	4	196	56
Unknown	17	1263	2411

Based on this information, the state of Wisconsin Board of Dentistry required that scavenging systems be installed in dental operatories when N<sub>2</sub>O is used and that the vacuum flow rate for the scavenging mask should be 45 lpm when administering a mixture of N<sub>2</sub>O and O<sub>2</sub> to the patient. The Board of Dentistry also recommended that the masks be purchased or retrofitted with a flowmeter to verify vacuum flow rates.<sup>92</sup> This data also showed that the scavenging system exhaust rate was related to the ambient concentrations of N<sub>2</sub>O in dental operatories, regardless of the type of scavenging system evaluated.<sup>93</sup> Figure 4 shows the concentrations of N<sub>2</sub>O in various operatories as a function of scavenging system exhaust rates.

#### Local (Auxiliary) Exhaust Ventilation--

In order to control for leakage around valves and fittings of the nasal mask, the use of local exhaust ventilation has been shown to be effective.<sup>94</sup> In addition, the use of local exhaust ventilation in tandem with scavenging systems was effective in reducing occupational exposure to N<sub>2</sub>O by 75 percent during dental surgery, as reported by Carlsson et al.<sup>17</sup> This type of ventilation effectively captures the waste anesthetic gases at their source, costs little to build, and works well in operatories with poor general ventilation. The major disadvantage is the proximity of the local exhaust opening to the patient (4 inches as recommended by Carlsson et al.). The proximity of this exhaust is distracting and may interfere with access to the patient's mouth by the dentist.

Figure 4. N<sub>2</sub>O concentration and scavenging system exhaust rates -- Wisconsin Data.<sup>93</sup>

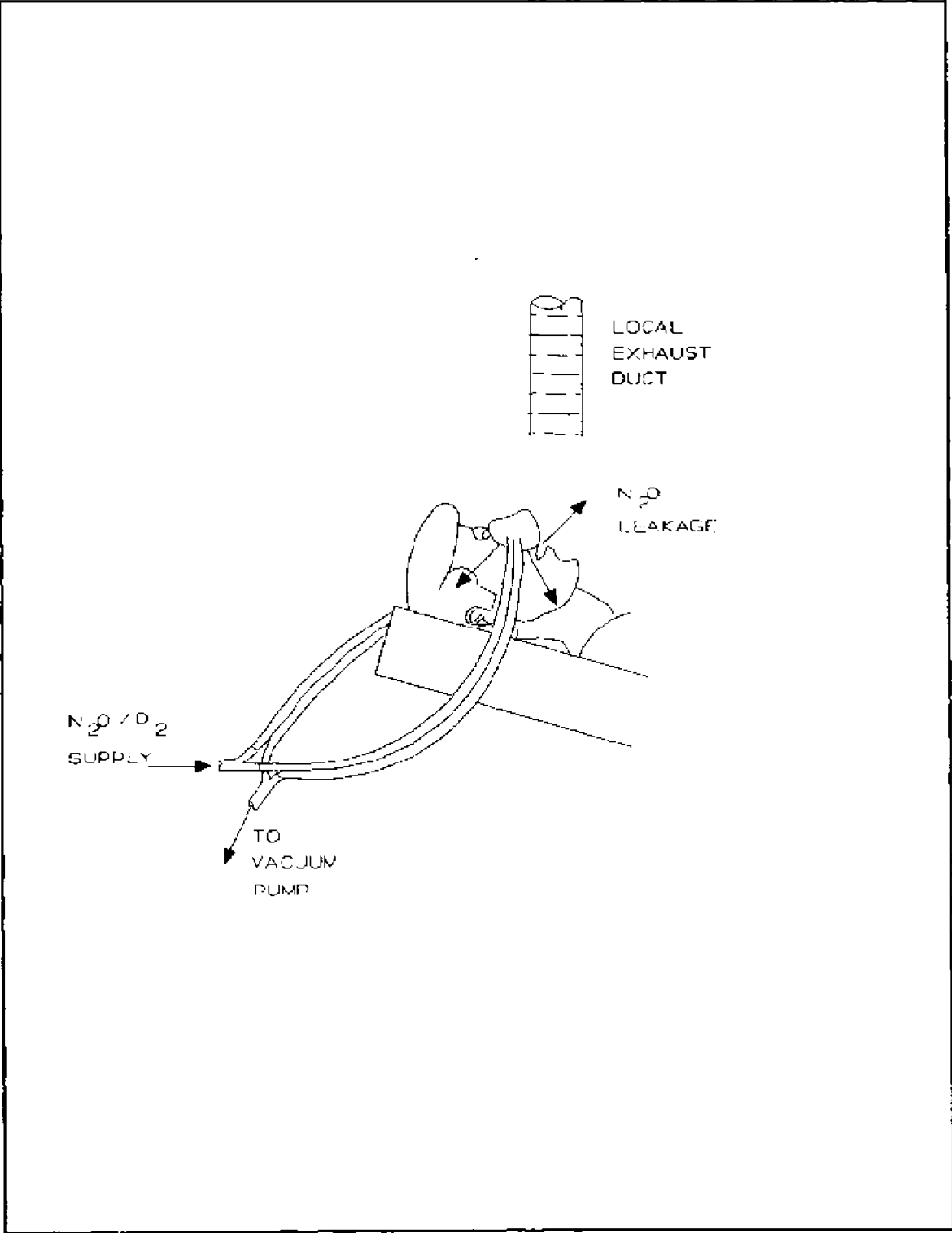


In another study, Middendorf and Jacobs fabricated a portable local exhaust ventilation system and tested its effectiveness in controlling nitrous oxide exposures.<sup>19</sup> For one operator, peak exposures were reduced from 600 ppm to less than 70 ppm. The authors concluded that a permanently installed local exhaust ventilation system could be designed that would be feasible for most operatories and should not interfere with dental procedures. Figure 5 illustrates an auxiliary exhaust scavenging system used to capture excess N<sub>2</sub>O from nasal mask leakage and patient mouth breathing.

#### General Ventilation--

The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) recommends up to 25 room air changes/hour for surgical suites.<sup>35</sup> However, there are no recommendations for room air exchange rates for dental operatories. It has been suggested that the guidelines provided by ASHRAE for surgical suites be adopted for dental operatories.

Figure 5. An auxiliary exhaust system for capturing  $N_2O$  from patient mouth breathing.



General ventilation is important when considering total control strategies for airborne contaminants. However, it can be inefficient when trying to control for N<sub>2</sub>O. Additional concerns for general ventilation are reentrainment of contaminated air through ventilation systems and migration of N<sub>2</sub>O to other rooms.

### Work Practices

Good work practices by the dentist and dental assistant are essential for controlling N<sub>2</sub>O exposure during administration. Good work practices by dentists to reduce N<sub>2</sub>O exposure have been reported in the literature. These include adjusting the scavenging system exhaust flow rate to 45 lpm; selection of the right size nasal mask for good fit; turning the N<sub>2</sub>O on only after the nasal mask has been secured on the patient; and flushing the anesthesia delivery unit and scavenging system with O<sub>2</sub> following N<sub>2</sub>O delivery. To control N<sub>2</sub>O emissions from the patient, dental personnel should instruct their patients to avoid mouth breathing during dental surgery, avoid excessive talking while N<sub>2</sub>O is being administered, and minimize facial movement to maintain the nasal mask seal.<sup>20</sup>

### Administrative Controls

#### Equipment Inspection and Maintenance--

Good equipment and proper maintenance are important when controlling N<sub>2</sub>O in the dental operatory. Routine inspection and maintenance of dental equipment are essential in order to reduce N<sub>2</sub>O leaks and to have the best performance of dental scavenging equipment. Procedures for evaluating and maintaining dental equipment have been published.<sup>73</sup>

#### Monitoring--

Routine monitoring of N<sub>2</sub>O concentrations in the dental work environment is needed to ensure that the engineering controls work properly and the environment maintenance program continues to perform effectively. Monitoring can be performed through conventional time-weighted average air sampling and by real-time air sampling.

## STUDY DESIGN

### STUDY SITE SELECTION

The project protocol included the following requirements for in-depth survey site selection: The facility (1) used at least one of the five scavenging systems selected to be evaluated; (2) had a minimum of four dentists; (3) had a minimum of four dental surgeries, with performance of operations in separate operating rooms; and (4) had the appearance of good work practices.

Four sites were selected for the in-depth evaluation of the Fraser-Harlake and Porter-Brown N<sub>2</sub>O scavenging systems: two surveys at a pediatric dental facility, one at a oral surgical clinic, and one at a dental clinic for the

developmentally disabled. In addition, walk-through surveys were conducted to evaluate qualitatively the Blue Mask and Comfort Cushion at two other facilities: a family and cosmetic dental clinic and an Indian Reservation Dental Clinic. Use of the MDT McKessen system was observed at the oral surgical clinic. The Blue Mask, Comfort Cushion, and MDT McKessen were not quantitatively evaluated because the design, function, and use of these masks were not sufficiently different from the Fraser-Harlake and Porter-Brown systems to warrant in-depth evaluation.

#### Survey #1: Pediatric Dental Facility

At the time of this survey, 9 dentists, 8 dental assistants, and 8 support staff were employed. The facility performed dental work on an average of 41 patients per day with approximately 7 percent of the patients receiving N<sub>2</sub>O during dental surgery. This facility had ten dental chairs, all equipped with anesthetic gas delivery and scavenging systems. The dental work area had over 3,260 square feet of working space with three types of dental operatories: closed (one chair per one room), semi-open (two chairs separated with 6 foot high partitions), and open (three chairs with no partitions). This dental facility had used the Fraser-Harlake scavenging system for seven years prior to this survey.

#### Survey #2: Oral Surgical Clinic

This facility employed approximately 6 oral surgeons, 8 surgical assistants, and 12 support staff who performed dental work on an average of 15 patients per day; approximately 50 percent of the procedures used N<sub>2</sub>O. This facility had ten dental chairs, all equipped with anesthetic gas delivery and scavenging systems. The surgical suites had floor to ceiling walls with single door entrances. This clinic had used the Porter-Brown scavenging system for more than ten years.

#### Survey #3: Dental Clinic for the Developmentally Disabled

All procedures were performed by dental hygienists in the dental clinic serving patients with disabilities. There was a common hall connecting two groups of four side-by-side chairs. A partition separated the two groups of chairs, but there were no partitions between chairs within each group. Limited use of N<sub>2</sub>O at chairs other than for the procedure under investigation was noted and effects were evaluated.

Management personnel at this dental clinic permitted NIOSH researchers to install and evaluate a local exhaust system to determine its effectiveness in reducing N<sub>2</sub>O from scavenging mask leakage and from the patients' mouth breathing during dental surgeries.

#### Survey #4: Pediatric Dental Facility

The fourth in-depth survey was conducted at the same pediatric dental facility as described in the first survey. Physical plant and personnel resources were very similar during the fourth survey as described during the first NIOSH survey. Scavenging systems were changed from the Fraser-Harlake to Porter-

Brown, and the ventilation improved, between the time of the first and fourth in-depth survey.

## METHODS

While the basic method for evaluating  $N_2O$  was similar in all four in-depth surveys, some differences based on knowledge gained from the prior in-depth surveys were applied to the subsequent ones. Because of this approach, better controls to reduce  $N_2O$  exposure were used in each succeeding in-depth survey. "In-depth survey" will be referred to as "survey" from this point on.

### SAMPLING METHODS

#### Personal and Area Sampling

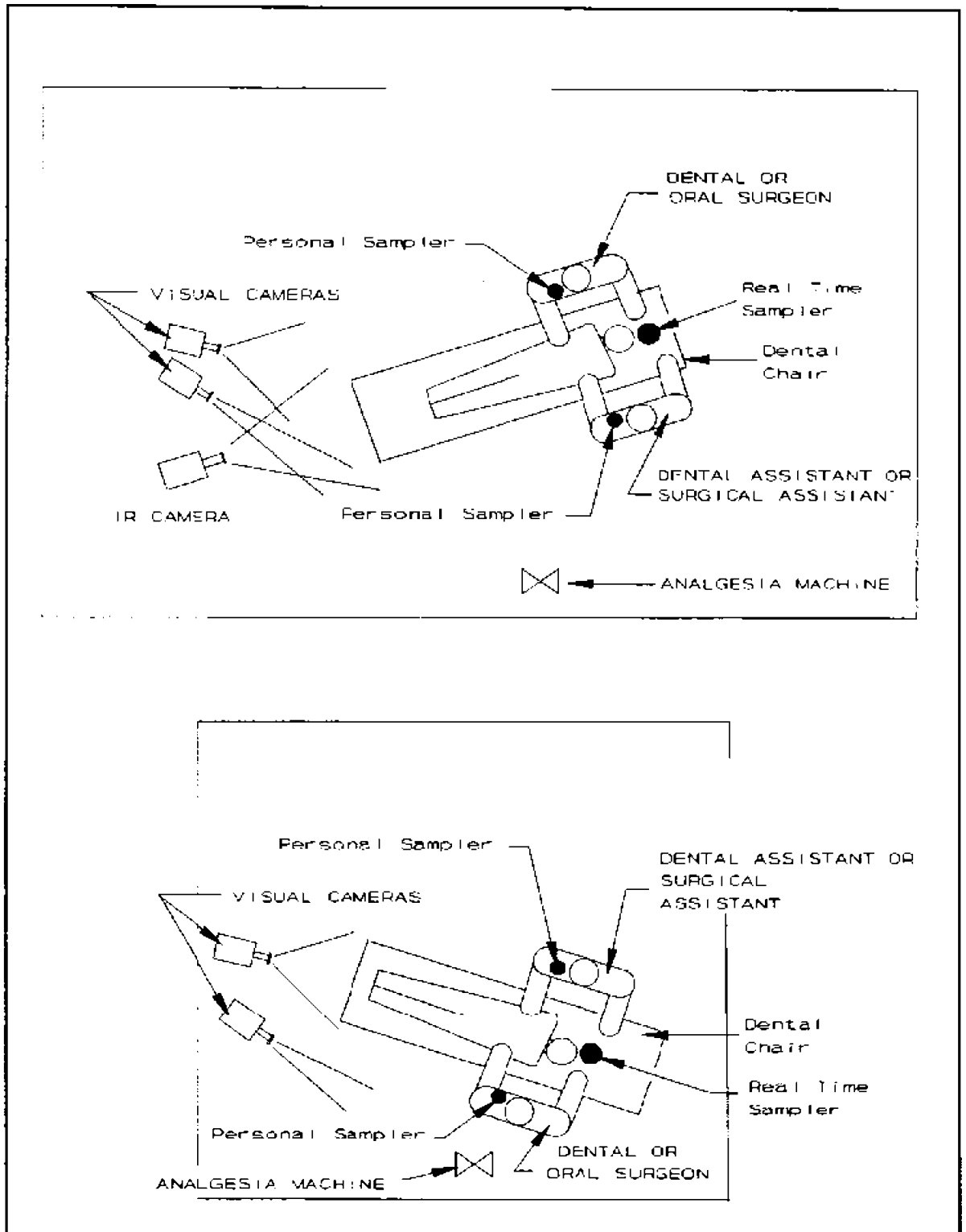
During the surveys, air samples were taken in the breathing zone of the dentists or oral surgeons and the dental assistants or dental hygienists. General area samples were taken at the room air supply and/or exhaust vents and areas outside the room. Personal and general area air exposures to  $N_2O$  were collected in 30-liter Tedlar bags and analyzed at the dental facility using a calibrated infrared gas analyzer (Miran 1A, Foxboro Instruments, Inc., Foxboro, Massachusetts). Battery-powered, universal flow sampling pumps (SKC 224-PCXR7, SKC Incorporated, Eighty Four, Pennsylvania) modified for bag filling were used to draw air through a section of tygon tubing into a bag. MSA Flo-Lite Pro™ Pumps, (Mine Safety Appliances, Pittsburgh, PA), were used in the third study. The sampling pumps were calibrated at a flow rate of 1.5 lpm for both personal breathing zone samples and for general area samples. The sampling pumps were started when  $N_2O$  was turned on and stopped when  $N_2O$  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). Analysis of  $N_2O$  samples was performed using a direct-reading, portable, variable-path length infrared spectrophotometer (Miran 1A) in accordance with NIOSH Method 6600.<sup>96</sup> The general configuration for personal and real-time  $N_2O$  sampling locations, dental or surgical suite layout, and visual and infrared videography setup for the case studies are shown in Figure 6.

#### Real-Time $N_2O$ Sampling

During each dental operation,  $N_2O$  was measured and recorded continuously. The infrared gas analyzer (Miran 1A) was used to measure the anesthetic gas concentrations. This instrument is a variable filter, variable path length infrared analyzer with 20.25 meter cell. It has direct-reading scales with a gas cell mixing 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, the output values at the peak and low exposures are truncated. However, the accuracy and ease of use of this instrument for real-time sampling greatly outweighs this limitation.



Figure 6. General configuration for personal, real-time, and infrared videography monitoring of N<sub>2</sub>O.



The Miran 1A sampling probe was located approximately 7 to 15 inches above and 6 to 8 inches behind the patient's mouth (the average monitored distance of the oral surgeon's and surgical assistant's breathing zones for each of the dental operations monitored). The instrument settings used for N<sub>2</sub>O analysis were wavelength of 4.48 micrometers, slit width of 0.50 millimeters, and a path length of 6.75 meters. The analytical limit of detection under laboratory conditions is 0.07 ppm; under field conditions in this study, the analytical limit of detection was 5 ppm. The Miran 1A has a detection range of approximately 1 to 1,000 parts of N<sub>2</sub>O. The detection range reported in the third study was 5 to 2000 ppm. Both a lecture bottle of electronics-grade N<sub>2</sub>O calibration gas and a bag of anesthesia-grade N<sub>2</sub>O gas were used to calibrate the instruments for these detection ranges; they were calibrated before and after each survey.

In the first survey, the real-time output from the Miran 1A was directly linked to an analog-to-digital signal board. For the second and third surveys the gas concentrations were recorded by a Rustrak Ranger™ four channel data logger. Information collected by the data logger was downloaded into a portable Compaq™ computer. The N<sub>2</sub>O data collected from each of the dental operations was organized by using Pronto™ and Lotus 123™ computer software. Miran 1A output for N<sub>2</sub>O was recorded at approximately 1-second intervals and the data was averaged every 15 seconds to simplify data analysis.

Two Miran 1A and one Miran 1B infrared gas analyzers were used for the third survey. Both Miran 1As were calibrated each day of operation over a range of approximately 8 to 2,000 parts of N<sub>2</sub>O ppm of air ppm. A bag of anesthesia-grade N<sub>2</sub>O and the Closed Loop Calibration System™ (The Foxboro Company, Foxboro, Massachusetts) were used.

Also at the third survey, sound pressure levels were measured for local exhaust ventilation systems. The sound pressure levels were measured near the dental hygienist's ear with a GenRad Type I Precision Sound Level Meter™ calibrated before and after each use.

Because the fourth survey was a combination of field and laboratory work, methods for conducting this survey are unique compared to the first three field surveys and are presented in detail later in this report.

#### Videc Recording and Documentation of Work Practices

Work practices of the dentists, oral surgeons, and their assistants were recorded (Panasonic™ video Recorder/Player Model #2, NV 8400 Camera; Panasonic Video Camera, Model #3245) on videotapes taken during surgery to discern potential anesthetic gas exposure during surgery. Using these videotapes, motion and time measurement techniques were used to catalog the work elements during the first two surveys. By running the videotapes at normal speed and "stop action," the work elements which might increase or decrease the exposure to anesthetic gas were analyzed and documented. These were selected for detailed analysis.

The real-time N<sub>2</sub>O concentration data were later synchronized with the videotapes to confirm observation of exposure sources and to compare N<sub>2</sub>O

concentrations at various stages during the surgical operation. A schematic diagram of the data acquisition system used to integrate data from real-time sampling with work practices is shown in Figure 7.

Parameters of the dental and surgical procedures documented for analysis for each operation included the following: (1) the  $N_2O$  concentrations for personal and real-time sampling; (2) the amount of  $N_2O$  administered; (3) the length of time the  $N_2O$  was administered; (4) the length of operation; (5) the real-time  $N_2O$  concentrations by team and type of surgery; (6) the length of time of operation; (7) the average concentration when  $N_2O$  gas was delivered; and (8) the average concentration after the  $N_2O$  was turned off.

### Infrared Thermography

Several of the operations were monitored with the use of an infrared scanner in order to visualize the  $N_2O$  escaping from the patient's breathing zone during surgery. This information is especially important in determining strategies for  $N_2O$  control around the mask and from the patient's mouth. The Infrared Thermography System consisted of an AGA Thermovision® 782 infrared scanner and display unit. A short wave band (2-5.6 microns) or a long wave band (8-12 microns) scanner was utilized depending on the absorption characteristics of the emission material.

A black screen approximately 14 inches high and 20 inches long was used as an infrared radiator. A constant temperature (120°F), evenly distributed across the face of the black screen, was maintained by a heated and stirred water bath attached to the screen.

During dental surgery, the path of  $N_2O$  was observed by locating the patient and dentist between the radiating surface (black screen) and the infrared scanner. As the  $N_2O$  passed between the radiating surface and the scanner, a portion of the radiated infrared energy was absorbed and a lower temperature was detected by the scanner. This provided an image of the emission showing the source and path of  $N_2O$ .

A Digital Infrared System for Coloration (DISCON™) was utilized to provide a color image. The DISCON converted the normal infrared gray scale to a ten-step color scale. The DISCON output, either color or gray scale, was transmitted to a red green blue (RGB) monitor for real-time viewing. The output can also be simultaneously transmitted to a Video Cassette Recorder (VCR) for real-time recording and later analysis. Figure 8 shows the configuration of the infrared thermography components used to detect and visualize  $N_2O$  in dental operatories.

The videotaped image of the  $N_2O$  was recorded on a VCR and later overlaid through a process of "videospitting" onto a corner of the visual image VCR. This technique of overlaying the infrared image of the  $N_2O$  emissions with the visual video image of the dental operations allowed NIOSH researchers to determine four exposure factors: (1) the source and path of uncontrolled  $N_2O$  during dental surgery; (2) whether the source and path of  $N_2O$  was a function of nasal mask leakage or patient mouth breathing; (3) whether the probe of the monitor was properly located to detect the  $N_2O$  emissions from the patient or

Figure 7. Data acquisition system for evaluating N<sub>2</sub>O exposure in dental offices.

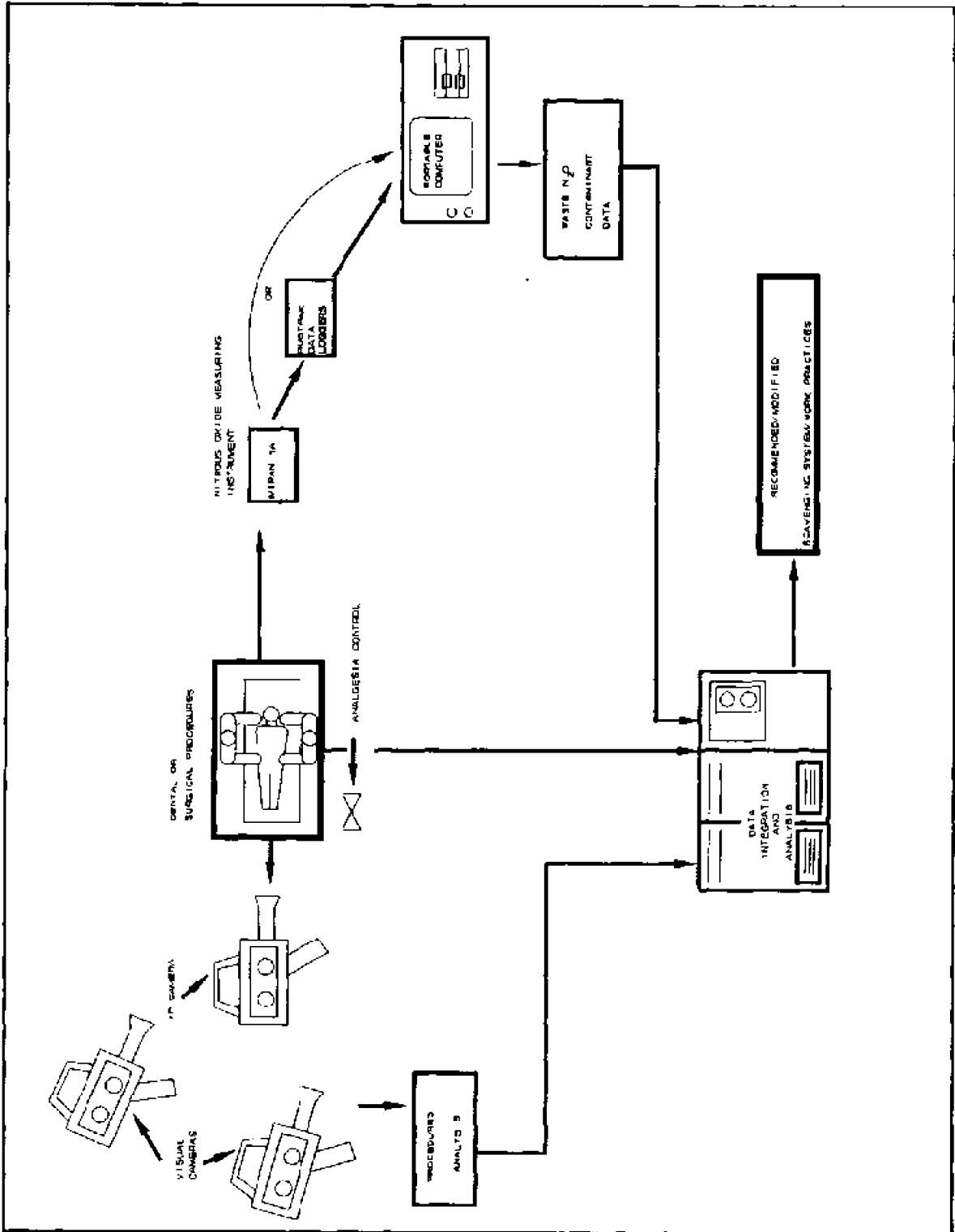
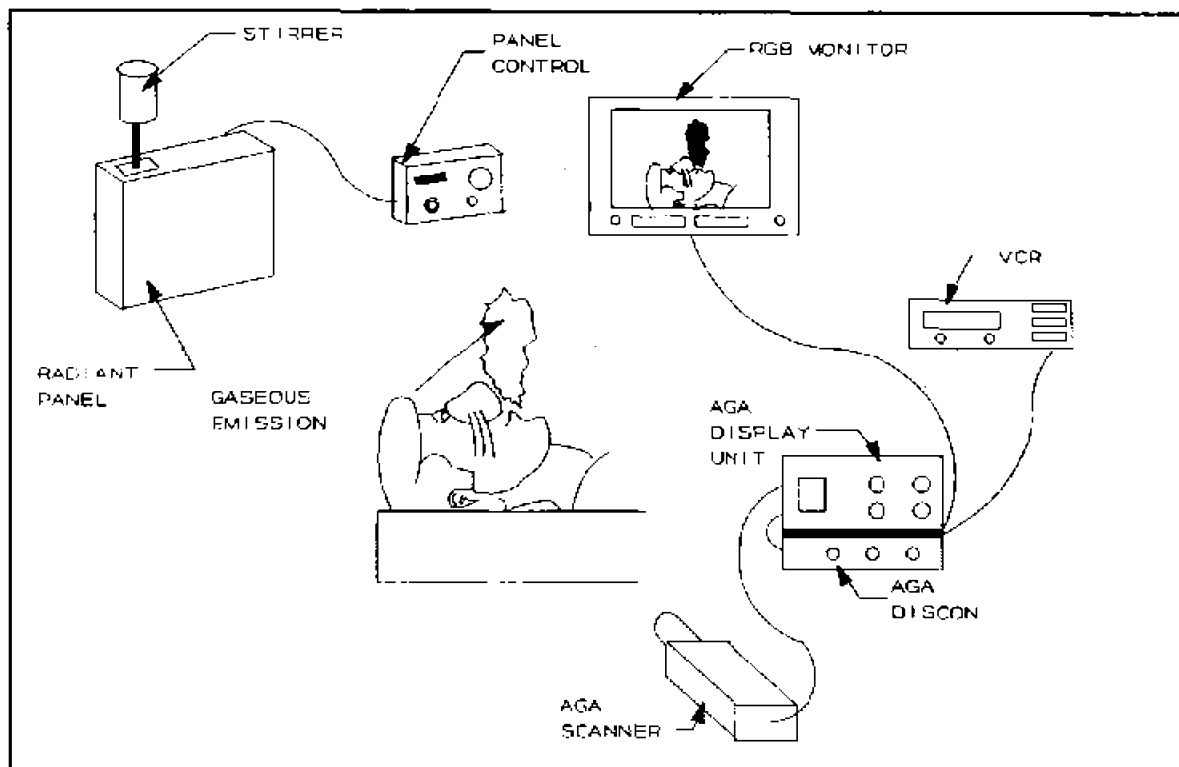


Figure 8. Basic configuration of the infrared thermography system to detect N<sub>2</sub>O in dental operatories.



the mask; and, (4) the proximity of N<sub>2</sub>O emissions to the breathing zones of dental personnel performing the operations.

## EVALUATION OF VENTILATION SYSTEMS

### General Ventilation

For the first two surveys, general ventilation measurements were taken for the dental operatories and surgical suites, and in locations where general area sampling was conducted, including dental laboratories, consultation room, equipment areas, dark rooms, sterilizer room, waiting room, offices, and hallways. The Kurz Model No. 480<sup>M</sup>, TSI Model No. 1650<sup>M</sup>, and Alnor Balometer<sup>M</sup> were used to measure air velocity and average flow rate, respectively.

Smoke tubes were used to observe airflow patterns in each room, especially near the ceiling, in an attempt to determine if there was adequate mixing of air throughout the room. Measurements were taken to determine if the supply register louvers directed most of the air toward the ceiling or if there was good mixing of the air around the dental chair. Building blueprints were used for locating air duct locations and comparing flow rates with building design specifications.

For the third survey, the volumetric airflow rate of each supply and exhaust vent opening in the dental clinic building wing was measured. Fresh air supply rates could not be measured because the fresh air supply inlet for the building was not accessible. However, the air sampling results showed that the concentration of N<sub>2</sub>O was below detectable limits in the return air stream.

#### SCAVENGING SYSTEM VENTILATION

##### Survey #1: Pediatric Dental Facility

The exhaust ventilation for the Fraser-Harlake Scavenging System was checked by using an airflow meter (Kurz). The exhaust rates of the scavenging system were measured using an in-line connection of the airflow meter between the scavenging mask and the exhaust port of the vacuum hose. The measurement was made after one of the dental operations in which the vacuum rate was adjusted by the dental assistants. The assistant adjusted the flow by listening to the noise level of airflow through the line; there was no flowmeter in the exhaust line to provide a visual indication of the flow rate.

##### Survey #2: Oral Surgical Clinic

For the Porter-Brown scavenging system, the exhaust vacuum rates were set to 45 lpm at the beginning of oral surgery by manually adjusting a valve connected to the scavenging vacuum line. A flow rate of 45 lpm was visually verified with a flowmeter (Dwyer<sup>TM</sup>). At the conclusion of each operation N<sub>2</sub>O was turned off and the vacuum system valve was manually closed to stop the airflow through the vacuum line.

##### Survey #3: Dental Clinic for the Developmentally Disabled

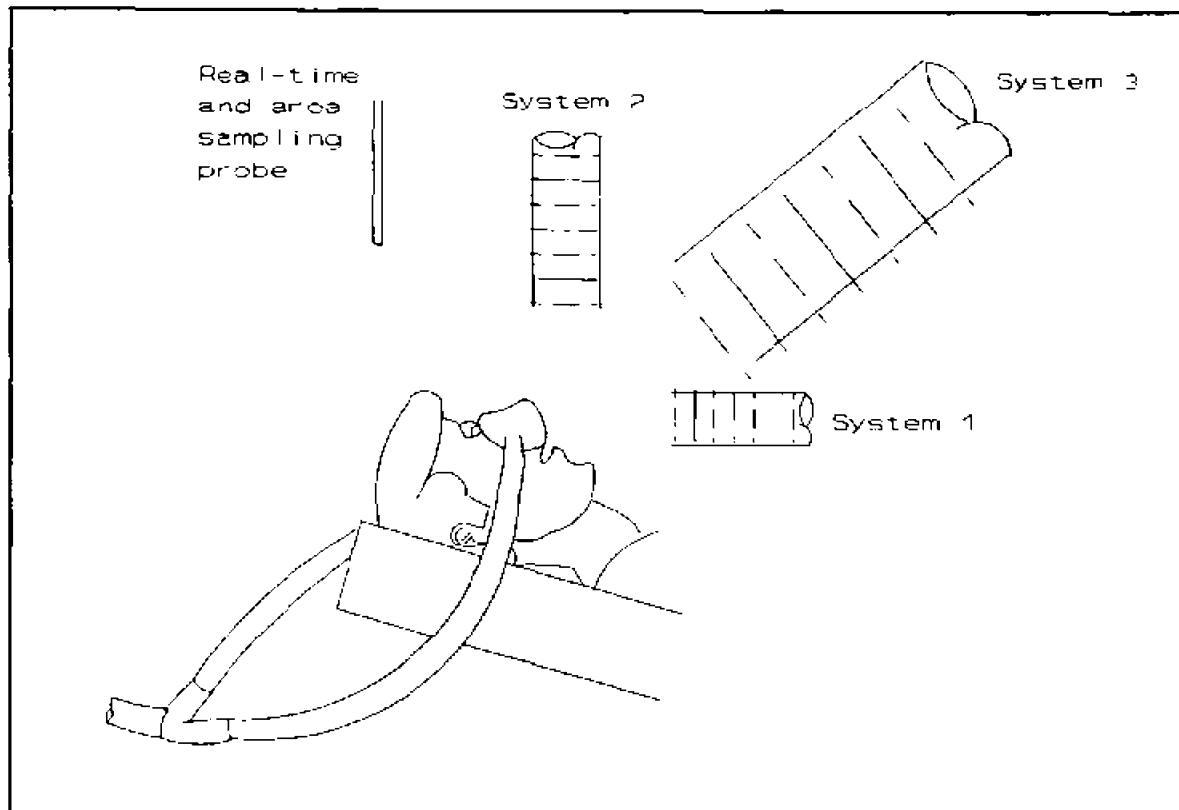
The Porter-Brown scavenging system was used for all dental procedures. As in the second survey, the exhaust flow rate was set at approximately 45 lpm. The flow rate was measured using a by-pass flowmeter supplied with the scavenging system. The scavenging system was manually turned on and off with N<sub>2</sub>O.

#### Local (Auxiliary) Exhaust Systems

The use of auxiliary exhaust systems were also evaluated at the Dental Clinic for the Developmentally Disabled. Of the 20 dental hygiene procedures (teeth cleaning) observed, six of the procedures were performed without the auxiliary exhaust ventilation system to provide a baseline assessment of exposure. Three auxiliary local exhaust configurations were used during the remaining 14 procedures. Positions for each exhaust system are schematically shown in Figure 9.

The three local exhaust ventilation systems had in common a hood opening located near the patient's mouth, a conveying duct, and a 10-inch centrifugal fan with a one horsepower motor located outside the building. The length of the conveying duct, suspended from the ceiling, was approximately 25 feet from the hood opening to the fan.

Figure 9. Locations of auxiliary exhaust systems for control of N<sub>2</sub>O mouth breathing.



System 1 employed an auxiliary exhaust system and a commercially-available hood and duct (Nederman Mini Extractor, Westland, MI) typically used in bench top industrial operations (e.g., soldering). This unit consisted of a 2.5-inch diameter nonflanged circular hood and 4 feet of 2.5-inch inner diameter duct equipped with three adjustable pivot points. Using the pivot adjustments, the hood opening was positioned over each patient's chest, 6 to 8 inches from each patient's mouth. The hood and pivot point system was connected to the exhaust fan using a 3-inch diameter flexible duct.

The system 2 auxiliary exhaust system consisted of only the 3-inch diameter flexible duct used in system 1. The end of the duct served as a plain, nonflanged hood opening. The hood opening was placed directly above the nose and mouth area and was located 6 to 10 inches away from each patient's mouth. Removal of the Mini Extractor resulted in an increased exhaust airflow rate.

System 3 was similar to system 2 except that the 3-inch duct was replaced by a 6-inch duct. This system had the hood opening positioned above the chest in front of the nose and mouth area, about 12 inches away from each patient's mouth.

Airflow measurements for each system were conducted with a pitot tube to determine the flow rate, and a swinging vane velometer (Alnor Instrument Company, Niles, IL) or hot-wire velometer (TSI, Inc, St. Paul, MN) measured the velocity at the face of the hood opening.

Because noise levels from the auxiliary ventilation were considered a potential problem by dental personnel, sound pressure levels were measured for local exhaust ventilation systems 2, 3, and 0 (without the local exhaust ventilation systems). The sound pressure levels were measured near the dental hygienist's ear with a GenRad Type I Precision Sound Level Meter (General Radio, Concord, MA) calibrated before and after each use.

#### Survey #4: Pediatric Dental Facility

The fourth survey was performed at the same facility as the first survey. Shortly after the completion of the first NIOSH survey, scavenging systems were changed from the Fraser-Marlake to the Porter-Brown scavenging system. Scavenging system exhaust vacuum rates were set to approximately 45 lpm by manually adjusting a valve connected to the scavenging vacuum line.

N<sub>2</sub>O exposures were measured in a dental operatory using two Mirans continuously sampling the breathing zones of the dentist and the dental assistant. One end of plastic tubing with an inside diameter of 1/4 inch was fastened to the lapels of the dental personnel and run first to a diaphragm pump and then to a Miran. The flow rates of the sampled air were each about 17 lpm. Analog data produced by these Mirans were digitized and stored in data loggers (Rustrak Ranger I, Model RR 400, Rustrak Instruments, East Greenwich, Rhode Island), then downloaded to a portable personal computer for later analysis. Also, a video recording was made of most of the operations in which N<sub>2</sub>O exposure concentrations were measured. The video was synchronized with the digitized N<sub>2</sub>O concentration data for later use in correlating events in the dental operation with features of the concentration data.

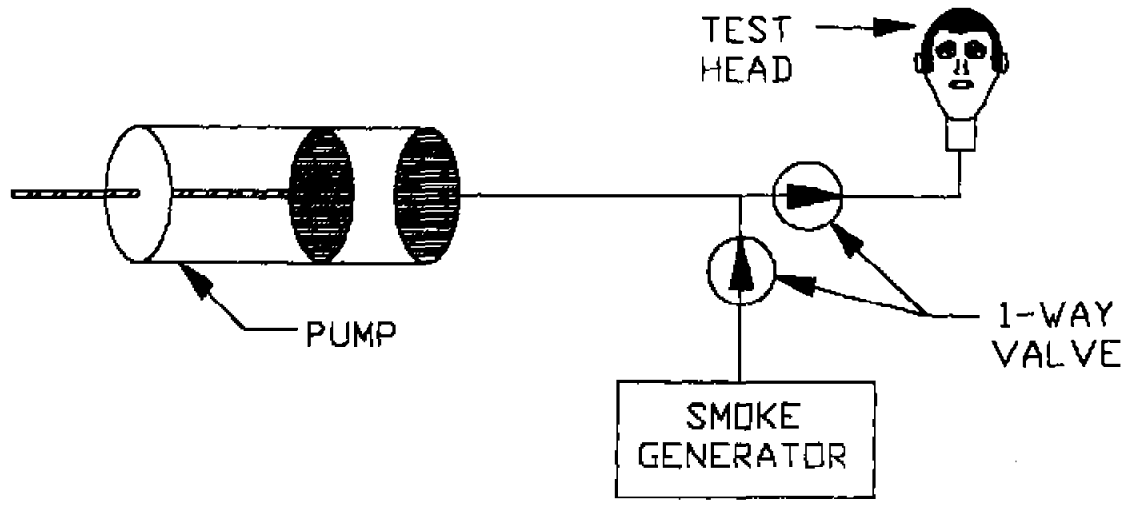
The speed of unconfined air was measured with a digital air velocity meter (Kurz Model 1440, Kurz Instruments, Incorporated, Monterey, California). Ambient air velocities in the laboratory were adjusted to the same range as those found in the operatory based upon air velocity meter measurements.

#### Laboratory Test Facilities and Instrumentation

Some of the qualitative laboratory testing of the various scavenging mask configurations and supplementary controls was performed using a head form connected to a breathing machine and a smoke generator (Figure 10). The breathing machine was driven by a variable speed motor. The travel of the piston also was adjustable. For the data reported here, the breathing machine was set for 15 cycles/minute and the volume per inhalation (exhalation) was 580 cm<sup>3</sup>, which corresponds to a resting breathing rate.<sup>97</sup> The smoke was delivered by tubing to the head form, either to its nose, or to its mouth, or to both the mouth and the nose. Qualitative evaluation of the performance of the equipment under test was based on visual observations of smoke capture.



Figure 10. Breathing simulator for qualitative mask leakage testing.



# BREATHING SIMULATOR FOR N<sub>2</sub>O EMISSION CONTROL TESTING

Quantitative laboratory testing of the leakage of N<sub>2</sub>O administration or control equipment was accomplished using the breathing machine and head form just described along with additional apparatus, as shown in Figure 11. Infrared Analyzer 1 measured the concentration *c* of tracer gas, either N<sub>2</sub>O or sulfur hexafluoride (SF<sub>6</sub>), released into the hood where the head form and equipment to be tested was located. The flow rate, *f*, of tracer gas entering the hood was determined by the following equation, using the tracer gas concentration, *c*, and measurements of the flow rate, *Q*, of air entering the hood and traveling down the duct:

$$c \left[ \frac{\text{volume tracer gas}}{\text{volume gas}} \right] \times Q \left[ \frac{\text{volume gas}}{\text{time}} \right] = f \left[ \frac{\text{volume tracer}}{\text{time}} \right]$$

where:

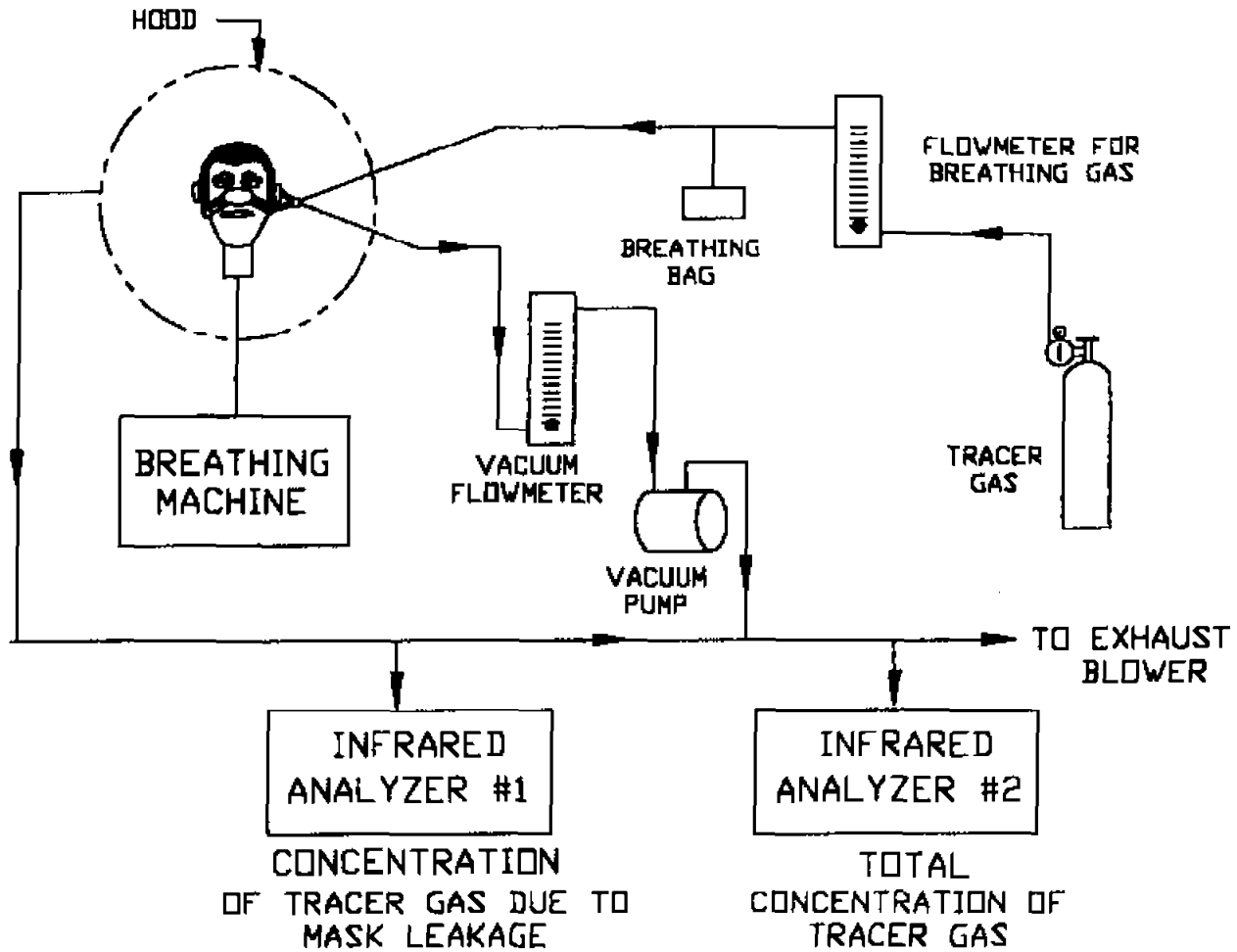
- c* was measured with Infrared Analyzer 1,
- Q* was measured in the duct with a Pitot tube, and
- f* was the flow rate of tracer gas in the duct, and thus, the flow rate of tracer gas not captured by the equipment under test.

Infrared Analyzer 2 allowed measurement of the sum of the flow rates of tracer gas captured by the test equipment and by the hood, and provided assurance that tracer gas was not escaping from the test system. (The infrared analyzers used in both the laboratory and the field work were Miran® Models 1A or 1B2™, The Foxboro Company, East Bridgewater, Massachusetts.) Each Miran sampled gas in the exhaust duct using a diaphragm pump, operating at 17 lpm, located between the duct and the Miran. The gas was extracted from the exhaust duct through ¼-inch diameter stainless steel tubes inserted into the duct along its diameter. Gas entered the steel tubes through five 1/16-inch diameter holes drilled in the tube and spaced evenly across the duct diameter. The exhaust of Infrared Analyzer™ 1 was routed back into the exhaust duct between the two Miran inlets. The exhaust of Infrared Analyzer 2 was routed back to the exhaust duct downstream of its inlet, preventing tracer gas contamination of the laboratory, which supplied fresh air for the hood. The breathing gas was supplied from a regulated compressed gas tank of air, containing 2 percent of either N<sub>2</sub>O or SF<sub>6</sub>. The breathing bag was a plastic bag of about 1-liter capacity. The breathing gas was maintained at a flow rate of 10.27 lpm. The flow rates of the breathing gas and the vacuum pump were measured with calibrated rotameters. The flow rate to the exhaust blower was determined by two 10-point pitot tube traverses made at right angles in the 14-inch diameter exhaust duct. The flow characteristics of the breathing machine were determined using a Medistor Pulmonary Function Analyzer (Model M-010, Cybermedic, Boulder, Colorado).

Calibration of the Mirans was accomplished with the arrangement of Figure 11. By turning off the scavenging exhaust flow, a known concentration of tracer gas was generated at the sampling points of both Mirans, since the tracer gas and hood flow rates were measured. This measured concentration agreed well with the concentration determined using the internal library of the 1B2.

In conjunction with the above quantitative leakage measurement system, an infrared (IR) imaging system (Thermovision 782, AGEMA Infrared Systems,

Figure 11. Quantitative mask leakage test facility.



## LABORATORY TEST FACILITY

Secaucus, New Jersey) was used to locate leaks in the systems under test. The source of IR energy was a square panel 18 inches on a side maintained at 120 °F. The apparatus under test was placed between the IR camera and the hot panel. Leaking tracer gas, such as N<sub>2</sub>O or SF<sub>6</sub>, strongly absorbed the IR radiation generated by the panel and was visible as a flowing plume or cloud on the IR system's video display.

### Laboratory Test Procedures and Observations

Control of mouth emissions was the original goal of this effort. The approach to this goal involved the following three steps: First, a series of local exhaust systems was constructed and tested qualitatively in the laboratory. Systems were tested using the apparatus shown in Figure 10 to determine which ones had the basic capability to capture mouth emissions. If this test was successful, the second step was to obtain an initial opinion of the system's acceptability in the dental practice. The director of the dental operator in which the field evaluation was accomplished provided this opinion. The third step was a field evaluation in the operator of those systems which had acceptably met the criteria of the first two steps. With controls in place and operating, personal sampling of the dentist and dental assistant was carried out for N<sub>2</sub>O exposure concentrations.

Because none of the controls passed the third step, tests were run to confirm the original assumption that the primary source of N<sub>2</sub>O exposure was mouth emissions. The apparatus of Figure 11 was developed to measure mask leakage. Also, an infrared imaging system was used to locate the leaks. Observations made with these two methods showed that the mask leaked when placed on the head form in what seemed to be a typical manner. Because the breathing bag was generally passive in the operator, indicative of an ill-fitting mask, it was concluded that the mask leaked in most operations, as it had in the laboratory, and was the usual cause of overexposure to N<sub>2</sub>O.

Improved control of mask leakage was attempted in several ways and leakage was again measured using the apparatus of Figure 11. First, increased flow of the mask's scavenger system was evaluated. When the scavenging flow was increased from 40 lpm to 62 lpm, the mask leakage decreased to 17 percent of its original value (Figure 12). The N<sub>2</sub>O concentration inside the mask was reduced to 73 percent of its original value as a result of this increase in scavenging flow (Figure 13). A second approach was to improve the mask fit. The data appears in Figure 14. Although a good-fitting mask (achieved by increasing the pressure of the mask's inner shell against the head form) resulted in low leakage, it may not be possible to assure this quality of fit under conditions commonly occurring in the operator. The third approach was the addition of a slotted skirt to the outer shell of the mask type used in the operator (construction diagrammed in Figure 15). The leakage was decreased considerably as shown in Figure 16 and was not dependent for success on the mask's quality of fit. A mask recently introduced on the market also was evaluated for comparative purposes, using the laboratory leak testing facilities (data shown in Figure 17). The three mask systems will be referred to as the following:

Figure 12. Standard and skirted mask laboratory leakage rates as a function of scavenging flow rate.

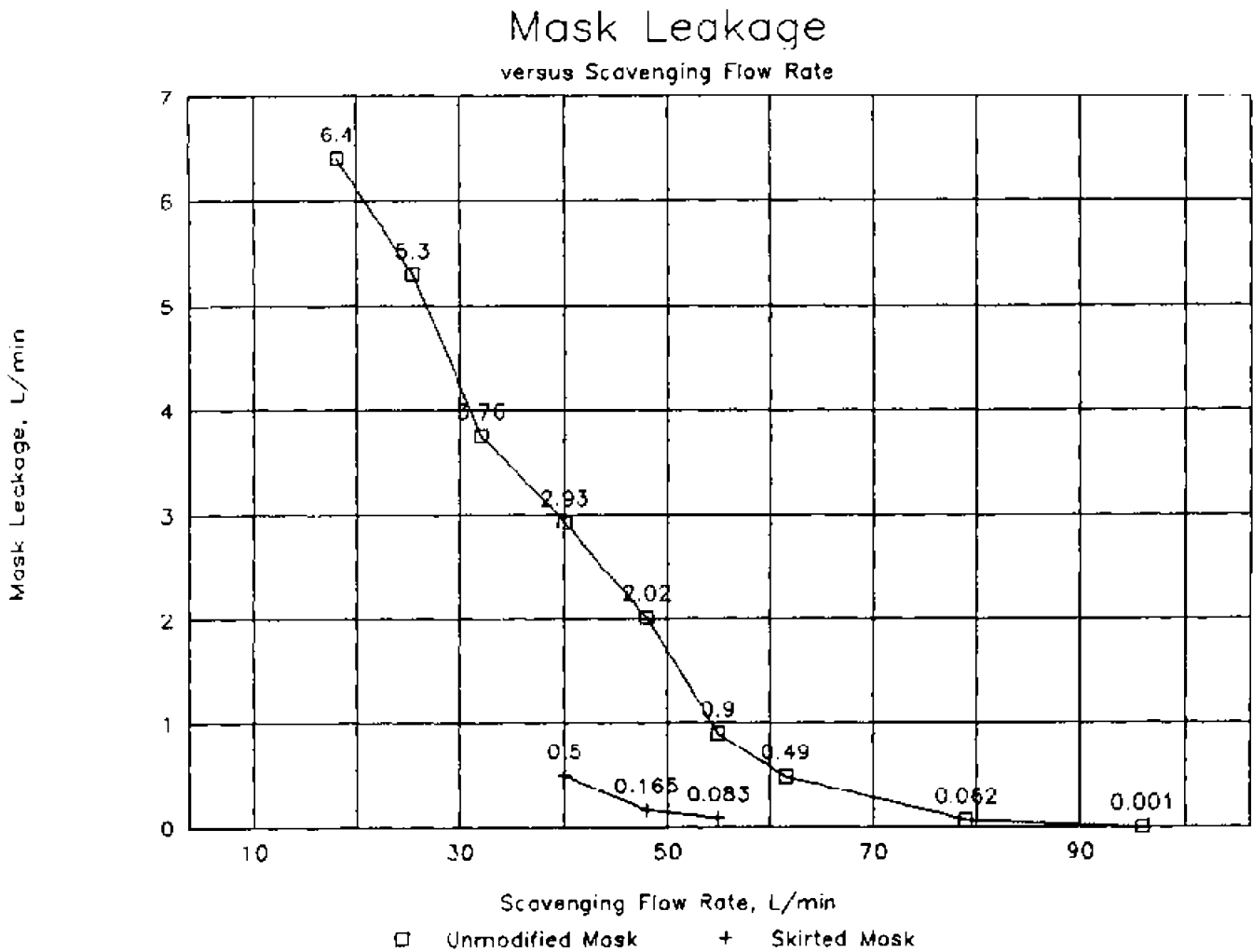
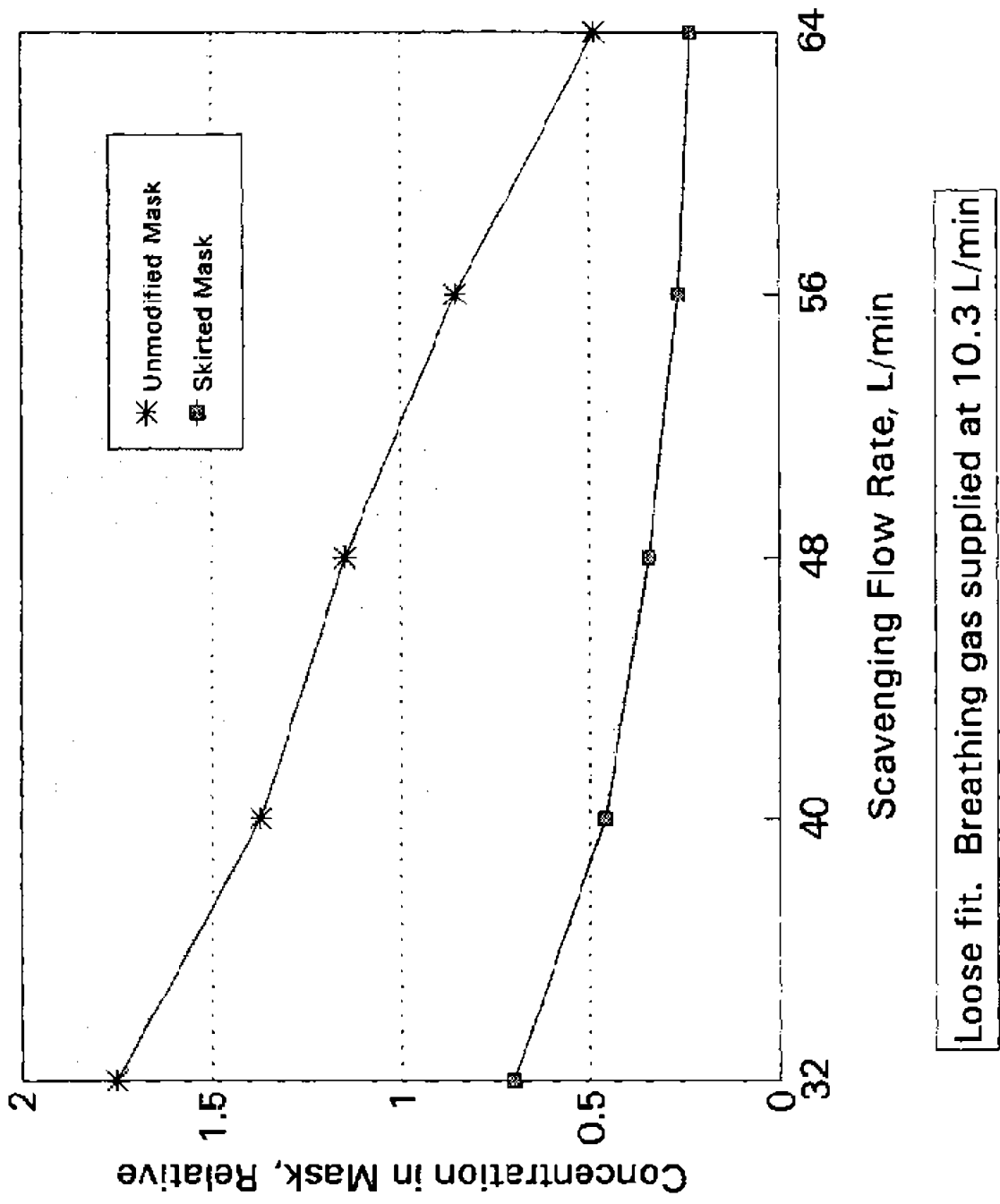


Figure 13. Relative concentration of breathing gas inside the mask as a function of scavenging flow rate as measured in the laboratory for the standard and skirted masks.



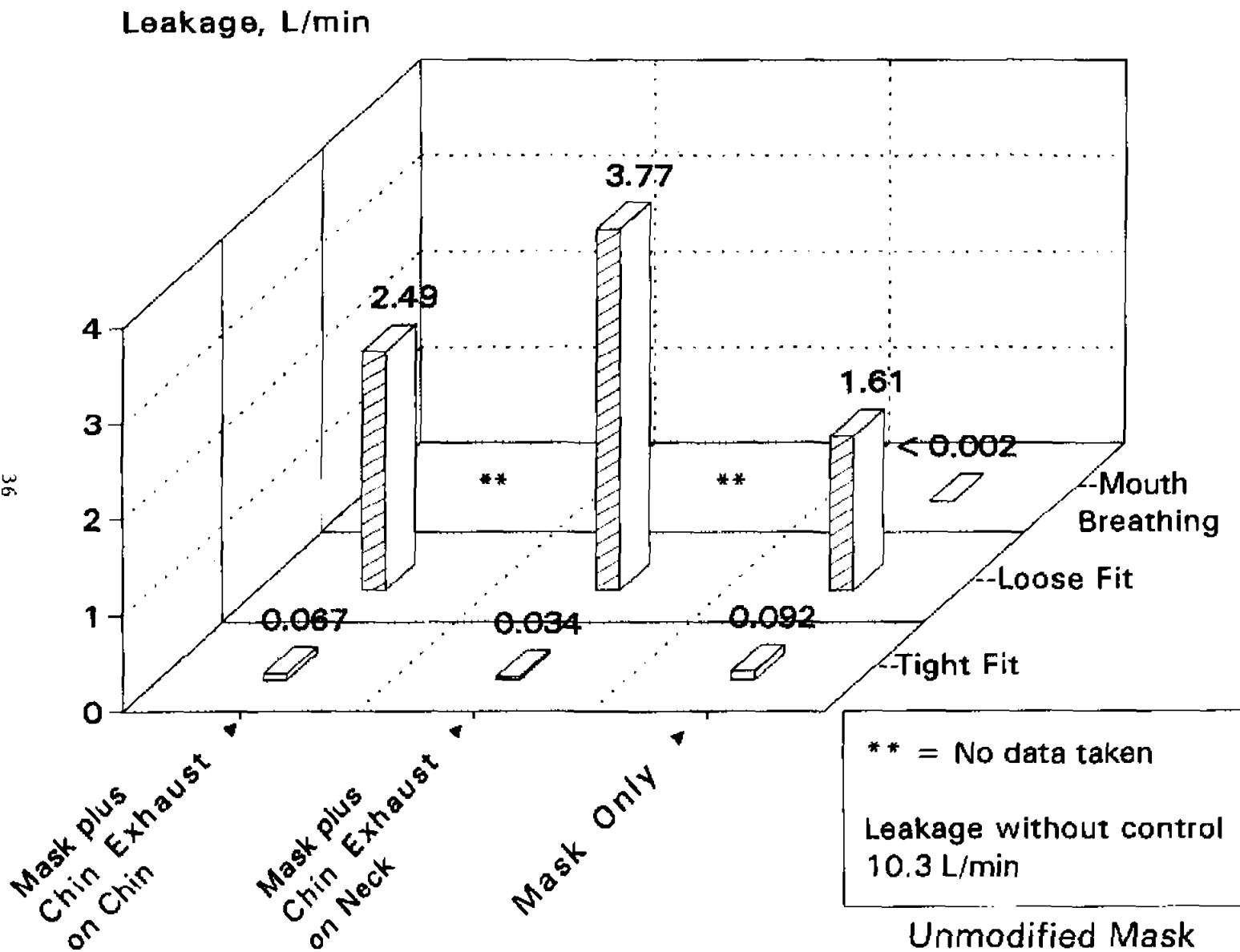
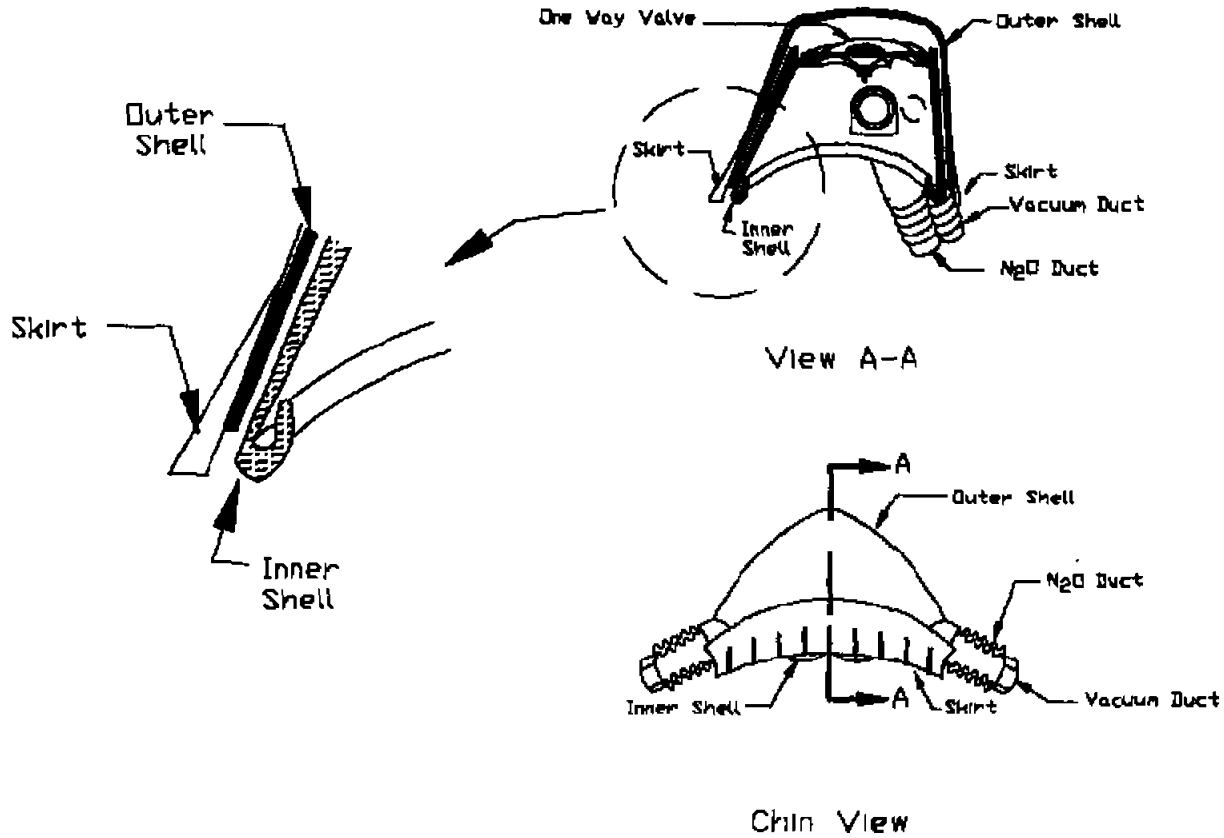


Figure 14. Laboratory leakage rates of an unmodified mask with tight and loose fits, nose and mouth breathing, and with a supplementary chin exhaust located on the head form's chin or neck.



Porter-Brown Mask With Skirt Added



Figure 16. Laboratory Leakage rates of a skirted mask with tight and loose fits, nose and mouth breathing, and with a supplementary chin exhaust located on the head form's chin or neck.

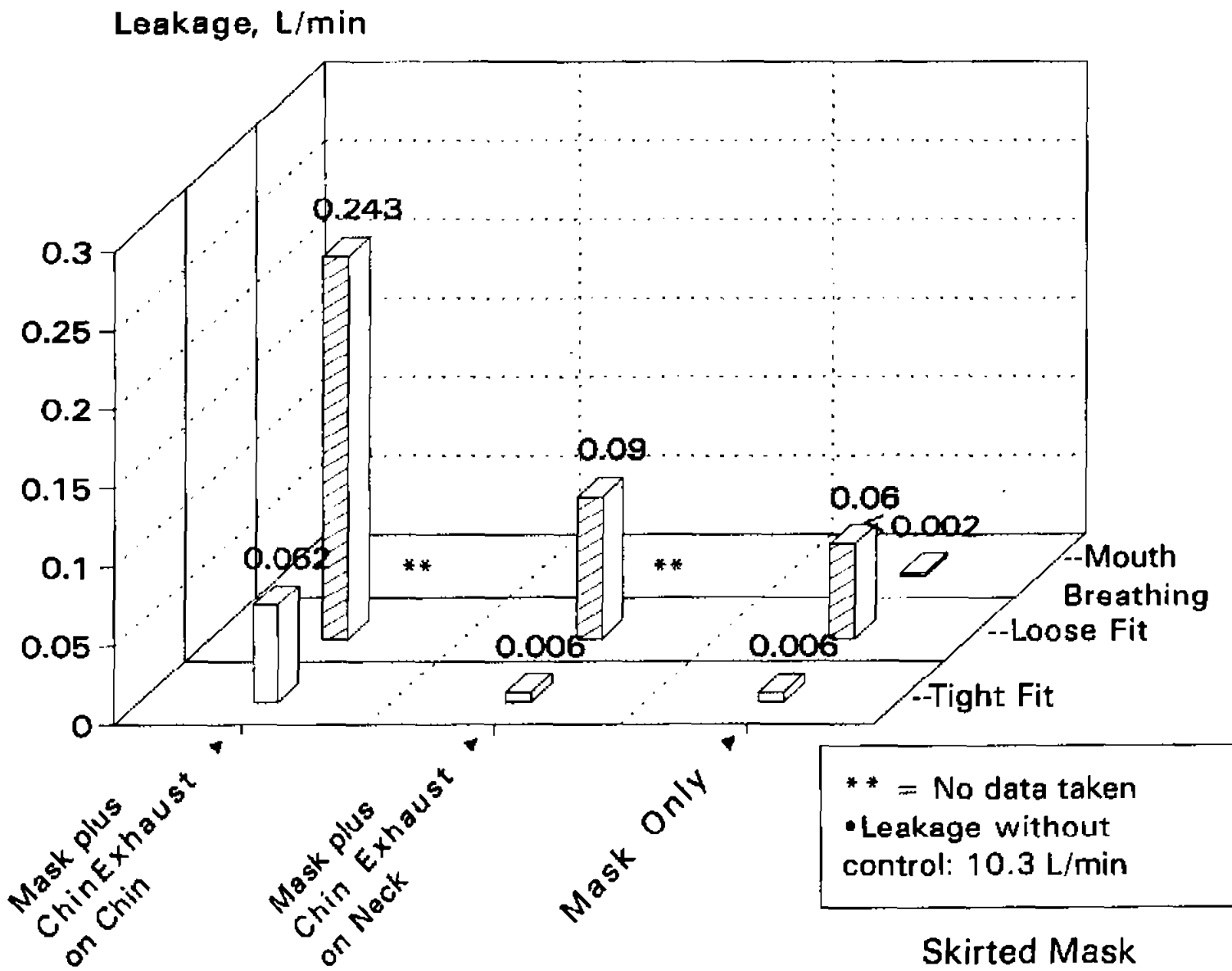
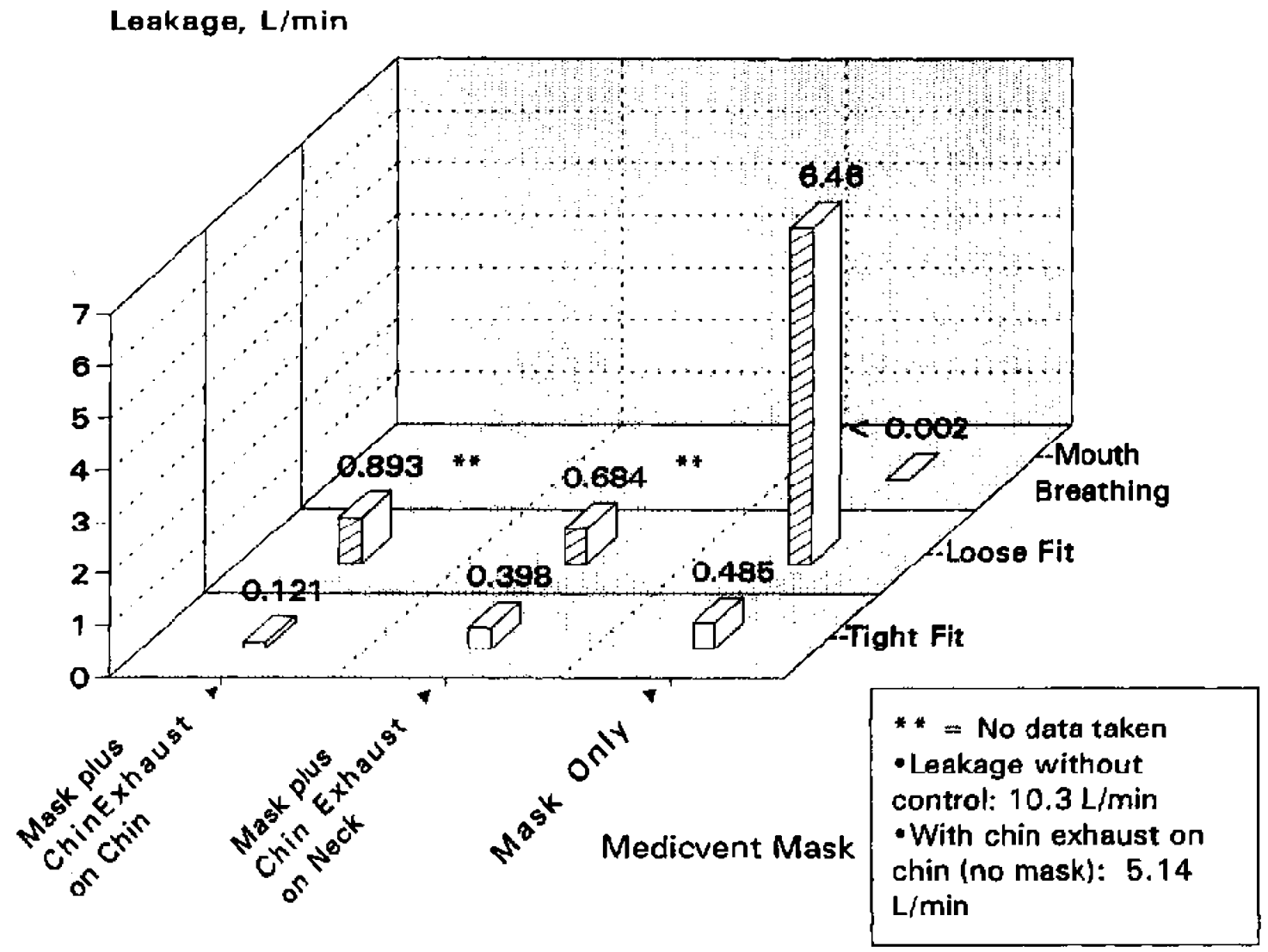


Figure 17. Laboratory leakage rates of the Medicvent mask with tight and loose fits, nose and mouth breathing, and with a supplementary chin exhaust located on the head form's chin or neck.



- Unmodified mask -- The latest available Porter-Brown mask (Porter Instrument Company, Hatfield, Pennsylvania) as received from the manufacturer.
- Skirted mask -- A Porter-Brown mask with a flexible, slotted skirt added to the outer shell.
- Medicvent<sup>™</sup> mask -- A recently-introduced mask (Model Ancvac-D, Medicvent AB, Umeå, Sweden) which includes a supplementary chin-mounted exhaust and has a much higher scavenging flow than the Porter-Brown masks.

#### LEAK TESTING SCAVENGING EQUIPMENT

N<sub>2</sub>O delivery equipment was visually inspected to ensure that all components were in place and that there were no obvious tears, cracks, abrasions, or worn spots. If there was an obvious problem with the general repair or maintenance of the equipment, components of the equipment was either repaired or replaced before leak testing was conducted.

During the first survey, leak testing of the low-pressure components of the anesthesia scavenging machine was performed as follows: the breathing bag was removed from the anesthesia machine, overfilled with oxygen, and the end of the bag was corked. It was submerged in water, and the bag was inspected and palpated to reveal leakage in the form of air bubbles. The hoses from the anesthesia machine were removed and a blood pressure gauge was adapted to fit the hoses. The hoses were sealed at one end and supplied with air to a pressure of 30 millimeters mercury (mm Hg). They were then submerged under water to reveal air bubble leakage. Leaks in high-pressure connection ports were checked by swabbing soap solution around the N<sub>2</sub>O and O<sub>2</sub> valve connections and checking for soap bubbles.

On the second survey, leak testing of low-pressure components of the anesthesia scavenging machine was determined by using the Miran 1A. After the end of the scavenging mask hose was blocked with the thumb, the gas delivery system was turned on. A tygon tube connected to the Miran 1A was used as a "sniffer" to detect N<sub>2</sub>O leaks, tracing the system from the wall connection to the mask connection. For high-pressure leaks, soap solution was applied with a swab applicator around the valve connections of N<sub>2</sub>O supply cylinders to check for leaks appearing in the form of soap bubbles. The supply cylinders of N<sub>2</sub>O and oxygen were located in a different section of the building, and the gases were supplied to the operatories through gas line connections.

On the third survey, leak testing of the scavenging system, all high-pressure connections, and the tank and manifold connections was performed with a Miran 1B (Foxboro Instruments). The gas delivery and scavenging systems at each chair were turned on, and the scavenging mask was placed in a gas-tight bag, which was then sealed. The N<sub>2</sub>O and O<sub>2</sub> valves were then opened to a flow rate of about 3 lpm. The probe for the Miran 1B was directed at various high- and low-pressure fittings along the gas delivery system to identify leaks. If a reproducible marked increase in N<sub>2</sub>O readings (10 ppm or more) was observed, a significant leak was considered to have been identified. For leaks identified in this manner, a soap solution was applied to locate the specific leak point.

The supply cylinders of N<sub>2</sub>O and oxygen were located in a closet in the building wing and were found to be free of leaks.

## DATA ANALYSIS

Statistical analysis of the personal sampling results for the dentists, their assistants, dental operation, and type of dental operation was conducted for the first two surveys. For the third survey, statistical analysis was conducted for personal sampling results of the dental personnel and for samples taken in the immediate area of the patient's mouth and local exhaust ventilation.

Because N<sub>2</sub>O concentrations in other parts of the dental suite were low relative to the dental operatories, no statistical tests were performed to compare sampling from these areas with personal sampling results.

### Survey #1: Pediatric Dental Facility

Paired Student's t-tests were used to compare differences in N<sub>2</sub>O concentrations between the personal breathing zone results of the dentists and dental assistants. Paired Student's 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.<sup>98</sup>

Analysis of variance (ANOVA) was used to compare N<sub>2</sub>O real-time sampling results for the three operatory configurations (i.e., open bay, semi-open, and closed room) that were evaluated.<sup>98</sup>

Mallows C<sub>p</sub> 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<sub>2</sub>O 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.<sup>99</sup>

### Survey #2: Oral Surgical Clinic

Data representing operations on nine patients by four dental teams were analyzed to determine how dental practices and other factors, such as probe distance and changes in N<sub>2</sub>O delivery concentration, affected N<sub>2</sub>O exposure concentrations.

If dental practices can affect the amount of escaped N<sub>2</sub>O, then one might expect to find similar effects resulting from different dental teams. The type of dental operation might also be a factor. Analysis of team and operation differences included the mean level (on a log scale) of N<sub>2</sub>O concentration as the dependent variable. Several limitations of using the logarithm mean level of N<sub>2</sub>O occurred: (1) positive concentrations of N<sub>2</sub>O were observed even before the source was turned on (apparently because residual N<sub>2</sub>O was trapped in the anesthesia delivery system from a previous operation); (2) in some of the data sets, positive N<sub>2</sub>O concentrations occurred before and at the same time the anesthetic gas was turned on; and (3) there was lag of one

or more time intervals before positive concentrations were observed after the source was turned on.

### Survey #3: Dental Clinic for the Developmentally Disabled

For statistical analysis, the concentration of  $N_2O$  in the dental hygienist's breathing zone, dental assistant's breathing zone, and area samples were considered the dependent variables. Local exhaust ventilation (with flow rates of 0, 1, 2, and 3), patient compliance (compliant as opposed to struggling and in need of physical restraint), and flow rate of delivered  $N_2O$  were the independent variables.<sup>99</sup> Dental hygienist was not used as an independent variable because 18 of 20 procedures were conducted by the same dental hygienist. The SAS<sup>TM</sup> general linear model (GLM) was used to analyze these relationships among dependent and independent variables. The geometric means and the upper 95 percent confidence limits of the dependent variables were evaluated against the NIOSH REL of 25 ppm to determine if the  $N_2O$  concentrations in the dental operatory were statistically less than the NIOSH REL.

### Limitations in Data Analysis

For each of the dental surgeries analyzed in the first and second studies, there were more than 150 possible models to compare. In all cases, the "best" of these differed from the next 20 to 30 models only slightly, based on the Mallows  $C_p$  statistic, the multiple correlation, the adjusted multiple correlation, and the site selection criteria. The selected model is at best only suggestive of important relationships. The selected model for  $N_2O$  exposure sources exhibited some limitations: (1) In some cases,  $N_2O$  from previous operations appeared to remain in the  $N_2O$  delivery system, even after operations where oxygen flushing was performed. It is hypothesized that most of the  $N_2O$  was in the reservoir bag, and/or leaking from the flowmeter. As a next operation began, this residual  $N_2O$  was breathed in and exhaled by the patient, thus making it harder to analyze the data for work practice effects. (2) There was some confounding among the variables which might have blurred the effects and produced numerical problems for least squares statistical analysis. (3) The sequence of occurrence effects factors were ignored. For example, the presence or absence of mouth breathing might have affected the manner in which other factors affected  $N_2O$  concentration. (4) Sample size differences and differences in patient behavior before and after the patient was fully sedated might have affected results.

## RESULTS

### SURVEY #1: PEDIATRIC DENTAL FACILITY

#### Air Sampling

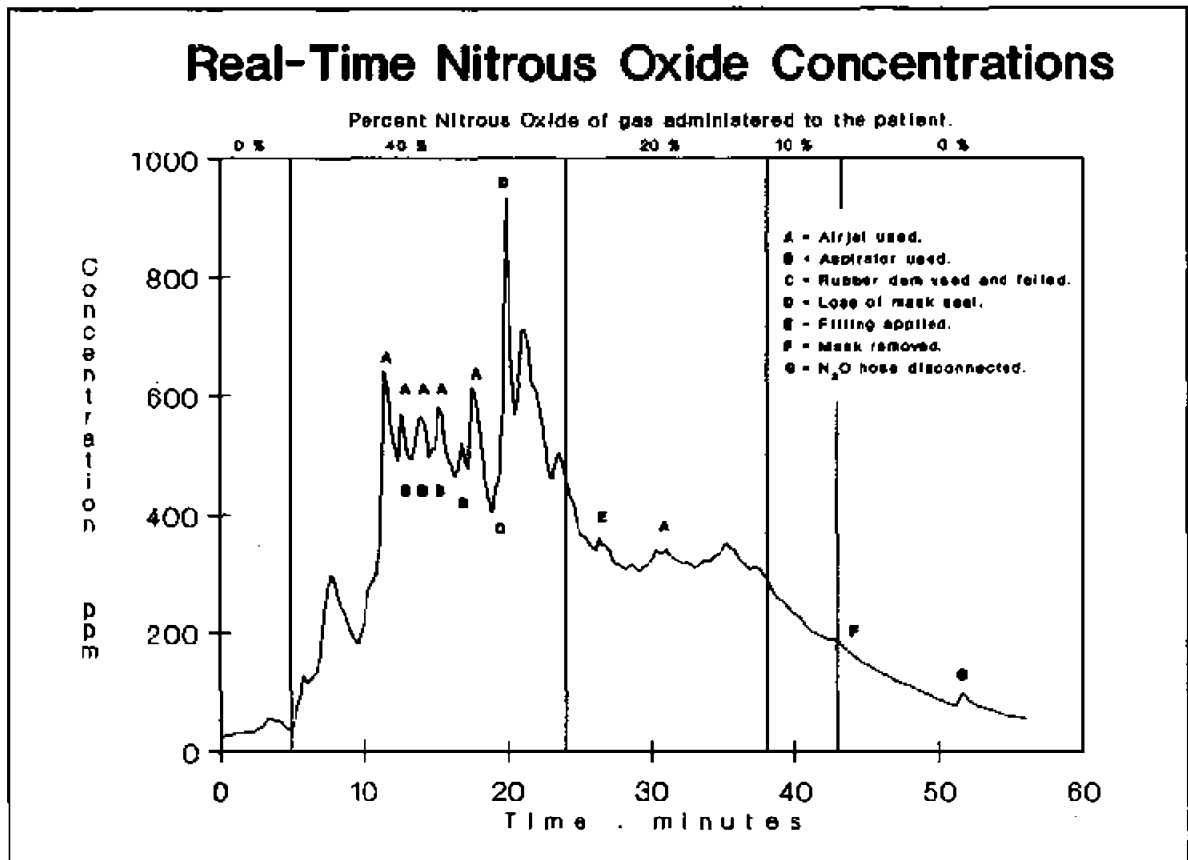
#### Personal--

$N_2O$  concentrations within the breathing zones of the dentist and dental assistant ranged from 25 ppm to 950 ppm. The average real-time concentration

was 350 ppm. Seven lpm of gas were supplied to the patient's nasal mask throughout the operation. N<sub>2</sub>O was supplied at 2.5 lpm while oxygen was supplied at 4.5 lpm. The mixture provided the patient with 40 percent N<sub>2</sub>O and 60 percent oxygen. During the 45-minute operation, the dentist "stepped-down" the N<sub>2</sub>O from 40 to 20 to 10 to 0 percent. The general area concentration of N<sub>2</sub>O subsequently decreased from over 200 ppm to 35 ppm 55 minutes after the operation began.

By combining direct N<sub>2</sub>O readings with the videotape analysis, several work elements appeared to influence the concentration of N<sub>2</sub>O during the course of surgery. These elements included use of the scavenging unit, the regulation of N<sub>2</sub>O concentration administered by the dentist, the use of a rubber dam (i.e., a 6- x 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. Also, the patient contributed to the exposure of the dentist and dental assistant through exhalation of N<sub>2</sub>O by talking, coughing, and yawning. A profile of the real-time sampling results for N<sub>2</sub>O and dental work activities during the operation is shown in Figure 18.

Figure 18. Changes in N<sub>2</sub>O concentration during dentistry.



The initial survey showed an average real-time N<sub>2</sub>O concentration of 352 ppm during dental surgery. It also showed that the use of this scavenging system did not guarantee a reduction to safe working concentrations of N<sub>2</sub>O. A NIOSH HETA study of the same facility in 1979 showed N<sub>2</sub>O concentrations for personal exposure ranged from 90 to 3500 ppm without a scavenging system.<sup>60</sup> While the scavenging system reduced N<sub>2</sub>O to lower concentrations, scavenging alone did not decrease it below the NIOSH REL. Work practices, including the regulation of N<sub>2</sub>O by the dentist during the course of the operation, location of the dentist's breathing zone to the patient's mouth, and use of a dental saliva aspirator and air jet appeared to influence the amount of N<sub>2</sub>O exposure dental personnel received while working.

Information gathered on the Fraser-Harlake scavenging system during follow-up surveys at the pediatric dental facility showed that N<sub>2</sub>O exposures were generally lower in the open bay (Operator 3-6) and semi-open bay (Operator 3-9), compared to the closed room. Table 4 shows the N<sub>2</sub>O concentrations for the dentists and dental assistants by operation and dental operator. The mean N<sub>2</sub>O concentration for dentists was 487 ± 366 ppm; for dental assistants,

Table 4. Summary of personal and real-time sampling data (ppm) for N<sub>2</sub>O during administration in a pediatric operatory.

Procedure ID	Room	Personal		Real-time Monitoring			
		Dentist	Dental Assis't	AVG	STD	MAX	MIN
Preliminary Survey	3-8	*	*	372	149	934	78
Dental Op. 1	3-11	233	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. () = Nitrous Oxide turned on prior to beginning of sampling period.

the mean N<sub>2</sub>O exposure was 150 ± 144 ppm. Paired Student's T-tests comparing N<sub>2</sub>O personal sample results of dentists with dental assistants showed a significant difference (X=6, p<.03). This difference may have resulted from a closer working proximity for the dentist than the dental assistant to the patient's mouth. If there is N<sub>2</sub>O leakage from the mask, and/or from patient mouth breathing, differences in exposure between the dentists and dental assistants may be significantly higher.

General Area--

General area sampling (Table 5) concentrations above the NIOSH REL were observed at the entry to the operatory in five of the six dental operatory runs and in three of the six main hallway runs. N<sub>2</sub>O was not detected at the appointment desk on any of the sampling runs.

Table 5. Summary of general area data (ppm) for N<sub>2</sub>O during administration.

	INIT CONC	ROOM SUPPLY	ROOM EXHAUST	ROOM DOOR	HALL	APPT DESK
Preliminary Survey	25	#	#	#	#	#
Dental Op. 1	4	0	31	##	##	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 operation number 1.

### = These runs were conducted to assess the feasibility of infrared thermography.

The closed, semi-open, and open bay operatories were evaluated for N<sub>2</sub>O 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 N<sub>2</sub>O recirculation from the wall air handling unit. The open bay, also showed recirculation of N<sub>2</sub>O from the wall units, but at a much lower concentration. These lower concentrations for the open bay may have been a function of several variables: (1) the larger area, allowing for more dilution of the N<sub>2</sub>O; (2) the amount of N<sub>2</sub>O administered over time; (3) the dental procedure underway; and (4) the proximity of the air-conditioning wall units to open bay chairs (approximately 10 feet further away than the semi-open bay). The air conditioning wall units provided N<sub>2</sub>O recirculation because these units could not be adjusted to entrain outside air alone. The wall unit dampers were usually closed to outside air during winter to conserve energy.

#### Real-Time--

Real-time sampling results for the dental operations ranged from an average N<sub>2</sub>O concentration of 206 ppm in Operating Room 3-11 (Dental Operation #1) to 770 ppm in the same operating room (Dental Operation #2). N<sub>2</sub>O concentrations exceeded 1000 ppm in five of the ten operations monitored. The real-time sampling and personal sampling results followed the same N<sub>2</sub>O concentration patterns. Analysis of variance showed the means of the three sampled areas (i.e., closed, semi-open, and open bay dental operatories) were not significantly different ( $p < .70$ ). This may be attributed, in part, to the low sample size and high variance in N<sub>2</sub>O concentrations within the different operatories.

There was no significant difference ( $p < .68$ ) between the means of the average real-time sampling results (442 ppm) and the average dentists' personal breathing zone results (487 ppm). However, the difference between the average real-time sampling results and the average breathing zone N<sub>2</sub>O concentrations among dental assistants (150 ppm) was significant ( $p < .014$ ). The real-time probe was positioned to maximize capture of N<sub>2</sub>O emission from the patients. Because the dentist worked in close proximity to the patient's mouth, it may be assumed that the real-time sampling results were more representative of the dentist's exposure than that of the dental assistant's.

#### Infrared Thermography

An infrared scanning camera was used during Dental Operations #8 and #9 to determine scavenging mask leakage during administration of N<sub>2</sub>O. This technique was very useful in determining N<sub>2</sub>O leakage around the patient's mask. The scanner helped determine that the Fraser-Harlake mask did not fit the patient's face properly, allowing N<sub>2</sub>O leakage between the mask and face seal. Furthermore, it was observed that sudden increases in N<sub>2</sub>O exposures observed from the real-time data could be traced to the patient's expired breath; when the patient inhaled, the N<sub>2</sub>O concentrations decreased. This indicated that patient breathing was an important factor in exposure to the dentist and dental assistant.

## Ventilation

### General--

The data from the first survey showed that there were differences in the measured flow rates for specified ventilation systems in the building. These differences were accounted for in part by acceptable variations from design flows and by changes in the ventilation systems from the original blueprint specifications.

The periphery of the building was fitted with wall, recirculation heating/air conditioning units manufactured by the Singer Company that met American Refrigeration Institute (ARI) Standard 310-70 specifications for function EA15. These specifications called for a cooling blower capacity of 290 cubic feet per minute (cfm) with 70 cfm (24 percent) maximum fresh air. The heating mode specification called for 280/60 cfm, which is a 21 percent maximum fresh air. The airflow from two Singer units was 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, which is reasonably close to the specification of 290 cfm.

### Scavenging System--

The effectiveness of the capture capacity of the anesthetic gas from the scavenging nasal mask is evaluated by inserting a flowmeter in the exhaust ports of the scavenging mask tubing, following a dental operation. The exhaust valve for the scavenging mask is adjusted at the beginning of an operation by the dental assistant and not changed throughout the surgery. For Dental Operation #7, the flowmeter showed the exhaust to be approximately 7 to 12 lpm. The scavenging system ventilation was not evaluated until this operation. It had been assumed that the scavenging system flow rates were automatically set at 45 lpm, the effective scavenging amount when 4 to 7 lpm of N<sub>2</sub>O and O<sub>2</sub> are mixed and delivered to the patient.<sup>15</sup>

### Work Practices and Changes in N<sub>2</sub>O Exposure

For the first seven runs, dental surgical activities were observed to determine if they influenced changes in N<sub>2</sub>O concentrations. When the dentist performed certain tasks, significant N<sub>2</sub>O concentration changes occurred: (1) turning the N<sub>2</sub>O gas on; (2) adjusting the concentration during the operation; and (3) turning the N<sub>2</sub>O gas off. Up to 98 percent of the changes in N<sub>2</sub>O exposure could be accounted for, based on the concentration in the gas delivered to the patient. Other dental work (i.e., the use of the rubber dam, the aspirator, and the air and water syringes) appeared to have little, if any, influence on changes in N<sub>2</sub>O concentration to which the dentist and dental assistant were exposed.

This pattern was also evident in the initial preliminary survey. Figure 18 shows that certain work activities were observed to change N<sub>2</sub>O concentrations. However, the changes were small and transient compared to the overall N<sub>2</sub>O concentration, as shown by the area beneath the graph curve. This was more apparent when the dentist changed the amount of N<sub>2</sub>O administered to the

patient from 40 to 20 to 10 percent, demonstrating that the primary source of exposure for this scavenging system was from N<sub>2</sub>O delivery concentration and the low scavenging system exhaust rate.

## SURVEY #2: ORAL SURGICAL CLINIC

Personal and general area air sampling was conducted for N<sub>2</sub>O exposure in nine dental operations using four surgical teams. All operations were performed using the Porter-Brown scavenging system. The duration of oral surgery for these operations ranged from 32 to 100 minutes. The percentage of time N<sub>2</sub>O was on during surgery ranged from 18 to 88 percent. The concentration of N<sub>2</sub>O administered to the patients ranged from 20 to 50 percent. It was constant throughout five of the procedures, but was varied for the others. The N<sub>2</sub>O supplied to the patient ranged from 2 to 3 lpm, while oxygen was supplied at 3 to 4 lpm. The total anesthetic mixture airflow administered to the patient for all operations was between 5 to 6 lpm. The oral surgery included (1) six operations for the removal of one wisdom tooth; (2) one for two wisdom teeth; (3) one tooth implant; and (4) one removal of mandibular canine. There were seven female patients and two male patients ranging in age from 20 to 75 years.

### Air Sampling

#### Personal--

Table 6 shows the N<sub>2</sub>O TWA concentrations during administration for personal and real-time samples for the nine operations. These concentrations ranged from less than the detection limit (<1 ppm) to 277 ppm for the oral surgeons and from less than the detection limit to 77 ppm for the surgical assistants. The overall average N<sub>2</sub>O concentration for the oral surgeons in the operations measured was 101 ( $\pm$  117) ppm, and for the surgical assistants 27 ( $\pm$  31) ppm. Concentrations for the oral surgeons averaged from less than 1 ppm for team #3 to 257 ( $\pm$  29) ppm for team #1. For the surgical assistant, concentrations varied from less than 1 ppm for team #3 to 77 ppm for team #4. The greatest difference in N<sub>2</sub>O concentrations between the oral surgeons and surgical assistants on the same team was found in team #1; the difference in concentration was approximately an order of magnitude higher (236 versus 20 ppm). N<sub>2</sub>O concentrations shown by personal sampling did not appear to be related to the type of operation performed.

The average N<sub>2</sub>O concentrations for the oral surgeons was 131 ( $\pm$ 129) ppm for Room D1218 and 25 ( $\pm$ 28) ppm for Room D1222; for the surgical assistants it was 24 ( $\pm$ 31) ppm and 34 ( $\pm$ 43) ppm, respectively.

#### General Area--

Results of the general area sampling data are shown in Table 7. There was no detectable initial N<sub>2</sub>O concentrations in eight of nine surgeries monitored by NIOSH personnel. The ninth surgery showed 13 ppm prior to the N<sub>2</sub>O being turned on. It is suspected that there was some residual N<sub>2</sub>O from the previous dental surgery where this anesthetic had been administered approximately

Table 6. Summary of personal & real-time N<sub>2</sub>O sampling (TWA during administration of N<sub>2</sub>O), percent of N<sub>2</sub>O administered, time of administration, and time of operation.

OPER #	ROOM # MASK	PATIENT/NOTES	SURGICAL TEAM	N <sub>2</sub> O TWA SURGEON	N <sub>2</sub> O TWA ASSIST.	N <sub>2</sub> O REAL-TIME	N <sub>2</sub> O RANGE	TIME (MIN) N <sub>2</sub> O ADMIN	TIME (MIN) N <sub>2</sub> O DETECTED	TIME (MIN) N <sub>2</sub> O > 25 ppm	LENGTH OF OPERATIONS TIME (MIN) SAMPLING
1	D1218 P-Brown	Female, 70 yrs. Mandibular Canine	#1	236	20	110	(20-40)	18.50	28.50	18.75	32.50
2	D1218 P-Brown	Male, 24 yrs. Removed 4 Wisdom	#1	277	16	135	(20-40)	31.00	39.25	31.25	39.25
3	D1218 P-Brown	Female, 24 yrs. Removed 4 Wisdom	#2	1	5	170	(33-50)	36.75	52.25	49.25	52.25
4	D1218 P-Brown	Female, 38 yrs. Removed 4 Wisdom	#3	*	*	11	(33)	15.25	55.00	43.75	62.50
5	D1218 P-Brown	Male, 26 yrs. Removed 2 Wisdom	#3	*	*	118	(33)	21.00	32.25	24.75	44.00
6	D1218 P-Brown	Female, 22 yrs. Removed 4 Wisdom	#4	138	77	173	(50)	27.72	33.00	28.5	45.75
7	D1218 P-Brown	Female, 75 yrs. Tooth Implant	#3	<1	<1	17	(33)	17.75	93.00	19	100.25
8	D1222 P-Brown	Female, 20 yrs. Removed 4 Wisdom	#2	45	64	30	(33-50)	45.20	46.20	40.4	51.50
9	D1222 P-Brown	Female, 24 yrs. Removed 4 Wisdom	#2	6	3	37	(50)	27.50	38.50	33.5	38.50

\* = Sampling time < 2 minutes for N<sub>2</sub>O

Table 7.

Results for general area sampling (ppm N<sub>2</sub>O).

OPERATION No.	INIT CONC	ROOM SUPPLY	ROOM EXHAUST	ROOM DOOR	HALL	APPT DESK
Oper. #1	<1	<1	4	<1	<1	<1
Oper. #2	<1	<1	3	<1	<1	<1
Oper. #3	<1	<1	<1	<1	<1	<1
Oper. #4	<1	<1	<1	<1	<1	<1
Oper. #5	<1	<1	1	<1	<1	<1
Oper. #6	<1	<1	27	3	<1	<1
Oper. #7	<1	<1	<1	<1	<1	<1
Oper. #8	<1	<1	8	2	<1	<1
Oper. #9	13	<1	22	8	<1	<1

30 minutes earlier. No N<sub>2</sub>O was detected in the surgical suite supply air, indicating that the N<sub>2</sub>O was not being entrained into the building's supply ventilation or that the recirculation of this air diluted concentrations below detectable limits. The N<sub>2</sub>O concentrations in the surgical suite exhaust air was low (range was <1 to 27 ppm) for all NIOSH-monitored surgeries. The N<sub>2</sub>O concentrations were low at the door of each suite, ranging from <1 to 8 ppm, indicating that the rooms were not under positive pressure. This was confirmed by using smoke from smoke tubes to observe the direction of airflow. No detectable concentrations of N<sub>2</sub>O were found in the hallway or at the appointment desk indicating that the N<sub>2</sub>O was not migrating from the operating suites or being ventilated into the hallway from other sources.

#### Real-Time--

The average N<sub>2</sub>O concentrations during administration for the nine operations ranged from 11 ppm to 173 ppm (Table 8). The overall mean N<sub>2</sub>O concentration was 89 ( $\pm 66$  ppm). When the values were averaged over the duration of the surgical operation (i.e., from when the operation started to when it ended), the values were slightly less: 6 to 137 ppm (Table 8). Peak N<sub>2</sub>O concentrations of over 1000 ppm were detected in two of nine operations. N<sub>2</sub>O concentrations decreased after the gas was turned off and averaged 2 to 61 ppm from the time the gas was turned off until surgery was completed. Table 8 shows the real-time N<sub>2</sub>O concentrations by team, time, and type of operation.

Table 8. Real-time N<sub>2</sub>O concentrations by team, time, and type of operation\*.

Oral Surgical Clinic - Summary of Surgery Time & N <sub>2</sub> O Averages in ppm for Each Operation									
OPER_#	Oper. #1	Oper. #2	Oper. #3	Oper. #4	Oper. #5	Oper. #6	Oper. #7	Oper. #8	Oper. #9
TEAM #	1	1	2	3	3	4	3	9	2
OPER_TYP	MCANE	WISD4	WISD4	WISD4	WISD4	WISD4	IMPLA	WISD4	WISD2
TIME_OP (m:n)	32	39	52	62	44	46	100	51	38
N <sub>2</sub> O_ON	19	31	37	15	21	28	18	46	28
PERCENT TIME_ON	57	79	70	25	48	61	18	89	72
N <sub>2</sub> O_OFF	8	7	12	42	18	9	73	3	6
AVGALL (ppm)	67	108.3	137	48	60	113	6	27	35
MAX	361	794.3	1672	321	759	915	125	239	271
S.D.	83	110.0	211	61	106	164	16	35	43
AVGDET (ppm)	75	110.1	137	54	84	155	6	30	39
MAX	361	794.3	1671	321	759	915	125	239	271
S.D.	84	109.2	211	54	117	174	17	35	45
AVGON (ppm)	110	134.7	170	11	118	173	17	30	37
MAX	361	794.3	1672	81	759	915	125	239	271
S.D.	83	108.4	237	20	129	184	28	37	47
AVGOFF (ppm)	12	5.6	61	68	9	33	2	9	13
MAX	134	24.5	348	321	85	114	20	65	83
S.D.	32	6.8	82	65	16	34	4	15	17

\* Key: Oper\_#: Operation Number, Team #: Team Number; Oper\_Typ: Operation Type; MCANE: Remove Mandibular Canine; WISD4: Remove 4 Wisdom Teeth; IMPLA: Implantation; WISD2: Remove 2 Wisdom Teeth; TIME\_OP: Time of Operation in Minutes; N<sub>2</sub>O\_ON: Time N<sub>2</sub>O Was On; percent TIME\_ON: Percent Time N<sub>2</sub>O is On; N<sub>2</sub>O\_OFF: Time N<sub>2</sub>O is Off During Operation; AVGALL: Average N<sub>2</sub>O Concentration During Operation; AVGDET: Average N<sub>2</sub>O Concentration for the Total Time N<sub>2</sub>O is Detected; AVGON: Average N<sub>2</sub>O Concentration from Time the Gas was Turned on to Time it was Turned Off; AVGOFF: Average N<sub>2</sub>O Concentration After the Gas was Turned Off; MAX: Maximum N<sub>2</sub>O Concentration During Operation; S.D.: Standard Deviation.

## Infrared Thermography

As in the first survey, infrared thermography was used to observe N<sub>2</sub>O emissions from mask leakage and patient mouth breathing.

## Ventilation

### General--

The general air supply system consisted of several units. Blowers manufactured by Barry Blower, Model No. 220, 90 BBC (DWDI), were used to supply air to several rooms, including the two sampled by NIOSH researchers. Of the total specified capacity of 8645 cfm, 690 cfm was dedicated to rooms 1218 and 1222. The air was exhausted from these and other rooms by two exhaust systems manufactured by Barry Blower, Model 7600 AF (DWDI). The specified capacity of each of these two systems was 56,200 cfm; 500 cfm was dedicated to room D1218 and 190 cfm to room D1222.

At the time of the NIOSH survey, the ventilation rates were within 24 to 60 percent in room D1218 (operations 1-7), and 13 to 18 percent of the original ventilation specifications in room D1222 (operations 8-9). Both rooms were under negative pressure; the total volume of air exhausted was 60 to 180 cfm greater than the supply volume. The remaining make-up air entered through the open door to each room.

The dimensions of Room D1218 were 17.2 by 17.2 by 9.9 feet high, a total volume of 2,300 cubic feet. The ventilation to the room was through one supply duct located in the ceiling and an open door and exhausted through five ceiling registers. The total air exhausted from this room provided an average of ten air changes per hour.

The dimensions of Room D1222 were 11.3 by 10 by 8.5 feet high, a total volume of 960 cubic feet. The ventilation to the room was supplied through one ceiling duct and an open door and exhausted through three ceiling registers. The total air exhausted from this room provided an average of 14 air changes per hour.

Smoke tube observations indicated that the supply air to each room remained near the ceiling and did not readily mix with the air already present in the rest of the room. Additional observations showed that the supply register louvers directed most of the air toward the ceiling and did not mix well with the air around the oral surgical chair.

### Scavenging System--

A flowmeter was connected into the scavenging exhaust system and flow rates were adjusted to approximately 45 lpm after the gas was turned on for both oral surgeries monitored. The exhaust rate for the scavenging unit was generally adjusted at the beginning of the operation by a member of the surgical team and not changed throughout the surgery. In one operation, the scavenging system exhaust was not turned on until a few minutes after the gas

was turned on (Operation #2). This potential problem could have been eliminated by an interlock between the gas delivery and exhaust system.

## Work Practices and Changes in N<sub>2</sub>O Exposure

### Surgical Teams and Type of Operation--

Four surgical teams and four types of operations were performed. The work practice analysis results based on team, time, and type of operation are shown in Table 8. Statistical analysis showed that of the differences (four teams and four operations) examined, only one was significant (team #3, Operation #5 at 118 ppm versus team #3, Operation #7 at 17 ppm;  $p < .05$ ).

### Personal Versus Real-Time Sampling Data--

Generally, average real-time sampling N<sub>2</sub>O concentrations (89 ppm) were more closely correlated with the oral surgeon's personal sampling results (101 ppm) than with the surgical assistant's results (27 ppm). However, the range of exposure for the personal sampling results was greater (<1 to 277 ppm) compared to the real-time results (11 to 173 ppm). There was no significant difference between the real-time and personal sampling results.

### Oral Surgeon and Surgical Assistant--

Statistical comparisons between the oral surgeon and the surgical assistant for seven paired samples for Operations #1, #2, #3, #6, #7, #8, and #9 showed the mean for the oral surgeon was 100 ( $\pm 118$ ), and 26 ( $\pm 31$ ) ppm for the surgical assistant. The median was 45 for the oral surgeon and 16 for the surgical assistant. The paired two-tailed T-test did not show significant differences between the two means ( $p = .142$ ). While the exposure of the oral surgeon tended to be higher in N<sub>2</sub>O concentration compared to the surgical assistant, there was a large variation between operations for the surgeon (<1 to 277 ppm); the variation for the surgical assistant was much lower, ranging from <1 to 77 ppm.

### Oral Surgeon and Real-Time--

The oral surgeon and real-time N<sub>2</sub>O concentrations for the seven paired samples were 89 ( $\pm 114$ ) and 94 ( $\pm 62$ ) ppm for real-time, respectively. The medians were 26 ppm for the oral surgeon and 98 ppm for the real-time measurements. The paired two-tailed T-test with 7 degrees of freedom did not show significant differences between the two means ( $p = .870$ ). The oral surgeon showed more variability between operations with a range of <1 to 277 ppm, compared to the real-time range from 11 to 173 ppm. The difference in results may be related to the closer proximity of the oral surgeon's breathing zone, to the patient's breathing zone compared to the real-time sampling probe placement. One oral surgeon showed higher N<sub>2</sub>O values (Operations #1 and #2), compared to the other surgeons. This surgeon's concentrations were an order of magnitude higher when compared to his surgical assistant (256  $\pm 29$  versus 18  $\pm 3$  ppm). As in the first study, the results consistently showed that real-time N<sub>2</sub>O results more closely reflected those of the oral surgeon than the assistant.



## Surgical Assistant and Real-Time--

The surgical assistant and real-time N<sub>2</sub>O concentrations for seven paired samples were 26 ( $\pm 31$ ) and 96 ( $\pm 110$ ), respectively. The median for the surgical assistant was 31 ppm and 67 ppm for the real-time measurements. The paired two-tailed T-test showed significant differences ( $p=.034$ ) between the mean concentrations for the surgical assistant and the real-time sampling results. The surgical assistant showed less variability between operations with a range from <1 to 77 ppm, compared to the real-time range of 11 to 173 ppm.

## Summary of Work Practices and Changes in N<sub>2</sub>O

Analysis of variance was used to examine team differences overall for N<sub>2</sub>O concentration when the N<sub>2</sub>O was on, off, and for both periods combined during surgery. The results suggest that team differences, if any, were too small to be detected; statistical significance was  $p < 0.35$ . None of the pairwise differences among teams was large enough for statistical significance, even when each was treated as a planned comparison.

Analysis of differences among types of dental surgery was performed by analysis of variance, ignoring possible differences associated with dental teams. Differences associated with type of dental surgery were too small to be detected with these data; significance level was  $p < 0.5$ .

The mean N<sub>2</sub>O concentrations, as a function of oral surgery type, ranged from 17 ppm ( $\pm 74$  ppm), for tooth implantation (operation #7), to 110 ppm ( $\pm 74$  ppm), for removal of the mandibular canine tooth (operation #1). None of the pairwise differences among surgery types were large enough for statistical significance, even when each was treated as a planned comparison.

Analysis was performed to relate the N<sub>2</sub>O concentration as a function of N<sub>2</sub>O percentage administered and for changes in the N<sub>2</sub>O sampling probe distance during oral surgery. This analysis indicated that when N<sub>2</sub>O percentage administered increased, the waste N<sub>2</sub>O concentrations tended to increase. The slope of the regression for waste N<sub>2</sub>O was based on the concentration of N<sub>2</sub>O administered. Thus, when N<sub>2</sub>O was administered at 33 percent, the waste N<sub>2</sub>O concentration was estimated to be 81 ppm. This N<sub>2</sub>O concentration was based on the slope estimate, the intercept estimate, and a real-time sampling probe distance of 11 inches. Under these conditions, when the concentration of N<sub>2</sub>O was administered at 40 percent, the waste N<sub>2</sub>O concentration was estimated to be 95 ppm; at 50 percent administration, the waste concentration was estimated to be 109 ppm.

As the probe distance from the patient's mouth was increased, there was generally a decrease in waste N<sub>2</sub>O concentration. The slope of the regression of waste N<sub>2</sub>O concentrations, based on the distance from the patient's mouth and the probe used to measure waste N<sub>2</sub>O, was estimated to be -7 ppm ( $\pm 18$ ). Therefore, the concentration of waste N<sub>2</sub>O was estimated to decrease by approximately 7 ppm for every inch the sampling probe was moved away.

Statistical analysis was also performed to determine if there were significant differences in N<sub>2</sub>O concentrations between the two surgical suites. Analysis was performed when the gas was on, off, and overall. While the observed N<sub>2</sub>O concentrations were lower in Room D1222 (i.e.,  $34 \pm 41$  ppm for the gas on), versus Room D1218 (i.e.,  $105 \pm 21$  ppm for the gas on), the differences were not statistically significant.

### SURVEY #3: DENTAL CLINIC FOR THE DEVELOPMENTALLY DISABLED

N<sub>2</sub>O concentrations were monitored for 20 operations at this dental clinic. All operations were performed using the Porter-Brown Scavenging System. Six of the operations were monitored for N<sub>2</sub>O using only the scavenging system; the remaining operations were monitored using three different configurations of auxiliary exhaust ventilation in conjunction with the scavenging system.

#### Air Sampling

##### Personal--

The first seven dental procedures somewhat confounded the effectiveness of the scavenging and auxiliary exhaust ventilation controls due to procedural errors or leaks in the N<sub>2</sub>O delivery system. During the first procedure, the scavenging system was inadvertently not turned on until the last three minutes of the procedure. This resulted in the highest observed exposure (1,800 ppm for the dental hygienist). This procedure was not included in the data analysis. In addition, all the N<sub>2</sub>O delivery systems within the clinic were found to have leaks. A leak free N<sub>2</sub>O delivery system was not obtained and used until after the seventh procedure. While the amount of N<sub>2</sub>O leaking from each delivery system was not quantified, it was determined by the on-site researchers that the leaks found during procedures 2 through 6 were not significant enough to exclude data from analysis.

Table 9 is a summary of the N<sub>2</sub>O concentration measurements for the 20 operations monitored. Excluding the first operation, N<sub>2</sub>O concentrations for dental hygienists ranged from 4 to 205 ppm, with an average concentration of  $55 \pm 57$  ppm. For the dental assistants, the range was 1 to 163 ppm, with an average concentration of  $40 \pm 55$  ppm.

When the scavenging system was used without auxiliary ventilation, the dental hygienists' N<sub>2</sub>O concentrations ranged from 33 to 205 ppm, with an average  $80 \pm 70$  ppm. For the dental assistant the range was 16 to 147 ppm, with an average concentration of  $55 \pm 62$  ppm.

When the small hood was used (2.5" hood, 160 cfm flow rate, and a capture distance of 6 to 8") the dental hygienists' N<sub>2</sub>O concentration ranged from 48 to 146 ppm, (average of  $112 \pm 55$  ppm). For the dental assistants, the range was 46 to 121, with an average concentration of  $110 \pm 59$  ppm.

The second system (3.0" hood, 250 cfm flow rate, and 6 to 10" capture distance), showed that dental hygienist's N<sub>2</sub>O concentration ranged from 2 to 48 ppm, with an average concentration of  $22 \pm 19$  ppm. The dental assistant's range was 2 to 65 ppm, with an average concentration of  $15 \pm 24$  ppm.

Table 9. Breathing zone, immediate area, and real-time, N<sub>2</sub>O concentration, based on auxiliary ventilation system used.

Observation No.	Duration (min)	N <sub>2</sub> O Concentration (ppm)				Vent system	N <sub>2</sub> O flow rate (lpm)	Other notes <sup>A</sup>
		Hygienist breathing zone	Assistant breathing zone	Area	Real-time integrated			
1	24	1809	89	440	727	0 <sup>1</sup>	3	a, b
2	24	146	46	123	255	1	3	b
3	26	55	---	117	129	0	2	b
4	25	142	163	106	125	1	4	b, c
5	29	48	121	47	52	1	2	b
6	30	205	147	357	380	0	3	b
7	24	42	65	102	111	2	5	b
8	25	13	9	9	14	2	3	c
9	16	3	5	4	5	2	3	
10	36	44	---	8	9	2	3	
11	22	61	16	119	146	0	4-3	c, d
12	26	47	24	142	129	0	2	
13	26	7	8	7	14	2	4-5	c, d
14	12	33	31	190	148	0	4	
15	23	18	---	6	---	2	3	
16	25	48	3	9	---	2	4	
17	27	2	2	---	---	2	3	
18	24	14	1	3	---	3	3	
19	24	118	2	6	---	3	3	
20	23	4	2	3	---	3	3	

--- Not measured. 1. system 0 (i.e., no auxiliary exhaust system) <sup>A</sup> a, Scavenger was off during procedure; b, leak detected in N<sub>2</sub>O delivery system; c, patient was not compliant; d, N<sub>2</sub>O adjusted during procedure.

For system 3 (6.0" hood, 630 cfm flow rate, and 12" capture distance), the N<sub>2</sub>O concentration for the dental hygienists ranged from 4 to 118 ppm, with an

average of  $45 \pm 63$  ppm. For the dental assistants, the range was 1 to 2 ppm, with an average of  $2 \pm 0.6$  ppm.

#### Real-Time--

When the real-time  $N_2O$  concentrations were mathematically integrated over the duration that  $N_2O$  was in use, they were not significantly different from the TWA background samples collected in the same location.

Excluding the first operation, overall  $N_2O$  concentrations for the immediate area sampling ranged from 5 to 380 ppm, with an average concentration of  $117 \pm 108$  ppm. When the results were analyzed for the scavenging system with auxiliary ventilation, the  $N_2O$  concentrations ranged from 129 to 380 ppm, with an average of  $186 \pm 109$  ppm.

When the auxiliary exhaust systems were used in conjunction with the scavenging systems, the first system reduced  $N_2O$  concentrations, which ranged from 52 to 255 ppm, with an average of  $144 \pm 103$  ppm. The second system reduced  $N_2O$  concentrations and ranged from 5 to 111 ppm, with an average concentration of  $31 \pm 45$  ppm. No real-time data were collected for the third auxiliary exhaust system.

The overall area results were higher than the personal sampling results because the sampling probe was located more in-line with the patient's mouth. The average concentration for the 18 procedures was  $75 (\pm 93)$  ppm. The average concentration without auxiliary exhaust was  $185 (\pm 101)$ . When auxiliary exhaust ventilation systems were used, the immediate area results were  $92 (\pm 40)$  ppm for the first system,  $21 (\pm 36)$  ppm for the second system, and  $4 (\pm 2)$  ppm for the third system.

#### Ventilation

##### General--

Seven registers supplied a total of 1000 cfm of air to the dental clinic, which had a volume of approximately 12,800 cubic feet. Variations in  $N_2O$  concentration have been shown, with higher concentrations closer to the  $N_2O$  delivery system. Even in operating theaters with high general dilution ventilation capacity, the effect of dilution ventilation on occupational exposure was limited.<sup>16</sup>

##### Scavenging System (Auxiliary) Exhaust--

Table 10 lists hood diameters, sound pressure levels, airflow rates, hood capture distance range from each patient's mouth, and calculated capture velocities for each system. The local exhaust capture velocity was calculated from the following equation:<sup>100</sup>

$$V = \frac{Q}{(10X^2 + A)}$$

Equation (2)

where: V - The capture velocity in feet per minute.  
 Q - The airflow rate in cubic feet per minute.  
 X - The distance in feet, from the hood to the point of capture.  
 A - The hood opening area in square feet.

Table 10. Local exhaust system measurements.

System No.	Vent Hood Diameter (in)	Noise Level (dBA)	Flow Rate Q (cfm)	Capture Distance Range X (in.)	Capture Velocity V (fpm)
0	No Hood	56	NA	NA	NA
1	2.5	--	160	6-8	64-36
2	3.0	67	250	6-10	96-35
3	6.0	81	630	12	62
NA Not applicable				-- Not measured	

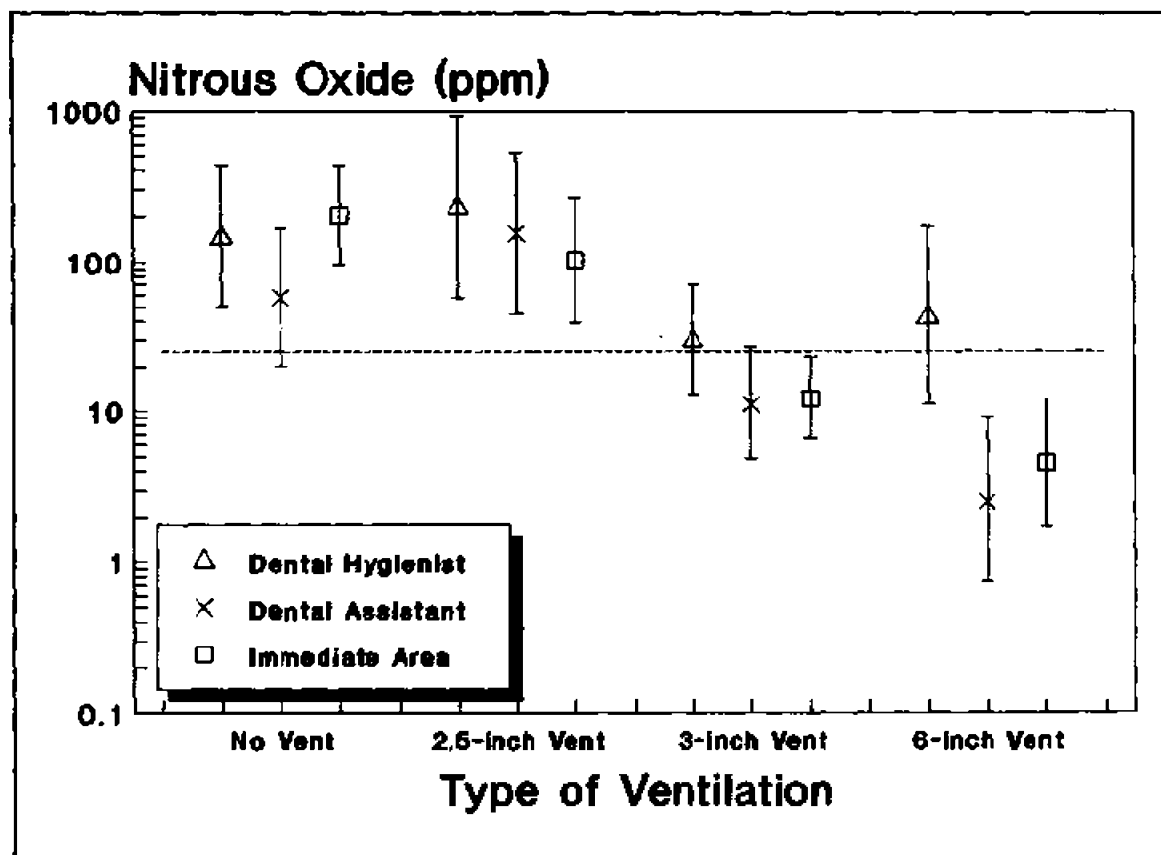
Although nitrous oxide flow rate and patient compliance may have an effect on N<sub>2</sub>O exposure, they had no significant effect on breathing zone or immediate work area N<sub>2</sub>O concentrations for the data reported in this study. Nitrous oxide was below the detectable limit for all of the general area samples collected just outside the operatory.

#### Performance of Auxiliary System Type--

Because the variances about the mean N<sub>2</sub>O concentrations were not homogeneous and increased with the mean, the N<sub>2</sub>O concentration values were log transformed before the comparisons among systems were made. Mean values were calculated using all the data except procedure one. Means and upper and lower 95 percent confidence limits are presented in Figure 19.

With system 0, observed exposure results were within the range observed by other researchers who used similar controls.<sup>91</sup> System 1 results were not significantly different from system 0 results. The analysis showed with 95 percent confidence that the dental hygienist's and dental assistant's N<sub>2</sub>O exposures and the immediate area N<sub>2</sub>O concentrations were greater than the NIOSH REL for these systems.

Figure 19. Summary of N<sub>2</sub>O exposure and immediate area concentration data when using three different auxiliary exhaust systems.



The dental assistant's exposures and the concentration of N<sub>2</sub>O in the immediate area were less than the NIOSH REL when using systems 2 or 3. The upper 95 percent confidence limit of the exposure (9 ppm) when using system 3 was less than the NIOSH REL. For system 2, the upper 95 percent confidence limit (27 ppm) was just above the NIOSH REL. Compared to the exposures without a local exhaust system, the assistant's exposures were significantly reduced when using either system 2 ( $p=0.05$ ) or 3 ( $p=0.001$ ).

System 2 was capable of controlling the exposures of the dental hygienist to concentrations below 60 ppm, based on the upper 95 percent confidence limit. System 3 was capable of controlling the exposures of the dental hygienist to below 135 ppm.

For the dental hygienist, the upper 95 percent confidence limits of the exposures when using exhaust systems 2 (70 ppm) and 3 (170 ppm) were greater than the NIOSH REL. Compared to the exposure without a local exhaust system, the hygienist's exposures were reduced when using systems 2 ( $p=0.07$ ) or 3 ( $p=0.160$ ), but not significantly ( $\alpha=0.05$ ). It is important to note that one dental procedure (procedure 19, 118 ppm) contributed substantially to the

hygienist's mean exposure when using system 3 and was well above the other values, 4 and 14 ppm.

When the analysis was done using only data collected after the N<sub>2</sub>O leaks in the delivery system were corrected, the following changes were obtained: (1) the dental assistant's upper 95 percent confidence limit of the exposures was less than the NIOSH REL for both system 2 (9.2 ppm) and 3 (3.3 ppm); and (2) compared to the exposures without local exhaust, the assistant's exposures were significantly reduced for both system 2 (p=0.0031) and 3 (p=0.002).

#### Work Practices and Changes in N<sub>2</sub>O Exposure

The real-time data allowed qualitative correlation between several work practices and changes in N<sub>2</sub>O concentration: (1) a marked reduction in N<sub>2</sub>O was observed when the scavenging system was turned on for the last three minutes of the first procedure; (2) the initial peak concentration of over 400 ppm during the first three minutes of procedure 7 quickly subsided when the exhaust system 2 was moved into its proper position, from 24 inches away to six to ten inches from each patient's mouth (for all other observations, each exhaust system was properly located prior to N<sub>2</sub>O delivery); and (3) the N<sub>2</sub>O concentration rapidly changed when the N<sub>2</sub>O was turned on or off for most of the procedures. In Figure 20, the real-time N<sub>2</sub>O concentration for observation 7 is plotted as a function of time. The real-time N<sub>2</sub>O concentration data were averaged at 30-second intervals and plotted.

#### SURVEY #4: PEDIATRIC DENTAL FACILITY

##### Air Sampling

The cooperative operatory was located in the pediatric ward of a teaching hospital. The patients ranged in age from 8 to 17 years. The unmodified masks were used to administer N<sub>2</sub>O. N<sub>2</sub>O concentration measurements made in the operatory were carried out in October and November of 1992, and were intended to demonstrate the effectiveness and acceptability of two new controls designed primarily to capture emissions from the patient's mouth. The first, an auxiliary exhaust (Figure 21), rested on the patient's chest. It was connected to a blower with flexible and rigid sections of vacuum cleaner hose and pipe. The blower was exhausted outside the building in which the operatory was located. The exhaust flow was 100 cfm. The air velocity in the operatory measured at the dentist's breathing zone with an air velocity meter ranged from 25 to 40 fpm. It is apparent from Figure 22, which shows the concentration of N<sub>2</sub>O in the dentist's breathing zone versus time for one operation, that the auxiliary exhaust was not effective in controlling the dentist's exposure while the high-speed drill was on. In the time interval from approximately 1400 to 3000 seconds, with the drill off, it appears that the auxiliary exhaust did have a significant effect on the dentist's exposure. The auxiliary exhaust normally was placed on the patient's chest so that the inlet to the tubing was 3 to 6 inches from the patient's chin. In this location, it occasionally interfered with the dentist's technique and was, therefore, lowered for sufficient access to the patient, but also was judged by several dentists not to be a significant interference problem.

Figure 20. Real-time  $N_2O$  concentration changes from auxiliary exhaust ventilation for Survey #3.

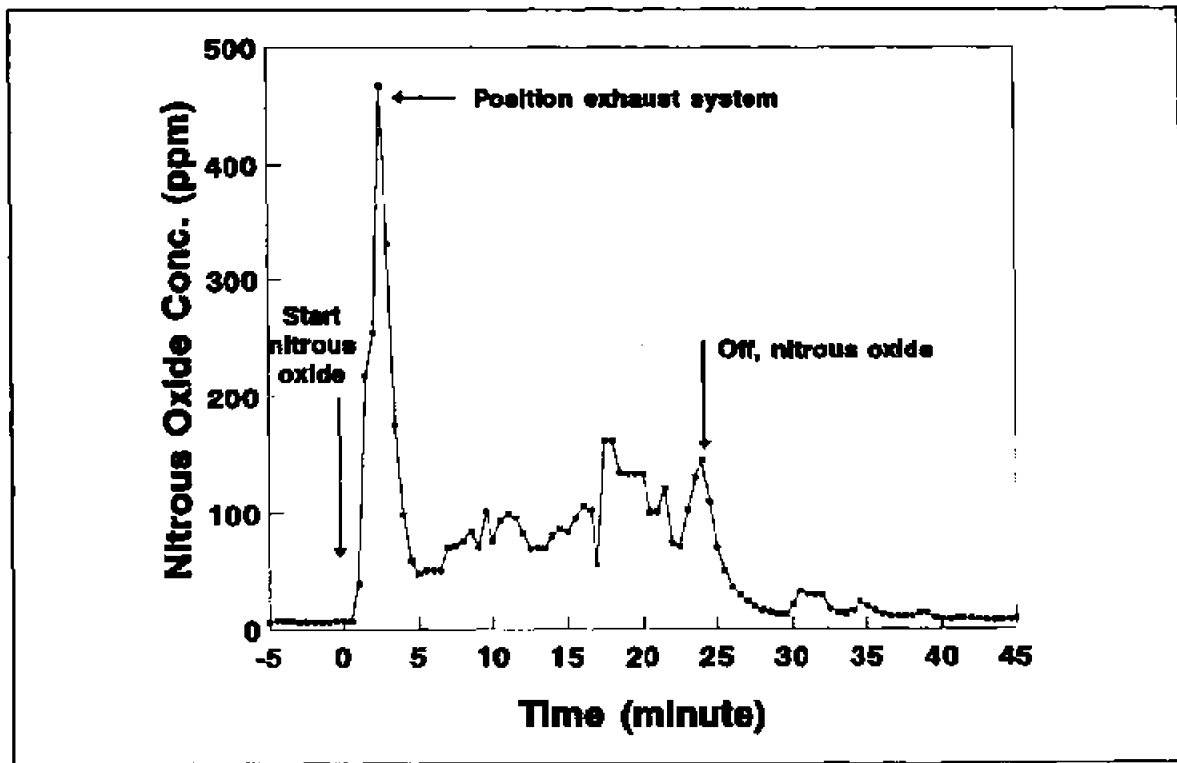
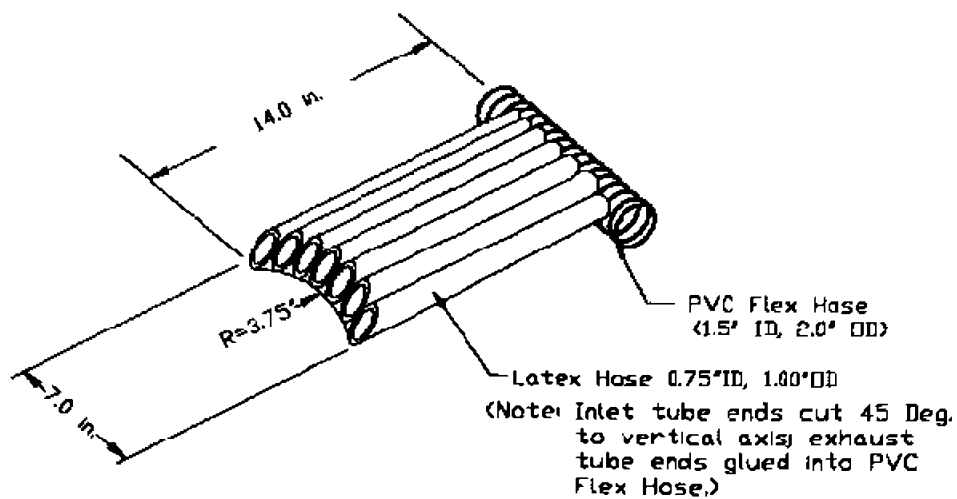


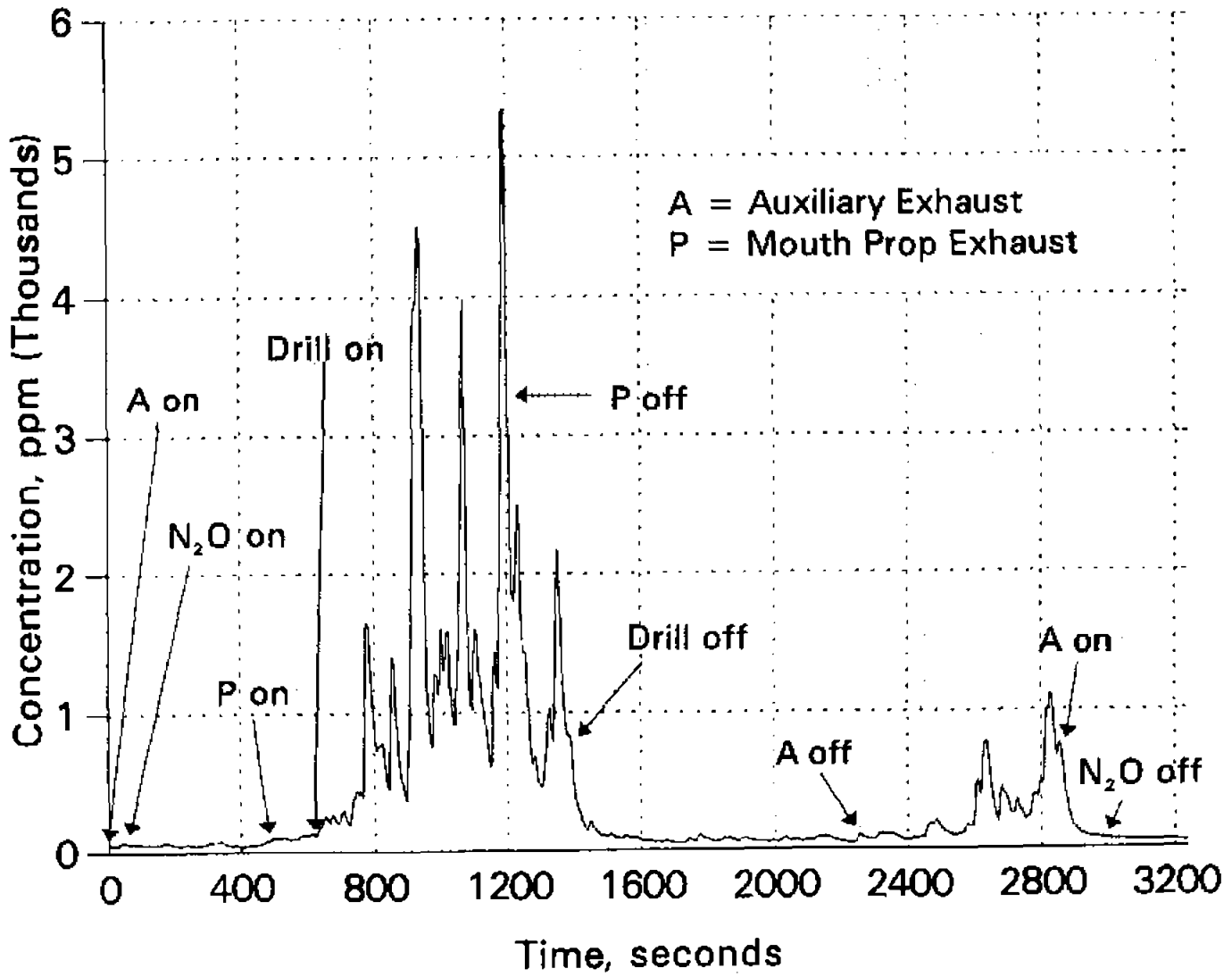
Figure 21. Diagram of laboratory designed auxiliary exhaust used in Survey #4.



## Auxiliary Exhaust



Figure 22. N<sub>2</sub>O concentration versus time in the dentist's breathing zone with various combinations of the auxiliary and mouth-prop exhausts in place.



The second control tested in the operator was based upon a modification of a mouth-prop commonly used in dental operations (Figure 23). The modification involved cutting off the two portions of the mouth-prop normally located in the patient's mouth and welding in their place two pieces of 1/4-inch diameter stainless steel tubing, bent to the shape of the removed pieces and connected outside the mouth by plastic tubing to a vacuum source. The total airflow rate through the mouth-prop control was 80 lpm. In this manner, mouth emissions could be captured at their source. Again, as seen in Figure 10, the operation of the mouth-prop exhaust was ineffective in controlling the dentist's exposure during high-speed drilling.

The high-speed drill (Midwest Model 8000™, Gendex Midwest, Des Plaines, Illinois) used in this operation was driven by an air turbine. It consumed 24±1 lpm of air, as measured in a free-running state in situ with a bubble meter. The drill had a supply port for the compressed air and an exhaust port for the air exiting the turbine. However, a jet of air escaped from both ends of the bearing in the drill head, apparently an unavoidable feature of the drill design.

A series of eight operations was observed in the dental operator, using different combinations of the mouth-prop and chest-mounted controls. Average exposure data for the dentist and the assistant are given in Figure 24 for these operations. Although two operations showed control of the dentist's exposure to below or near the NIOSH REL, there was very little correlation between the activity of the control and the resulting exposure concentrations. Turning a control on or off during an operation generally produced no observable change in exposure concentrations, as shown in Figure 22.

The scavenging flow rate of the masks was measured in the operator for each of the flow controllers. Originally, seven of the eight controllers, when set as directed by the manufacturer, actually produced a scavenging flow rate below the recommended minimum of 40 lpm. When informed of the problem, the manufacturer replaced all eight of the original units, which also flowed less than 40 lpm. A third set of flow controllers supplied by the manufacturer all flowed at least 40 lpm, with an average of 41.3 lpm. N<sub>2</sub>O exposure data reported here were obtained with the original set of flow controllers in operation. However, several subsequent measurements of N<sub>2</sub>O exposure concentrations showed no noticeable improvement in exposures when the scavenging flow rates were set to 40 to 45 lpm.

## Ventilation -- Laboratory Experimentation

### Scavenging System (Auxiliary) Exhaust--

Observations of the mouth-prop and the auxiliary exhaust leakage were made using the apparatus of Figure 10. Ambient air velocity in the vicinity of the head form ranged from 30 to 50 fpm as measured with an air velocity meter. Little or no smoke was observed escaping when these controls were in place and while the head form was simulating mouth breathing. When the operator data indicated that these controls were ineffective in controlling N<sub>2</sub>O exposures, leakage from the masks was suspected and tested using the apparatus of Figure 11. Results are shown in Figure 14. The mask as supplied by the manufacturer

Figure 23. Mouth-prop exhaust.

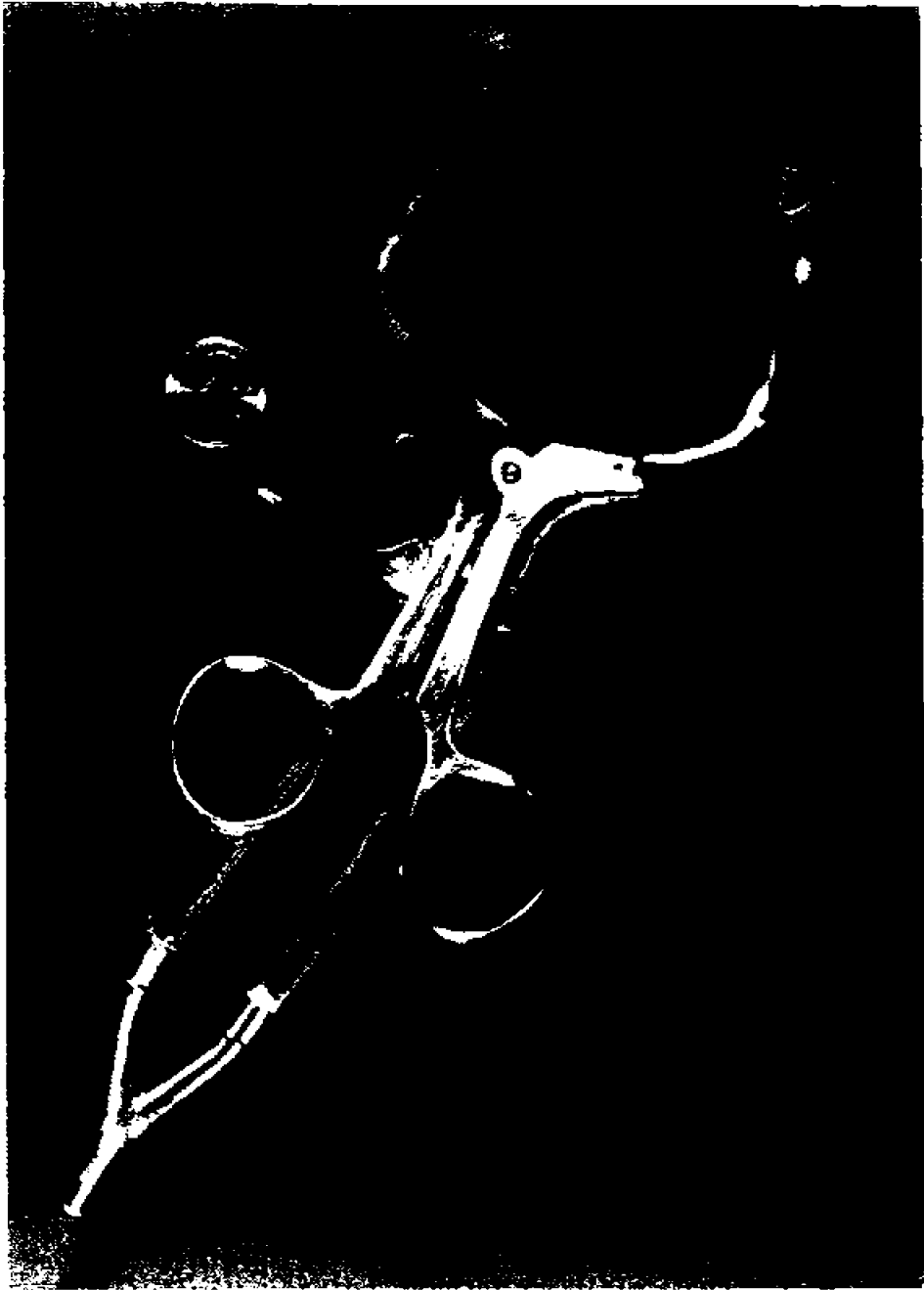
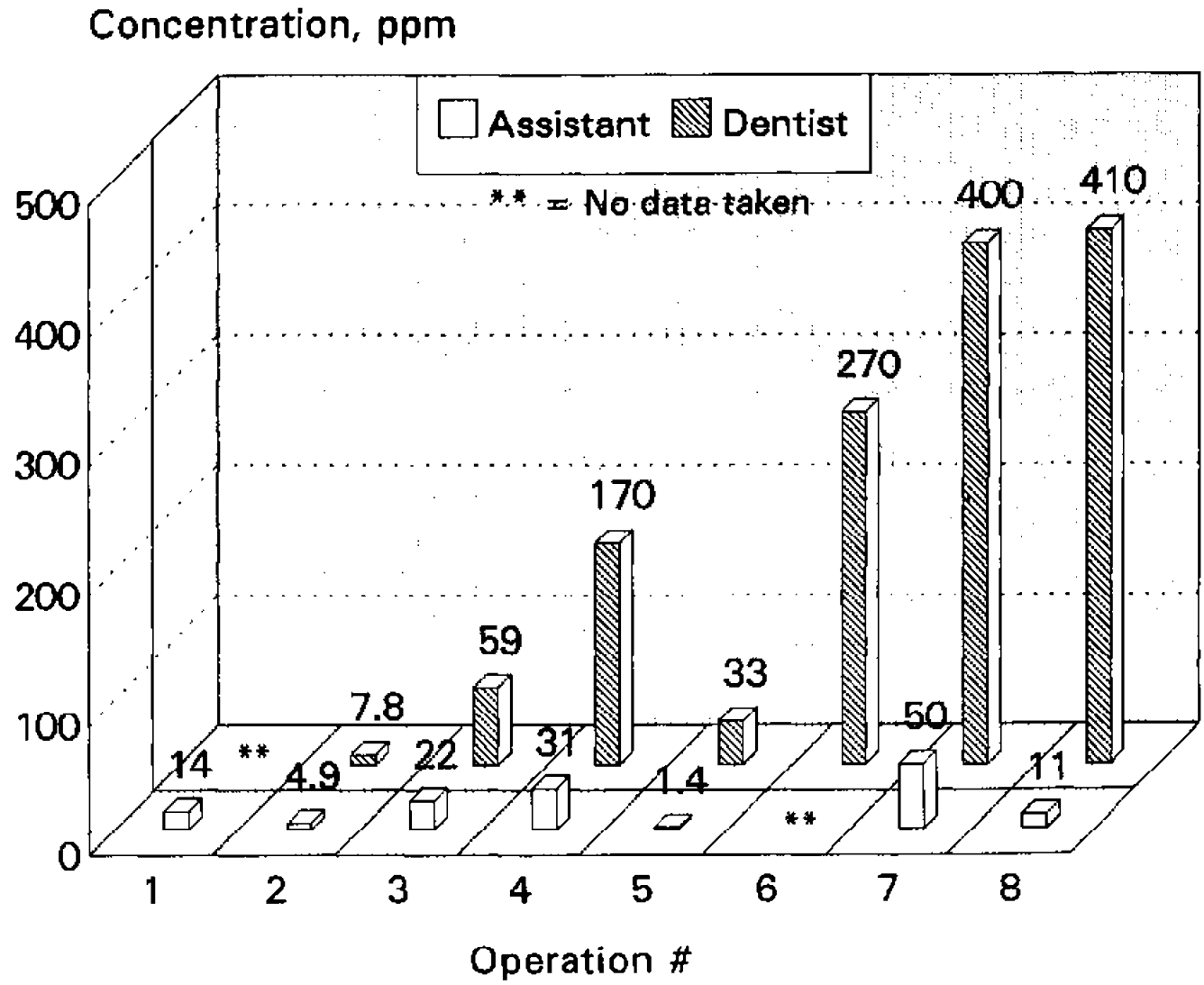


Figure 24. Dentist's and assistant's breathing zone concentrations of N<sub>2</sub>O averaged over the procedure.



(Porter-Brown) typically leaked considerably when placed on the head form with average care. Observations of the leakage with the IR imaging system showed that during exhalation, a jet of gas escaped from gaps between the mask and the head form. When the breathing machine was not operating, the mask did not leak. By increasing the scavenging flow rate, the leakage was reduced, but not eliminated (Figure 12). In Figure 13, the relative concentration of the anesthetic gas in the mask is shown for various scavenging flow rates. The fit of the masks was improved and the leakage reduced by exerting more pressure on the mask, which forced it into firmer contact with the head form (see Figure 14). A good-fitting, low-leakage mask resulted in an active breathing bag, whereas a poor-fitting mask resulted in a largely passive breathing bag. Also, an improvement to the standard Porter-Brown mask was made by adding a flexible skirt with slits in it to the outer shell of the mask (Figure 15). The leakage rate of the mask with the added skirt was low and did not depend upon the quality of fit to the head form (data shown in Figure 16). Finally, leakage measurements were made using the Medicvent mask, which includes a chin-mounted exhaust as a supplementary control for N<sub>2</sub>O emissions. Leakage data obtained with this and other combinations of controls are shown in Figures 14, 16, and 17. The scavenging flow rate for the Medicvent mask was 250 lpm. Its supplementary chin exhaust also flowed at 250 lpm.

## DISCUSSION

Analgesia machines for dentistry are designed to deliver up to 70 percent (700,000 ppm) N<sub>2</sub>O to a patient during dental surgery. The machine restricts higher concentrations of N<sub>2</sub>O from being administered to protect the patient from hypoxia. In most cases, patients receive between 30 to 50 percent N<sub>2</sub>O during surgery. The amount of time N<sub>2</sub>O is administered to the patient depends on the dentist's judgment of patient needs and the complexity of the surgery. The most common route of N<sub>2</sub>O delivery and exhaust is through a nasal scavenging mask attached to the patient. While performing dental surgery, a dentist's breathing zone is within 8 to 15 inches of the patient's mouth. Even when there is room ventilation, the anesthesia equipment is in good repair, and dental personnel know how to operate the scavenging equipment properly, N<sub>2</sub>O concentrations for the dentists can range from less than 25 ppm to well over 1000 ppm. As these studies have shown, the difference in exposure depends on the concentration of N<sub>2</sub>O administered to the patient, the length of time N<sub>2</sub>O is administered, the working distance of the dentist to the patient, the scavenging system exhaust rate, the fit of the mask on the patient, patient compliance, patient mouth breathing, and auxiliary local exhaust rate and hood location. Limiting N<sub>2</sub>O concentrations, as well as the length of time N<sub>2</sub>O is administered to the patient, is a prudent work practice the dentist can use to control exposure. However, the most reliable and effective method is through engineering controls.

One of the most effective and efficient means of controlling N<sub>2</sub>O concentration is by operating a scavenging system at the proper exhaust rate. A scavenging system exhaust rate of approximately 45 lpm has been recommended as the optimum rate to keep N<sub>2</sub>O concentrations low. Exhaust rates greater than 45 lpm have not been shown to significantly reduce N<sub>2</sub>O concentrations. In

addition, the increased air flowing through the mask causes higher noise levels and is distracting to the dentist. Conversely, exhaust rates substantially less than 45 lpm result in higher N<sub>2</sub>O concentrations to dental personnel (Figure 4). Data analyzed by NIOSH researchers from 300 dental operatories located in the state of Wisconsin confirm these principles.

#### SCAVENGING SYSTEM CONTROLS

When scavenging system controls were used, NIOSH researchers found that personal N<sub>2</sub>O exposures for primary operators (i.e., dentists, oral surgeons, and dental hygienists, respectively) exceeded the NIOSH REL in 100 percent of all operations on the first survey, in 50 percent on the second survey, and in 30 percent on the third survey. Over the three surveys, it was determined that scavenging systems, when properly used and maintained, can effectively reduce and control N<sub>2</sub>O in a dental work environment. Each survey provided information about the performance of existing N<sub>2</sub>O controls, and ways additional controls could further reduce exposure. The findings of this research confirm many of the recommendations presented in the NIOSH Technical Report entitled "Control of Occupational Exposure to N<sub>2</sub>O in the Dental Operatory" (page 37).<sup>15</sup> In this report, the control measures included the following: using nasal scavenging equipment, venting waste N<sub>2</sub>O outside the building, minimizing conversation with the patient, testing the anesthesia equipment for leakage, performing preventive maintenance, employing air sweep fans when N<sub>2</sub>O concentrations are not achieved by the above measures, having an N<sub>2</sub>O air monitoring program, selecting analgesia and scavenging equipment, and obtaining documentation from equipment suppliers on patient safety and ways to effectively minimize N<sub>2</sub>O exposure among dental personnel.<sup>15</sup>

An important element missing from this list is the need for proper ventilation and flow rate monitoring. Although the effectiveness of reducing N<sub>2</sub>O when the scavenging system ventilation rate is set to approximately 45 lpm is mentioned elsewhere in the report, it was not presented in the recommendations section. The omission of the proper scavenging flow rate monitoring devices undermined the effectiveness of the scavenging systems when in use.

The three surveys performed by NIOSH researchers confirmed that many of these recommendations, correctly implemented, effectively reduce N<sub>2</sub>O exposure. Training dental personnel to operate and maintain the N<sub>2</sub>O delivery and scavenging equipment maximizes the effectiveness of other controls. When a system is not properly maintained, other controls are less effective. In each survey, dental personnel indicated to NIOSH researchers that they did not fully understand the operation and limitations of the scavenging system because instructions were lacking. The instructions had been passed to them by "word-of-mouth," or, in some cases, the manufacturer's instructions were lost or had been discarded or were not easy to understand. Education, training, and maintenance issues were problematic in all three surveys.

#### SURVEY #1: PEDIATRIC DENTAL FACILITY

All ten operations exceeded the NIOSH REL for the dentists and the dental assistants. The major source of N<sub>2</sub>O exposure was caused by inadequate scavenging system ventilation. The principal reasons for the poor scavenging

system ventilation were the following: (1) the lack of knowledge among dental personnel at this facility about the importance of proper exhaust rates; (2) the absence of a flowmeter to indicate scavenging exhaust rates; and (3) the excessive noise generated from air rushing through the scavenging mask when operated above approximately 15 lpm.

#### Performance of Fraser-Harlake Scavenging System

NIOSH researchers discovered that the exhaust valve setting, subjectively adjusted to approximately 7 to 12 lpm by the dental assistant prior to surgery, remained at this rate until the dentist turned the N<sub>2</sub>O off. The exhaust valve is attached to a corrugated breathing hose approximately 4 feet from the scavenging mask. The dental assistant adjusted this valve by listening for the "hissing" noise created by the exhaust air flowing through the plastic dome of the scavenging nasal inhaler. As the vacuum rate was increased, more air flowed through the restricted opening in the plastic dome causing the noise level to increase. The design of the mask exacerbated the loudness of the noise; therefore, the dental assistant decreased the scavenging exhaust rate to reduce the noise level to a minimum.

#### Control of Airborne Exposures

##### Personal--

N<sub>2</sub>O concentrations exceeded the NIOSH REL for all dentists and real-time samples taken during the survey. Dentists had slightly higher exposures on average compared to the real-time sampling location (487 versus 442). The difference was not significant. The higher exposure for the dentists may be from their closer working proximity to the patient's breathing zone compared to the location of the real-time probe. The average exposure for dental assistants was 150 ppm. The difference between the average exposure for the dentists and dental assistants was significant ( $p < .05$ ). The higher exposures for the dentists are again attributed to the closer working distance to the patient's scavenging mask and mouth (8 to 15 inches) as compared to the working distance of the dental assistants (15 to 30 inches).

##### General Area--

General area N<sub>2</sub>O concentrations were approximately an order of magnitude lower than the personal sampling results (i.e., < 40 ppm). Results showed that low concentrations of N<sub>2</sub>O were present in dental operating rooms prior to the start of surgery in nine of ten operations monitored by NIOSH researchers. This initial concentration was a result of residual N<sub>2</sub>O from dental operations which preceded the NIOSH monitored operation and poor general dilution ventilation. Overall, open and semi-open room architecture had lower average N<sub>2</sub>O concentrations (17 ppm) than closed room concentrations (60 ppm). The reason for this difference may be due to dilution of the N<sub>2</sub>O in the larger, open rooms and by random air currents caused by dental personnel walking in the hallways adjacent to the operatories. The closed room showed no recirculation of N<sub>2</sub>O through the general air ventilation system. In addition, no N<sub>2</sub>O was found at the appointment desk area.

## Work Practices

There were several work practice elements that were evaluated for changes in  $N_2O$  concentrations including local anesthetic injection, instrumentation or extraction of teeth, restoration of teeth, the use of an air aspirator, air and water syringes, and the use of rubber dams. However, because of the low scavenging exhaust rates observed during dental surgery, the specific aspects of work practices on changing  $N_2O$  concentrations were not significant for the operations monitored.

Further analysis showed that the most important predictive elements for  $N_2O$  concentration and changes in  $N_2O$  concentration occurred when the dentist turned  $N_2O$  on, when the dentist adjusted the  $N_2O$  concentration during surgery, and when  $N_2O$  was turned off.

## Mask Leakage and Patient Activities

The infrared scanner was used to determine  $N_2O$  leakage from the patient's mask and exposures originating from mouth breathing. Toward the end of the first survey, NIOSH researchers synchronized the changes in  $N_2O$  concentrations from the videotaped real-time data with infrared scanning of  $N_2O$  during patient surgery. This technique showed when there was a mask leak or when the patient was mouth breathing. Also, producing a videotape with an overlay of the infrared thermography provided a training tool for dental personnel to visualize high exposure areas to be avoided.

## Ventilation

General ventilation measurements were taken in a closed room, semi-open bay, and open dental bay. The highest exposure to  $N_2O$  occurred in the closed room. This room was supplied with air from the building ventilation system. The size of this room was relatively small, about 900 cubic feet. Measurements showed 120 cfm supply air to this room, providing eight air changes per hour. The operatories in the larger open areas had single unit wall-mounted air conditioners, but were without dedicated supply ventilation. These open areas had lower exposures. Since the closed room had the highest  $N_2O$  concentrations, it might have been that the release of  $N_2O$  overwhelmed the general ventilation system. Because of the relatively high  $N_2O$  concentrations, purging this room with low velocity convection currents was not adequate. Dilution ventilation and air mixing of polluted air can have immediate benefits in many situations; however, it is not an effective method of control since it can transport the anesthetic gas to other areas.

## SURVEY #2: ORAL SURGICAL CLINIC

### Performance of Porter-Brown Scavenging System

Overall, the waste  $N_2O$  concentrations were low compared to the first survey because of controlled administration of  $N_2O$  to the patient, regulated and monitored exhaust of waste  $N_2O$  through the scavenging system, good work practices of the surgical team, and generally good maintenance of the scavenging system. The only uncontrolled sources of exposure were mouth



breathing by the patient, the occasional misalignment of the nasal mask when the patient's head was moved during the surgical procedure, and/or an occasional ill-fitting nasal cone. Poor room ventilation with regard to general air mixing was noted during the survey. The infrared camera provided additional confirmation of poor room air mixing. This was visually documented as the patients exhaled  $N_2O$ , which tended to linger in the breathing zone of the oral surgeons and surgical assistant.

#### Control of Airborne Exposures

##### Personal--

$N_2O$  concentrations exceeded the NIOSH REL of 25 ppm during administration in four of the nine operations by oral surgeons and in two of the nine operations for the surgical assistants. Oral surgeons had an average of three times higher  $N_2O$  exposure (101 ppm) than surgical assistants (27 ppm). As in the first survey, this might have been attributed to the closer working proximity of the oral surgeon to the patient's breathing zone.

General ventilation also appeared to be a factor as the random local air currents in both surgical suites slowly dissipated the waste gas from the patient's breathing zones. Overall, the personal exposures were higher for the surgical staff working closest to the patient's breathing zone. However, there were exceptions. For example, during three of the operations (Operations #3, #8, and #9), the evaluated oral surgeon was left-handed and worked on the patient's left side. His exposures were generally lower ( $17 \pm 24$  ppm) than the surgical assistant's, who worked on the patient's right side ( $24 \pm 35$  ppm). Initially, it was believed that air currents from the ceiling supply ventilation may have channeled the air from the patient's left to right side, thus, exposing the surgical staff on the right side to more  $N_2O$  than the one on the left. However, detailed analysis of the infrared videotapes showed that this surgeon tended to work in a more erect posture over the patient's mid-torso rather than above the patient's mouth. This difference in location and posture appears to have caused lower  $N_2O$  exposures for the surgeon than the surgical assistant, whose head was over the patient and closer to the patient's breathing zone.

##### General Area--

Fifty-four TWA general area bag samples were collected. The majority of these samples showed no detectable concentrations of  $N_2O$ , and the remainder showed concentrations close to or below 25 ppm. The initial  $N_2O$  concentration in the rooms showed no concentrations in eight of nine surgeries monitored. There was no  $N_2O$  detected in the surgical suite supply air, which indicated that  $N_2O$  was being neither entrained into the building's supply ventilation nor diluted by recirculation of this air to concentrations below detectable limits. The  $N_2O$  concentrations were low at the door of each suite ranging from 0 to 8 ppm, suggesting that the rooms were not under positive pressure. No detectable concentrations of  $N_2O$  were found in the hallway or at the appointment desk, indicating that the  $N_2O$  was not migrating from the operating suites or being ventilated into the hallway from other sources.

It appears that based on the general area sampling, N<sub>2</sub>O did not readily diffuse into the air and that pockets of N<sub>2</sub>O could slowly migrate within the surgical suite, depending upon the direction of ventilation and random air currents generated by the movement of personnel in the suite.

### Work Practices

The specific effects of work practices on changing N<sub>2</sub>O 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 the time (in minutes) of oral surgery, concentration of N<sub>2</sub>O administered to the patient, changes in the concentration administered to the patient, use of surgical tools, movement of the sampling probe during surgery, and type of surgical operations (such as tooth drilling and tooth removal). Other aspects of the surgery were also evaluated including patient talking, yawning, or mouth breathing.

As in the first survey, the predictive elements for changes in N<sub>2</sub>O concentration were the following: (1) when the oral surgeon turned the N<sub>2</sub>O on; (2) when the oral surgeon adjusted the N<sub>2</sub>O percentage during surgery; and, (3) when the oral surgeon turned the N<sub>2</sub>O off. Other predictors were patient talking and/or patient mouth breathing, which was observed on the infrared camera. All patients were instructed prior to surgery to breathe through the nose, not the mouth. During Operation #4, the infrared camera showed that the patient cooperated with the oral surgeon's request until he began to extract the patient's wisdom teeth. Until this point, very low concentrations of N<sub>2</sub>O were detected. However, when the surgeon started to extract the patient's teeth, the patient began to mouth breathe. Higher N<sub>2</sub>O concentrations were detected, not only by the infrared camera but also by the Miran 1A, and beginning to climb to peak exposures of over 300 ppm. The most interesting aspect of this operation was that the significant concentrations of N<sub>2</sub>O were detected only after the gas was turned off by the oral surgeon, and the patient having returned to normal breathing, become a secondary source of waste N<sub>2</sub>O to dental personnel. Even more interesting, the average N<sub>2</sub>O concentration during the time of administration was 11 ppm for the real-time sampling probe. However, after the N<sub>2</sub>O was turned off, the average concentration was 68 ppm. The time of administration was only 15.25 minutes, but the time of N<sub>2</sub>O detection lasted 55 minutes and exceeded 25 ppm for nearly 44 minutes. This information shows the importance of controlling patient mouth breathing as a secondary source of N<sub>2</sub>O exposure to dental personnel, and the importance of good general ventilation in the operation.

Statistical analysis of differences in N<sub>2</sub>O concentrations among the oral surgical teams, type of surgeries, and rooms did not show statistically significant differences. However, the range of N<sub>2</sub>O concentrations showed that there may have been differences between operations (i.e., the overall N<sub>2</sub>O concentration for Operation #3 was 136 ppm, whereas it was only 6 ppm for Operation #7). The reason statistically significant differences were not found may have been dependent on two factors: (1) the wide variance in N<sub>2</sub>O concentrations within and between operations; and (2) the relatively small number of operations evaluated for such differences. The variance in N<sub>2</sub>O concentrations was most likely caused by patient exhalation through the mouth.

Further analysis showed high N<sub>2</sub>O concentrations were caused by misdirection of patient mouth breath: (1) air currents from the room randomly directed N<sub>2</sub>O into the sampling probe; and (2) the patient's mouth was inadvertently aligned by the oral surgeon to the sampling probe so that the patient exhaled N<sub>2</sub>O directly into the probe. This alignment was dependent on the oral surgeon's movement and orientation of the patient's head while performing surgery.

Changes in N<sub>2</sub>O concentrations also were observed when N<sub>2</sub>O delivered to the patient varied from 30 to 50 percent. Statistical modeling showed that, as the concentration of N<sub>2</sub>O increased by 10 percent, there was a 14 ppm increase in waste N<sub>2</sub>O concentrations. This modeling also showed that the measurement of N<sub>2</sub>O concentrations were a function of the probe distance. For every inch the probe distance was increased from the patient's mouth, there was a decrease of 7 ppm in detected N<sub>2</sub>O. These changes did not appear to significantly influence overall N<sub>2</sub>O concentrations for the real-time monitoring.

#### Mask Leakage and Patient Activities

The infrared scanning camera proved to be a valuable tool in determining N<sub>2</sub>O leakage from the patient's mask and 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. The infrared camera was also useful in evaluating the direction and dispersion of N<sub>2</sub>O after it was exhaled by the patient. The surgical team member with the higher N<sub>2</sub>O exposure tended to be located closer to the patient's breathing zone. Typically, this was the oral surgeon. However, as reported previously, when the oral surgeon worked farther from the patient's breathing zone, the detected N<sub>2</sub>O exposures were lower, an important fact, because emission concentrations of N<sub>2</sub>O may not have been less than in other operations.

One of the observations made by using the infrared scanning camera was that N<sub>2</sub>O does not appear to disperse evenly when the patient breathes from the mouth. The camera showed that when N<sub>2</sub>O is emitted from the patient's mouth, it rises in a narrow plume. Depending on the work location of the surgeon and his assistant, they may get a direct blast of this gas in their breathing zones. In addition, it was also determined that exposure can be dependent upon random air currents of the room. Generally, the closer the oral surgeon is to the patient, the higher the exposure. The infrared scanner helped to explain some of the variations in the N<sub>2</sub>O real-time data and to tie in surgical work practices as a function of changes in N<sub>2</sub>O exposure.

The location of the sampling probe can be very important with regard to detecting waste N<sub>2</sub>O. If the probe is placed too far away from the patient's breathing zone, the readings may be lower and not represent personal exposure. If the probe is too close to the patient, it may get "spikes" of N<sub>2</sub>O from the patient and show peak exposures over 1000 ppm. Statistical analysis of N<sub>2</sub>O concentrations showed this to be the case; as the real-time sampling probe was moved farther from the patient, there was a tendency for the concentration to decrease.

Because of the potential variability in collecting real-time N<sub>2</sub>O samples, the usefulness of this technique is limited with regard to correlating surgical practices with exposure. If real-time sampling is conducted to correlate surgical practices with exposure, then the probe should be attached to the surgeon's lapel near his breathing zone.

## Ventilation

The scavenging mask air valve is adjusted to provide approximately 45 lpm by a member of the surgical team prior to beginning dental surgery. A flowmeter, which is connected to an exhaust port located on the wall of the dental operatory, is used to ascertain the proper flow rate. The flowmeter can be observed by a member of the surgical team at any time. The flowmeter used in this study was supplied as part of the scavenging system and has convenient markings to indicate the proper position for the flow ball to obtain an exhaust flow rate of approximately 45 lpm.

## Modification of Porter-Brown Scavenging System to Improve Effectiveness

Several observations were made by NIOSH researchers with regard to the design and performance of the Porter-Brown Scavenging System. It was recommended to the manufacturer that the mask could be physically streamlined to improve the fit to the patient's nose and to be less obtrusive to the dentist while working in the oral cavity. It was also recommended that the mask be made more pliable to reduce leakage around the nose. A further recommendation was to include a flowmeter as part of the N<sub>2</sub>O scavenging kit to assure proper exhaust velocity. The manufacturer of this equipment followed the recommendations, redesigned the mask, and developed a low cost flowmeter as part of the scavenging system. This mask has been commercially available since late 1991 and is reported to perform better than the original Porter-Brown Scavenging Mask.

## SURVEY #3: DENTAL CLINIC FOR THE DEVELOPMENTALLY DISABLED

### Performance of Porter-Brown Scavenging System with Local Exhaust

#### Personal--

As with the other surveys, leaks were detected in the N<sub>2</sub>O delivery system. However, the leaks were judged to be insignificant by the NIOSH research team because of several factors: (1) the concentration of nitrous oxide declined rapidly after each procedure; (2) there were no elevated concentrations of nitrous oxide at the start of any of the 20 procedures monitored; (3) the leaks could not be detected when the sampling probe of the leak detector (Miran 1B) was moved 12 inches from the leaking source; and, (4) there were not significant differences in any of the breathing zones or immediate area N<sub>2</sub>O concentrations for system 0 (i.e., no auxiliary exhaust system) before and after the N<sub>2</sub>O leaks were corrected. All leaks were fixed after procedure 7.

When no auxiliary ventilation was used in conjunction with the scavenging system, the observed exposure results were within the range observed in earlier surveys and by other researchers who used similar controls. System 1

results were not significantly different from system 0 results; the dental hygienist's and dental assistant's N<sub>2</sub>O exposures were greater than the NIOSH REL for system 1 (p < 0.05).

The analysis showed with 95 percent confidence that the dental assistant's exposures were less than the NIOSH REL when using systems 2 or 3. Although the average N<sub>2</sub>O concentration of the dental hygienist's samples was reduced when using either system 2 or 3, it was still greater than the NIOSH REL. System 2 was capable of controlling the exposures of the dental hygienist to concentrations below 60 ppm. System 3 was capable of controlling the exposures of the dental hygienist to below 135 ppm. During procedure 19, the hygienist inadvertently partially blocked the local exhaust hood and placed her breathing zone between the patient and the hood. Although this act may have caused of the high N<sub>2</sub>O exposure for this dental hygienist, it shows the importance of hood positioning so that the contaminated air is not drawn through the breathing zone of dental personnel. When procedure 19 is excluded from the analysis, the average exposure for dental hygienists was controlled to concentrations below 44 ppm.

#### Real-Time--

The real-time N<sub>2</sub>O concentrations were mathematically integrated over the duration that N<sub>2</sub>O was in use. The real-time data allowed qualitative correlation between several work practices and changes in N<sub>2</sub>O concentration: (1) a marked reduction in N<sub>2</sub>O was observed when the scavenging system was turned on for the last three minutes of the first procedure; (2) the initial peak concentration of over 400 ppm during the first three minutes of procedure 7 quickly subsided when the auxiliary exhaust system was moved into its proper position, i.e., adjusted from 24 inches to 6 to 10 inches from the patient's mouth (for each of the other observations, the exhaust systems were properly located prior to N<sub>2</sub>O delivery); and (3) the N<sub>2</sub>O concentration rapidly changed when the N<sub>2</sub>O was turned on or off for most of the procedures.

#### Ventilation -- Auxiliary Exhaust

Due to the layout of the clinic (a common hall with minimal partitions between chairs), considerable amounts of foot traffic generated air currents, which may have decreased the collection efficiency of the ventilation system. Results using the described systems might be more favorable in a smaller, closed architectural setting where foot traffic and subsequent air disturbance would be reduced. Such a dental clinic would be characterized as having "still" air currents, the range of 50-100 feet per minute (fpm) is an appropriate capture velocity.<sup>55</sup> In the surveyed clinical setting, with minimal partitions separating the chairs, the upper limit (100 fpm) of this range would have been more appropriate, but was not explored (e.g., "foot traffic" can generate velocities up to 300 fpm).

Hollonsten has shown that in operating theaters, a 3-inch hood, local exhaust system with a capacity of 100 cfm must be placed within 12 inches of the N<sub>2</sub>O generation source. His work also showed the same hood with a capacity of 30 cfm could effectively eliminate N<sub>2</sub>O if placed 6-inches from the source. A similar dental operatory study showed that an optimal capacity for an

auxiliary exhaust is about 120 cfm, is positioned 8-inches or less in front of the patient, and can control exposures to below 25 ppm.<sup>10</sup> In both of these studies, the noise of the exhaust systems were considered a nuisance.

The dental staff indicated that the local exhaust hood positioned over each patient's chest, from 6-8 inches above each patient's mouth (systems 1 and 6) to 10 inches directly above each patient's mouth (system 2) were impediments to performance. The local exhaust hood placement of 12 inches above and in front of each patient's mouth for system 3 was not as intrusive during the procedures. The dental staff indicated that the noise levels of systems 2 and 3 interfered with communications between the staff members and between the staff and the patients.

#### SURVEY #4: PEDIATRIC DENTAL FACILITY AND LABORATORY FINDINGS

As noted earlier, the high-speed drill produced two jets of air that escaped from the head of the drill. These air jets could entrain N<sub>2</sub>O emissions from the mouth or mask, carrying them into the operatory away from potential capture points and, possibly, directly into the breathing zone of dental personnel. It seems likely that elimination of these jets from the high-speed drills would reduce N<sub>2</sub>O emissions and consequent exposures to dental personnel.

Figures 14, 16, and 17, show that the addition of a chin exhaust to the unmodified mask and to the skirted mask resulted in an increase in the systems' leakage rates when the fit was loose, whereas the Medicvent mask always performed better when the chin exhaust was added. It appears that airflow associated with the chin exhaust pulled breathing gas out of the loose-fitting masks that had relatively low scavenging flow rates, allowing the ambient airflow to carry the gas away. The Medicvent mask, with a higher scavenging rate, was less affected by external airflows in its ability to retain breathing gas.

Figures 12 and 13 show that, although mask leakage could be reduced by increasing the scavenging flow rate, the concentration of the breathing gas (N<sub>2</sub>O) decreased if the rate at which breathing gas was supplied remained constant. Thus, to maintain a sufficient concentration of anesthetic gas in the patient's breathing zone, additional gas would have to be supplied as the scavenging rate increased.

In order to evaluate the measured mask leakage rates, consider the following: A constant exposure to a 25 ppm concentration of N<sub>2</sub>O over a typical procedure duration of 25 minutes would result in the same dose as exposure to a 50 percent concentration over 0.075 seconds. The minimum volume of the 50 percent mixture required for this exposure is 12.5 cm<sup>3</sup>, assuming the dentist breathes at a rate of 10 lpm. The minimum constant mask leakage rate that would supply this amount of the 50 percent mixture in 25 minutes is 0.5 cm<sup>3</sup>/min. The significance is that a very small mask leakage rate has the potential to cause an overexposure to N<sub>2</sub>O. However, it seems unlikely that such a minimum leakage by itself could actually cause an overexposure because of the necessity for the dentist's breathing zone to be located constantly at the leakage site. Nonetheless, the dentist frequently does work not only very

close to points at which breathing gas may escape into the environment, but also for extended periods. There is very little opportunity for the gas to mix with and be diluted by ambient air. Also, normally there is a significant ambient concentration of  $N_2O$  which contributes to the exposure. For these reasons, a maximum permissible "good fit" leakage rate of  $0.5 \text{ cm}^3/\text{min}$  may be a reasonable one. Finally, if the mask is accidentally or intentionally moved from a good-fitting position or if a poor fit results from lack of care or capability in original placement,  $12.5 \text{ cm}^3$  of breathing gas would be released in  $\frac{1}{4}$  second from a conventional mask, having a poor-fit leakage rate of  $3000 \text{ cm}^3/\text{min}$ . Occasional such releases of breathing gas would normally be very difficult to avoid with a conventional mask, especially with an uncooperative patient. Since over  $500 \text{ cm}^3$  are drawn in during a single inhalation, the release of  $12.5 \text{ cm}^3$  could easily lead to  $N_2O$  exposures in excess of the NIOSH REL.

The inlets to the personal sampling system for  $N_2O$  in the operatory were located on the dentist's and assistant's lapels, a typical location used by industrial hygienists. Because of the large spatial gradients in the concentration of  $N_2O$  in the breathing zone, this sampling location may not have given a good representation of the actual exposure of dental personnel. Inhaled concentrations may be considerably different than the concentrations at the lapel, either higher or lower. This potential shortcoming of the study was considered of secondary importance to eliminating mask leakage as a source of exposure and was not further investigated or corrected.

The most significant observation arising from this study is that even with scavenging, a commonly used mask does not reliably control  $N_2O$  emissions to current NIOSH recommendations, because of leakage between the mask and the patient's face. It is evident that simply increasing the scavenging flow rate to a reasonable degree does not eliminate mask emissions. It is possible that adding an elastic headband to the mask may improve its fit to the point of eliminating emissions, based upon laboratory observations. However, the need for the dentist to move the mask periodically affects the reliability of this approach. Also, a redesigned mask, incorporating a flexible slitted skirt on its outer shell, can considerably enhance capture of the gas leaking from the inner shell, regardless of the fit and with little or no further modification of the system, as has been shown in this study. The slits are necessary to prevent formation of a vacuum seal between the skirt and the patient's face, which would result in direct vacuum application to the patient's lungs. In addition, mouth breathing can be easily controlled by a chin-mounted exhaust, such as supplied with the Medivent system, or by a chest-mounted device, such as constructed and tested here. In the laboratory testing data presented here, the mask alone was sufficient to capture emissions occurring during mouth breathing. It may be, however, that even though mouth emissions do not escape into the environment when one of these controls is in place, the dentist could inhale the emissions moving from the patient's mouth to the exhaust inlet. In follow-up work, a mask with improved emissions control, such as the skirted mask tested here, should be constructed and evaluated in an operatory. A reliable evaluation would probably necessitate relocating the sampling inlet from the lapel of the dentist, at least, to a point within an inch or two of the nose.

## EDUCATION AND TRAINING IN USING DENTAL SCAVENGING EQUIPMENT

In discussions with dental personnel on all three surveys, it was determined that they knew very little about the selection, use, and maintenance of N<sub>2</sub>O scavenging equipment. NIOSH researchers observed that purchase and selection of scavenging systems depends to a large extent on the type of anesthesia equipment available and contacts with sales representatives. In addition, instructions on how to set up and operate the scavenging units appeared to be word-of-mouth, each dentist and dental assistant having their own style of using the scavenging equipment. For example, during the first survey, different dental assistants adjusted 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. The setup and operation of the scavenging system was the responsibility of the dental assistants, and unless something was obviously wrong, no further adjustments were made.

During the second survey the selection of the scavenging system exhaust rate was based on knowledge of superior performance at the recommended rate of 45 lpm, but, as in the first survey the dental support staff received very little education and training in the use and maintenance of scavenging equipment. Unfortunately, the manufacturer's instructions are usually discarded when the scavenging equipment is removed from its shipping material. NIOSH researchers observed that instructions on operating the Porter-Brown scavenging units were word-of-mouth; each oral surgeon and surgical assistant had their own style of using the scavenging equipment. Similar problems regarding use and maintenance of scavenging equipment were found on the third survey as well.

## MAINTENANCE OF ANESTHETIC DELIVERY AND SCAVENGING SYSTEM EQUIPMENT

During the first two surveys, NIOSH researchers performed a general inspection of the N<sub>2</sub>O anesthesia delivery and scavenging equipment to make sure no obvious problems were present, such as cracks, holes, or tears in the hoses, breathing bags, or scavenging masks. Generally, the N<sub>2</sub>O delivery machine equipment was in good repair, including no leakage from high to low pressure connections from the gas cylinders and connections to the anesthesia delivery system. However, occasionally, equipment, such as the breathing bag, the scavenging mask hoses, and the scavenging mask, were not as well maintained. In the first survey during one of the operations, it was discovered that a breathing bag was not connected to the anesthesia machine, and several of the scavenging system hose connections, including some new hoses, were not leak proof. In another instance the N<sub>2</sub>O supply and exhaust hoses connected to the scavenging mask had been reversed. Such occurrences result from poor scavenging mask design because the ports should be color coded or size indexed to prevent inappropriate connections.

During the second survey, NIOSH researchers observed that the N<sub>2</sub>O 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 surgical suites. It also was observed that replacement parts were available when needed. However, NIOSH researchers discovered a small tear in the breathing



bag that could result in leakage of  $N_2O$ . It was immediately replaced with a new one when the surgical team was informed.

The third survey was the most problematic, having poor equipment maintenance and  $N_2O$  leakage. Using a Miran 1B to test each of the gas delivery and scavenging systems, first day of sampling found that all  $N_2O/O_2$  delivery systems in the dental clinic leaked. A nonleaking anesthesia "head" was obtained on the second day of the study. Other sources of leaks found by researchers included cracks in the breathing bags, cracked and worn hoses, and loose retainer screws located on the  $N_2O$  control heads. When the equipment was replaced with new nonleaking equipment,  $N_2O$  concentrations were decreased.

## CONCLUSIONS

### SCAVENGING SYSTEM CONTROLS

Based on the findings of this research,  $N_2O$  exposures can potentially be controlled in dental operatories to the NIOSH REL of 25 ppm or lower during the time of administration when engineering controls, proper  $N_2O$  equipment maintenance, good work practices, and effective local, auxiliary, and general ventilation controls are used. When the scavenging system ventilation was operated at 7 to 12 lpm, personal  $N_2O$  exposures for primary operators exceeded the NIOSH REL in all operations. When scavenging system controls were operated at the recommended 45 lpm, the REL for personal exposures for the primary operator was exceeded in 57 percent of the operations. However, when scavenging systems were operated at 45 lpm in conjunction with properly placed auxiliary exhaust operating at 250 CFM or greater, personal exposures did not exceed the NIOSH REL for dental assistants.

### MASK LEAKAGE AND PATIENT ACTIVITIES

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. For example, it was determined that  $N_2O$  does not disperse evenly when the patient mouth breathes. When  $N_2O$  is emitted from the patient's mouth, it rises in a narrow plume. If a surgical team member is in the direct path of this plume, it results in "peak" exposures which may exceed 1,000 ppm for that team member. In other situations, the surgeon may miss the plume altogether, or it may enter the breathing zone of the surgical assistant.  $N_2O$  exposure was dependent upon the random currents of the room, patient mouth breathing, and the breathing zone locations of the surgical team (i.e., the closer the breathing zone of the dentist/surgeon is to that of the patient, the greater the exposure). Rubber dams did not effectively reduce exposure. Through the use of infrared thermography, it was determined that  $N_2O$  was redirected out of the sides of the patient's mouth, rather than being trapped inside as previously thought. While the redirected plume may lower exposure directly above the rubber dam, it may not lower exposure to all surgical team members as the gas can migrate into their breathing zones.

## VENTILATION

### General

None of the dental facilities had ventilation systems with adequate air volume to purge and control  $N_2O$  to below the NIOSH REL in areas where this anesthetic was being used.  $N_2O$  exposures were typically higher in closed rooms as opposed to semi-open and open rooms. In some instances, low concentrations of  $N_2O$  were present in dental operating rooms prior to the start of surgery, possibly because of residual  $N_2O$  from previous dental operations and/or poor general dilution ventilation.

### Scavenging System with Auxiliary Exhaust Ventilation

Auxiliary exhaust ventilation was successful in controlling  $N_2O$  exposure below the NIOSH REL. However, when the evaluated exhaust duct openings were placed closer than 12 inches to the patient's mouth; they interfered with the dental hygienist's work. At distances greater than 12 inches, relatively large amounts of air needed to be exhausted (500 to 700 cfm), in order to achieve the necessary capture velocity.

### EDUCATION AND TRAINING IN USING DENTAL SCAVENGING EQUIPMENT

It was determined that although scavenging system use is increasing in dental operatories, dental personnel are not properly trained to operate and maintain the  $N_2O$  delivery and scavenging equipment and to maximize their effectiveness. In addition, dental personnel have very little education and training regarding the selection of scavenging masks. Instructions from the manufacturer are usually filed away, misplaced, or discarded when the scavenging equipment is removed from its shipping material.

### ADMINISTRATION OF $N_2O$ DURING SURGERY

There was variability in the concentration of  $N_2O$  delivered to the patient, as well as in the duration of delivery. Administration of  $N_2O$  concentration ranged from 20 to 50 percent and appeared to be based on the professional judgment of the dentist and perception of patient needs. One of the oral surgeons administered  $N_2O$  during the initial phase of the surgery and subsequently turned off the  $N_2O$  when the anesthetic took effect, relying on the effects of local anesthesia. As a result of this practice, the  $N_2O$  concentrations were considerably lower than other procedures monitored by NIOSH researchers.

## RECOMMENDATIONS

Reducing the amount and frequency of  $N_2O$  administration to the patient is one of the most effective methods of control. Prudent use of this anesthetic will significantly reduce exposure; not using  $N_2O$  will eliminate the hazard altogether. However, when  $N_2O$  is used, a combination of scavenging system, general and auxiliary exhaust ventilation, good work practices, and equipment maintenance is needed to reduce and control exposures.

Specific recommendations for controlling N<sub>2</sub>O are presented in a step-wise fashion, in order to maximize the effectiveness of these controls. The recommendations are organized into categories which include the anesthesia delivery and scavenging system ventilation, general ventilation, auxiliary exhaust ventilation, equipment maintenance, work practices, administrative controls, environmental monitoring, and training and education. Table 11 (appearing at the end of this section) gives a step-by-step approach for reducing and controlling N<sub>2</sub>O in dental operatories below the NIOSH REL. In addition, a more thorough discussion of controlling N<sub>2</sub>O sources from gas cylinder supply to end use is presented in Appendix A.

## EXPOSURE SOURCES AND CONTROL METHODS

### Anesthesia Delivery and Scavenging System Controls

#### Exposure Sources--

There are many exposure sources from the delivery and use of N<sub>2</sub>O in dental operatories. These sources include leaks from the high-pressure connections, such as from the gas delivery tanks, the wall connectors, hoses connected to the anesthesia machine, and the anesthesia machine itself. Low-pressure leaks occur from the connections between the anesthesia flowmeters and the scavenging mask. This leakage is due to loose fitting connections, defective and worn seals and gaskets, worn or defective breathing bags and hoses, and loosely assembled or deformed slip joints and threaded connections.

#### Control Methods--

To reduce the potential for N<sub>2</sub>O leakage, all connections should be visually inspected to see that all parts are properly in place and that all fittings are secure. Leak testing the equipment and connections should be done following visual inspection. Use of a portable infrared spectrophotometer which is calibrated for N<sub>2</sub>O detection is recommended.

When leakage from the anesthesia equipment is stopped, then control of N<sub>2</sub>O at the scavenging mask is the next priority. Leakage from the scavenging mask can be one of the most significant sources of N<sub>2</sub>O exposure. While there is some dilution of N<sub>2</sub>O due to mixing with room air, the breathing zone of the dentist is within inches of the mask, resulting in intermittent exposures exceeding 1,000 ppm. To control such exposures:

1. The scavenging system exhaust rates should be approximately 45 lpm. Flow rates less than 35 lpm may result in significant N<sub>2</sub>O exposure. Flow rates higher than 45 lpm do not significantly reduce N<sub>2</sub>O exposure.
2. Suction pumps should have enough power to maintain a scavenging flow at the nasal mask of 45 lpm. Suction pumps also should have enough power to overcome the static pressure drop associated with the maximum number of installed or "designated" in-line scavenging units which are operated at the same time.

	PROCEDURE	CONTROL
STEP #1	VISUALLY INSPECT ALL N <sub>2</sub> O EQUIPMENT (BREATHING BAG, HOSES, MASK, CONNECTORS) FOR WORN PARTS, CRACKS, HOLES, OR TEARS.	REPLACE DEFECTIVE EQUIPMENT AND/OR PARTS.
STEP #2	TURN ON THE N <sub>2</sub> O TANK AND CHECK ALL HIGH TO LOW PRESSURE CONNECTIONS FOR LEAKS (USE A PORTABLE INFRARED SPECTROPHOTOMETER SUCH AS A MIRAN 1A OR 1B, USE SOAP SOLUTION TO CHECK FOR BUBBLES AT HIGH PRESSURE CONNECTORS. (SEE METHODS SECTION FOR DETAILS).	DETERMINE LEAK SOURCE AND FIX. IF TANK VALVE, REPLACE TANK; IF WORN O-RINGS, GASKETS, VALVES, HOSES, OR FITTINGS, REPLACE. CONTACT THE MANUFACTURER FOR PARTS REPLACEMENT. FOR THREADED PIPE FITTINGS, USE TEFLON® TAPE. DO NOT USE THIS TAPE ON COMPRESSION FITTINGS.
STEP #3	SELECT SCAVENGING SYSTEM AND MASK. MASK SHOULD COME IN VARIOUS SIZES TO FIT PATIENT. SCAVENGING SYSTEMS SHOULD OPERATE AT AIRFLOW RATES UP TO 45 LPM.	PROVIDE A RANGE OF MASK SIZES FOR PATIENTS. CHECK TO SEE THAT NOISE LEVELS AT THE MASK ARE ACCEPTABLE WHEN THE SCAVENGING SYSTEM EXHAUST RATE IS OPERATED AT 45 LPM.
STEP #4	CONNECT MASK TO HOSE AND TURN ON VACUUM PUMP BEFORE TURNING ON N <sub>2</sub> O. SCAVENGING SYSTEM VACUUM PUMP MUST HAVE CAPACITY TO SCAVENGE TO 45 LITERS PER MINUTE PER DENTAL WORKSTATION.	DETERMINE PROPER VACUUM PUMP SIZE FOR MAINTAINING 45 LPM FLOW RATES, ESPECIALLY WHEN INTERCONNECTED WITH OTHER DENTAL SCAVENGING SYSTEMS. IF UNDERSIZED, REPLACE PUMP.
STEP #5	PLACE MASK ON PATIENT AND ASSURE A GOOD, COMFORTABLE FIT. MAKE SURE RESERVOIR (BREATHING) BAG IS NOT OVER OR UNDER INFLATED WHILE THE PATIENT IS BREATHING.	SECURE MASK WITH "SLIP" RING PROVIDED. OBSERVE RESERVOIR (BREATHING) BAG FOR "GOOD ACTIVITY" FROM PATIENT BREATHING.
STEP #6	CHECK GENERAL VENTILATION FOR GOOD ROOM AIR MIXING. EXHAUST VENTS SHOULD NOT BE CLOSE TO AIR SUPPLY VENTS (USE SMOKE TUBES TO OBSERVE AIR MOVEMENT IN ROOM).	IF GENERAL ROOM AIR MIXING IS INADEQUATE, THEN INCREASE THE AIRFLOW OR REDESIGN. IF EXHAUST VENTS ARE CLOSE TO AIR SUPPLY VENTS, RELOCATE (CHECK WITH VENTILATION ENGINEERS TO MAKE ADJUSTMENTS).
STEP #7	CONDUCT PERSONAL SAMPLING OF DENTIST AND DENTAL ASSISTANT FOR N <sub>2</sub> O EXPOSURE (USE DIFFUSIVE SAMPLER OR INFRARED SPECTROPHOTOMETER).	IF PERSONAL EXPOSURES EXCEED 150 PPM, IMPROVE MASK FIT AND MAKE SURE IT IS SECURE OVER THE PATIENT'S NOSE. MINIMIZE PATIENT TALKING WHILE N <sub>2</sub> O IS ADMINISTERED.
STEP #8	PERSONAL SAMPLING RESULTS SHOULD NOT EXCEED 25 PARTS N <sub>2</sub> O PER MILLION PARTS AIR DURING THE TIME OF ADMINISTRATION.	IF PERSONAL EXPOSURES ARE LESS THAN 150 PPM BUT GREATER THAN 25 PPM, IMPLEMENT AUXILIARY EXHAUST VENTILATION NEAR THE PATIENT'S MOUTH. CAPTURE DISTANCE SHOULD BE NO GREATER THAN 10 INCHES FROM THE PATIENT'S NOSE AND MOUTH AREA AND NO LESS THAN 250 CFM AT THE HOOD OPENING. REPOSITION AUXILIARY EXHAUST HOOD AS NEEDED DURING OPERATION TO AVOID CAPTURE OF N <sub>2</sub> O THROUGH DENTIST'S AND DENTAL ASSISTANT'S BREATHING ZONE.

3. All suction pumps aspirating  $N_2O$ -contaminated air from the patient's mask or mouth should be vented outside the building and away from fresh air inlets.
4. The scavenging system should always be on when  $N_2O$  is used: its use should be continued during recovery from analgesia in order to capture  $N_2O$  retained by the patient. An automatic interlock system is recommended to assure that the  $N_2O$  cannot be turned on unless the scavenging system is activated.
5. A flowmeter should be connected to the scavenging system vacuum line and positioned so that it is visible at all times to dental personnel. A bypass flowmeter may have an advantage over an in-line flowmeter because the former avoids moisture problems from the dental operations in the vacuum line and interference with the flowmeter ball and airflow scale.
6. Scavenging system manufacturers should supply a flowmeter kit with their scavenging system so that such systems can be monitored for recommended flow rates to make the system as effective as possible.
7. Scavenging masks should be available in a variety of sizes to fit easily over the patient's nose. The mask should be pliable, so that when the mask is secured around the patient's nose leaks are minimized. To secure the mask gently to the patient, the mask should be fastened to the patient's nose prior to surgery by using a slip clamp, or comparable device, connected to the analgesia hoses which gather near the back of the patient's head and dental chair headrest. Most commercially available scavenging masks are equipped with slip clamps. A visual observation should confirm a reasonable fit.

## VENTILATION

### General Ventilation

1. Supply register louvers located in the ceiling should be designed so as to direct the fresh supply air toward the floor and toward the dental chair to provide mixing, dilution, and removal of the contaminated air from the operating room. Exhaust register louvers should not be located near the supply air vents because this will short circuit the airflow, thereby preventing proper mixing and flushing of the contaminants from the room.
2. If the  $N_2O$  concentration is above 25 ppm for dental personnel, then airflow should be increased in the room to allow for more air mixing and further dilution of the anesthetic gas. The recirculation of room air is not recommended; it should be exhausted outdoors and away from windows, doors, and air intake vents.
3. Sweep fans have been shown to be effective in mixing room air and dilution of anesthetic gas.<sup>15</sup> However, sweep fans should be installed with caution since placement of the fan may increase exposure by generating eddies in the breathing zone of the dentist or entrainment of

the anesthetic from the patient's mask and mouth to the dentist's breathing zone. If sweep fans are used, the location of the fan should be so that the room air is blown past the dentist toward the patient. An air velocity of approximately 50 to 75 cfm at a distance of 3 to 4 feet from the patient's head is recommended.<sup>15</sup>

4. Users of N<sub>2</sub>O should consult 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) for more detailed information regarding ventilation guidelines.<sup>102</sup>

#### Local Exhaust Ventilation

Local exhaust ventilation has been shown to be effective in reducing N<sub>2</sub>O. However, there are practical limitations in using it in the dental operator which must be considered. These include proximity to the patient, interference with dental practices, noise, and installation and maintenance costs. It is most important that the dentist does not work between the patient and the local exhaust duct, since this will cause the contaminated air to be drawn through the dentist's breathing zone.

#### ADMINISTRATIVE CONTROLS AND N<sub>2</sub>O MONITORING

1. Annual reviews of N<sub>2</sub>O use should be conducted, as well as reviews of the waste gas reduction methods employed at the facility. 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 diffusive sampling (passive monitors).<sup>103</sup>
2. When real-time sampling is conducted, the sampling train should be attached to the lapel of dental personnel to obtain personal exposure data. The sampling port of the sampling train should be connected on the dominant work side of dental personnel (i.e., right side if the dentist is right-handed; left side if left-handed).
3. If diffusive samplers (also known as passive dosimeters) are used, it is important to use the method of sampling exposure recommended by NIOSH: Uncap the dosimeter when N<sub>2</sub>O is turned on, and recap it when the N<sub>2</sub>O is turned off. Keep a time log for the administration of N<sub>2</sub>O. Indicate to the company performing the analysis that the results are to be reported for the time the dosimeter is open and not for an 8-hour day. Present instructions for dosimeters indicate that exposure times will be for 8-hours unless otherwise indicated.
4. Dentists should request information from dental equipment suppliers on the proper use of the equipment and its effectiveness in reducing N<sub>2</sub>O prior to purchase. Suppliers need to be informed when and where their products leak.

5. Improving instructions and providing educational updates by the manufacturers to sellers and users may help reduce overall N<sub>2</sub>O exposure by more efficient and prudent use of such systems.

#### EQUIPMENT MAINTENANCE

This research suggests that leaks are a potential cause of excessive N<sub>2</sub>O exposure in dentistry. The analgesia equipment contains rubber and plastic components which may be degraded by the N<sub>2</sub>O and O<sub>2</sub>, as well as by repeated sterilization for infection control.

1. All rubber hoses, connections, tubing, and breathing bags should be frequently checked to assure that this equipment is in good working order. Rigorous leak testing can be performed according to the manufacturer's recommendations or by the procedures outlined in the "Methods" section of this report. If new anesthesia gas delivery and scavenging systems leak because of design and/or quality control problems, manufacturers should be contacted, along with appropriate representatives of the American Dental Association and the Food and Drug Administration, to assure that such problems are fixed immediately.
2. For gas cylinders, Teflon<sup>®</sup> tape should be used on all pipe-threaded connections through which N<sub>2</sub>O flows. Tape should not be used on compression fittings.
3. High- to low-pressure connections should also be checked regularly. O-rings may become worn and should be replaced periodically.
4. The nitrous oxide/oxygen gas mixing system should be evaluated for leaks when first installed and periodically thereafter. This should be performed daily with pressure gauge readings coupled with periodic use of an infrared gas analyzer.

#### WORK PRACTICES

1. The dental personnel should inspect the anesthesia machines and all connections before starting anesthetic gas administration. Breathing bags should be attached to the anesthesia machine, and hoses and clamps should be in place before turning on the anesthetic gas. Avoid over- or underinflating breathing (reservoir) bag while patient is breathing.
2. The scavenging mask should be connected properly to the gas delivery hose and the vacuum system. Indexing connection ports with different diameter hoses to reduce the possibility of incorrect connection of the gas delivery and scavenging hoses is recommended.
3. N<sub>2</sub>O should not be turned on until the following is in place: (a) the vacuum system scavenging unit is operating at the recommended flow rate of 45 lpm; and (b) the scavenging nasal cone is secured over the patient's nose prior to surgery.

4. To reduce leaks around the nasal cone during gas delivery, the slip clamp that is attached to the scavenging nasal inhaler hoses should always be used to seat the mask securely on the patient's nose.
5. Oxygen should be administered to the patient through the analgesia equipment for at least 5 minutes following dental surgery, before the gas delivery system is disconnected from the patient and before the scavenging system vacuum is turned off.
6. Patients should be encouraged to minimize talking and mouth breathing during dental surgery. However, some talking may be necessary in assessing the level of analgesia.
7. Dental personnel should avoid getting in the direct breathing path of the patient when mouth breathing is apparent.

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## APPENDIX A

### ANESTHESIA EQUIPMENT AND EMISSION SOURCES

The purpose of this section is to familiarize the reader with N<sub>2</sub>O use in dentistry and to briefly describe the sources of N<sub>2</sub>O exposure, from gas filled cylinders to the dentist's end use of this gas. Exposure to N<sub>2</sub>O in dental operatories may occur from a variety of sources. These emission sources include the following: compressed gas cylinders (stationary and portable); the gas piping system for stationary gas cylinders; the anesthesia machine, the breathing system, reservoir bag, breathing tubes, and the N<sub>2</sub>O gas delivery mask.

#### Compressed Gas Containers

Gases used in dental operatories may be supplied from a bank of gas cylinders located in a central area and connected to a building piping system, or from smaller, portable gas cylinders located in or near the dental operatory.<sup>1</sup> The capacity of a gas cylinder is designated alphabetically, ranging from size A (smallest) to size H (largest). The cylinder sizes commonly employed in a dental practice are the size E for portable units, and the size H (oxygen) and size G (nitrous oxide) for central systems.<sup>2</sup> The size E cylinder of oxygen contains about 66 liters, while the size E nitrous oxide cylinder contains 1,590 liters. The H oxygen cylinder contains over 5,300 liters, while the G nitrous oxide cylinders contain 13,000 liters. Nitrous oxide cylinders are color coded light blue; the oxygen cylinder is color coded green. The American Dental Association (ADA) has provided recommendations for safe handling and use of these cylinders. These recommendations include the following instructions: (1) Open cylinder valves very slowly in a counterclockwise direction. Close all cylinder valves tightly when not in use; (2) Use no grease, oil, or lubricant of any kind or type to lubricate cylinder valves, gauges, regulators, or other fittings that may contact gases; (3) Store full cylinders in the vertical position; (4) Store cylinders in an area where the temperature does not fluctuate, particularly avoiding heat; and (5) Handle cylinders with care. Especially avoid dropping.<sup>2</sup>

#### Gas Piping Systems

Large dental clinics typically use a piping system to deliver nonflammable gases, such as nitrous oxide and oxygen. The piping system has the following: (1) a central supply system with control equipment; (2) a piping network that delivers the gases to locations where they may be required; and (3) station outlets at each point of use.

Central supply has facilities for storage of gases, controls to deliver the gases to the piping system at the desired pressure, and alarms and safety devices. A common type of gaseous oxygen and nitrous oxide supply system includes two banks of cylinders. When one bank of cylinders is depleted, a pressure sensor switches on the second bank of cylinders. The depleted bank is then replaced with full cylinders to continue the cycle. The cylinders are connected to a manifold (header) that converts them into one continuous supply. Check valves are placed in the lead between each cylinder and

manifold header. Switch-over from the empty to full cylinder is done by a pressure-sensitive switch known as a manifold changeover device.<sup>4</sup>

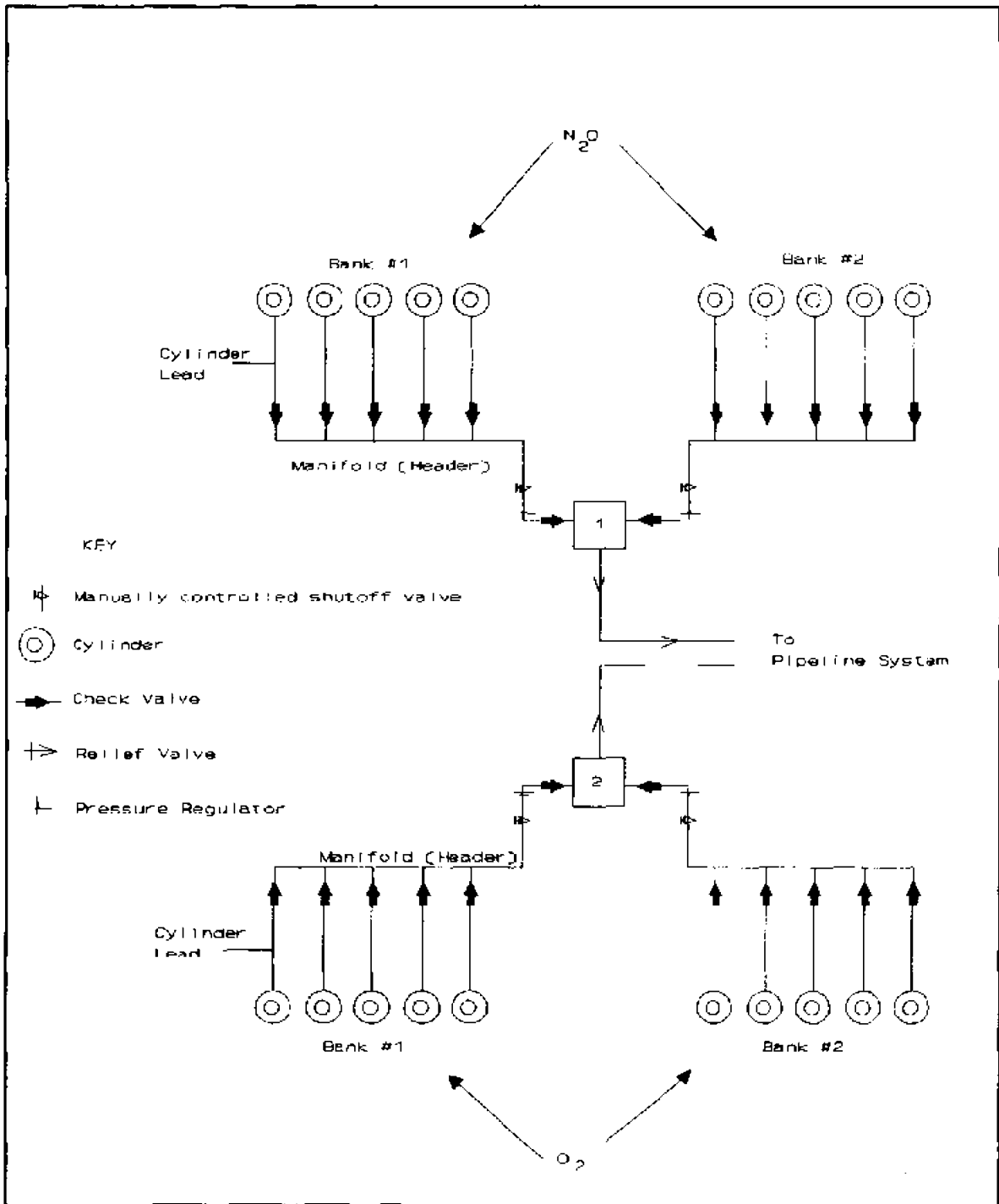
Each bank of cylinders has a pressure regulator that reduces the pressure and maintains the pressure on the downstream side within prescribed limits despite the pressure upstream. If nitrous oxide cylinders are located in a cold place, the regulator may freeze. High use of gas also can cause a regulator to freeze.<sup>5</sup> Shutoff and check valves are important safety features of a central supply system. A manually operated shutoff valve is recommended upstream of each pressure regulator and a shutoff valve or check valve downstream.<sup>73</sup> Figure 25 is a schematic of a central oxygen and nitrous oxide supply system with reserve supply. Boxes 1 and 2 are the manifold change over devices.

Pipeline distribution systems consist of a main line, risers, and branch (lateral) lines. The main line connects the central source to either risers (vertical pipes), branches (lateral pipes), or both. The main supply line must be equipped with a shutoff (stop) valve located near the entry of the gas source into the building or room. The purpose of the shutoff is for an emergency, routine maintenance, or modifications of the piping system.

The piping system terminates at the station outlet where the user connects and disconnects to equipment either directly or by a flexible hose. At the station outlet, there is a faceplate that is permanently labeled with the name and/or symbol of the gas it conveys. The identifying color also may be present. Each station outlet must contain a valve that opens to allow gas flow when the male probe is inserted and closes automatically when the connection is broken. The station outlet must incorporate a shutoff valve to permit repair or maintenance of other components without effect. Seals or O-rings are used between the secondary and primary valve assemblies to provide a gas-tight fit. Degradation of these seals or O-rings due to age results in leaky outlet stations, requiring seal or O-ring replacement.

Each station outlet must incorporate the fixed female component of a noninterchangeable connection, either a Diameter Index Safety System Connection or a quick coupler. The Diameter Index Safety System (DISS) was developed to provide threaded noninterchangeable connections for medical gas lines at pressures of 200 pounds per square inch gauge (psig) or less.<sup>6</sup> DISS connections consist of a body, nipple, and nut combination. The safety system is based upon two concentric and specific bores in the body and two concentric and specific shoulders on the nipple. To have noninterchangeability between different connections, the two diameters on each part vary in opposite directions, so that as one diameter increases, the other decreases. Quick couplers have become popular because gases are frequently needed without delay. The quick coupler should allow the desired apparatus to be connected from the station outlet by a one-step motion using one hand. Each quick coupler has male and female components that are noninterchangeable between gases. The male member is called a plug, striker, probe, or jack. The female component is called a socket. Insertion into an incorrect outlet is prevented by indexing — the use of different shapes for mating portions, different spacing for mating portions, or a combination of these.<sup>6</sup>

Figure 25. Schematic of a central oxygen and nitrous oxide supply system with reserve supply.



Hoses used to connect anesthesia machines and other apparatus to the fixed station outlet should have permanently attached, noninterchangeable connectors. The outlet connector (that connects the hose to the anesthesia machine) should be the DISS, while the connectors at the end of the station outlet should be quick couplers.<sup>6</sup> This configuration will encourage making connections and disconnections at the station outlet rather than at the back of the machine.

### The Analgesia Machine

A 1979 American National Standards Institute (ANSI) standard for anesthesia machines establishes the basic performance and safety requirements for components of analgesia machines.<sup>7</sup> All American anesthesia machine manufacturers have agreed that machines sold after 1984 will comply with the standard. Figure 26 is a schematic of the analgesia machine with the arrangement of the components grouped according to high, medium, and low pressure O<sub>2</sub> and N<sub>2</sub>O gas delivery.

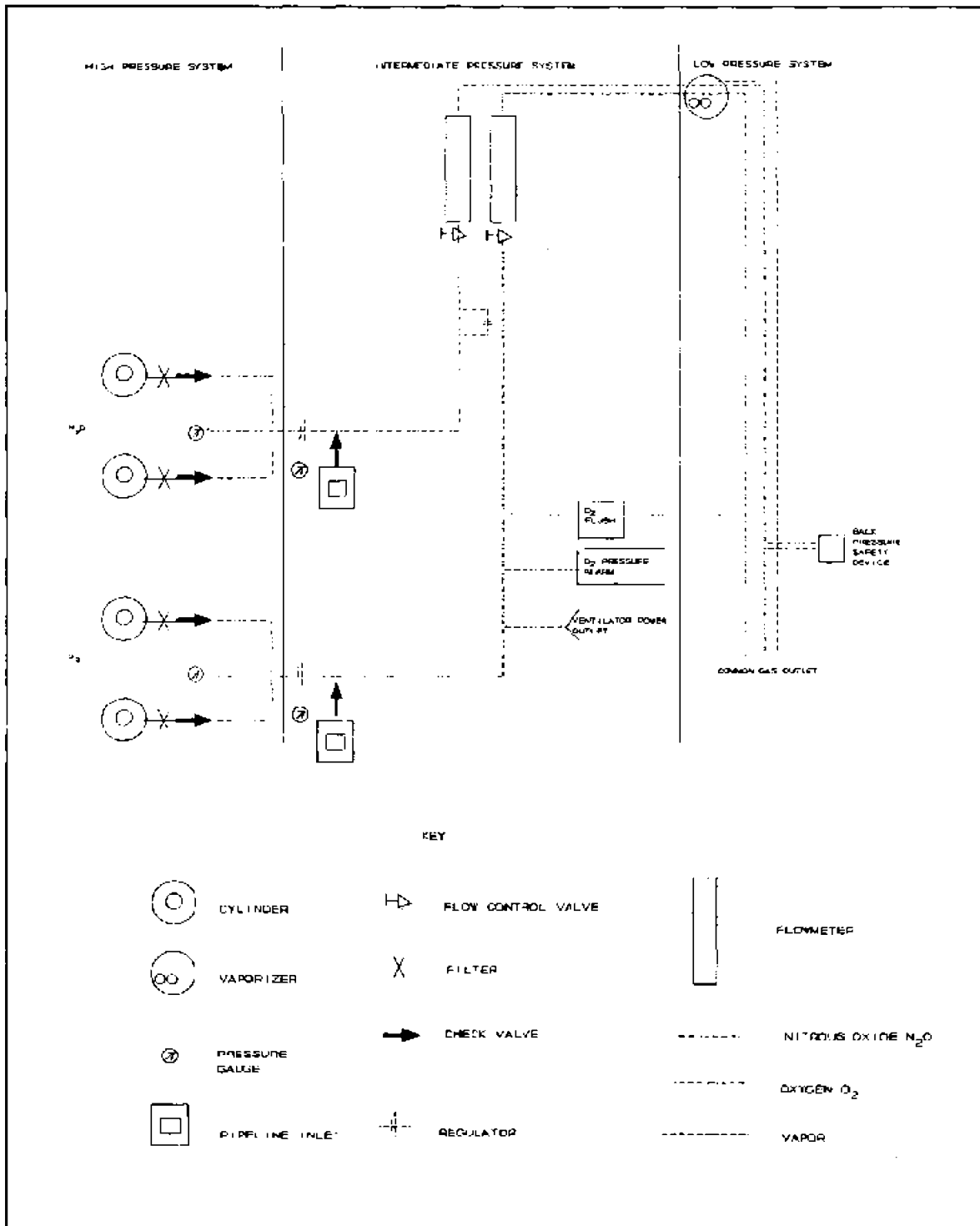
The high-pressure system consists of machine parts that receive gas at cylinder pressure. These include the following: (1) the hanger yoke that connects a cylinder to the machine; (2) the yoke block, used to connect cylinders larger than size E or pipeline hoses to the machine through the yoke; and (3) the cylinder pressure gauge, showing the gas pressure that converts a high, variable gas pressure into a lower, more constant pressure suitable for use in the machine.<sup>73</sup>

The hanger yoke assembly orients and supports the cylinder, provides a gas-tight seal, and ensures a unidirectional flow of gases into the machine. This assembly has the following parts: (1) the body, which is the principal framework and supporting structure; (2) the retaining screw, that is used to tighten the cylinder into the yoke and helps establish a seal; (3) the nipple, through which gas enters the machine; (4) the index pins that prevent attachment of an incorrect cylinder to the yoke; (5) the washer, which also helps to form a seal between the cylinder and the yoke; (6) a filter to remove dirt from the cylinder contents; and (7) the check valve assembly, which ensures a unidirectional flow of gases through the yoke.

A cylinder pressure gauge is required for each gas supplied in cylinders. The gauges are usually of the Bourdon tube type.<sup>8</sup> The machine standard requires that the full scale pressure indication be at least 33 percent greater than the maximum cylinder pressure. All cylinder gauges on a machine must have an equal span angle (between 180 and 280 degrees) from the lowest to the highest pressure indication, with the lowest indication between 6 and 9 on a clock face.

Oxygen pressure failure devices are required on all ANSI-approved machines. Delivery of a hypoxic gas mixture due to a gradual or abrupt failure of the oxygen supply during an anesthetic procedure can be a serious problem. The ANSI machine standard requires that an anesthesia machine be equipped with an oxygen pressure device, such that a reduction in oxygen flow due to a drop in the oxygen supply pressure of 50 percent below normal will result in the cessation of flow of all other gases, including compressed air, or will

Figure 26. Schematic of anesthesia machine with the arrangement of the components grouped according to high, medium, and low pressure O<sub>2</sub> and N<sub>2</sub>O gas delivery.



automatically produce a proportional drop in the flow of the other gases. Oxygen failure safety valves are located in the intermediate pressure lines upstream of the flow control valves of all gases, except oxygen. Oxygen pressure acts as a control for all other gas systems. Therefore, when oxygen pressure drops, the other valves close and halt the delivery of all other gases. Audible and/or visible warning of the loss of oxygen pressure is another approach to this pressure loss. There are two types of alarms: high-pressure and low-pressure.<sup>9</sup> High pressure alarms are sensitive to depletion of oxygen in cylinders attached to the machine. Low-pressure alarms are sensitive to a reduction in oxygen pressure in the intermediate pressure oxygen system. Since most anesthesia machines are operated from pipeline supplies, low-pressure alarms are more common. Alarms are classified by what powers the alarm, of which there are three: (1) oxygen whistles are designed to direct a stream of oxygen through a whistle when the oxygen pressure falls below a certain value;<sup>10</sup> (2) nitrous oxide whistles divert a stream of nitrous oxide through a whistle when the oxygen pressure falls;<sup>11</sup> and (3) electronic alarms incorporate a pressure-sensitive switch that initiates an audible or visible signal when the oxygen pressure falls below a preset value.

The flowmeter assembly controls, measures, and shows the rate of gas flow passing through it. Most current anesthesia machines currently in use have individual flow control valves for each gas (i.e., nitrous oxide and oxygen). The flowmeter subassembly has a tube through which the gas flows, an indicator, a stop at the tube's top, and a scale that shows the flow. The indicator, or flowmeter, has a rotating bobbin, or rotor, usually made of aluminum, with a diameter larger than that of the body. Diagonal grooves, or flutes, are cut into the rim. When gas passes between the rim of the bobbin and the wall of the tube, it impinges on the flutes, causing the bobbin to rotate. Sequence of flowmeters is of great importance from a human factor's point-of-view. The right-hand location of oxygen flowmeter is the standard in the United States and Canada, but is in disagreement with the world standard of oxygen on the left side. Confusion about flowmeter sequence could be a cause of hypoxia.<sup>12</sup>

One important hazard associated with flowmeters is the possibility that the operator may set the flows so that a hypoxic mixture will be delivered. To prevent this, various devices have been developed. Touch-coded oxygen flow control knobs are one safeguard for an anesthesia machine standard that requires the oxygen flow control knobs to have a characteristic fluted profile and be as large or larger than all other flow control knobs. The tactile and visual identity should reduce the hazard of confusion between the oxygen flow control knob and the knob of another gas and reduce unintentional turning off or adjustments to lower settings. Another control on several anesthesia machines regulates the minimum flow of oxygen required before other gases can flow. This minimum flow is preset at the factory and an alarm will sound if the oxygen flow goes below a certain minimum -- even if no other gases are being administered. A third control regulates minimum oxygen flow in proportion to total gas flow, ensuring that a hypoxic mixture will not be delivered.

Oxygen-nitrous oxide proportioning devices offer an alternative to conventional flowmeter tubes.<sup>13</sup> These devices combine nitrous oxide and

oxygen flowmeter assemblies so that the percentage of oxygen and total fresh gas flow is dialed directly. The relative concentration of nitrous oxide and oxygen is varied by adjusting the concentration dial from 30 to 100 percent oxygen. Adjustment of the second dial, the flow control dial, causes the flows for both nitrous oxide and oxygen to increase or decrease, but they remain in the proportion set on the concentration dial. Another type of gas mixer is the monitored dial mixer that allows nitrous oxide and oxygen to be mixed in any proportion from 30 to 100 percent oxygen at total gas flow rates between 1 and 20 liters/min.<sup>14</sup>

There can be several problems with flowmeters, such as inaccuracy,<sup>15</sup> improper assembly or calibration,<sup>16</sup> dirt,<sup>17</sup> back pressure, improper alignment,<sup>18</sup> static electricity,<sup>19</sup> and float damage.<sup>20</sup> The flow control valve should be closed when the cylinder valves are opened or the pipeline hoses are connected to the machine. This will prevent the sudden rise of the indicator to the top of the flowmeter tube, which might damage the indicator or allow it to remain unnoticed at the top of the flowmeter. Flowmeter tubes may get dirty and require occasional cleaning. Cleaning of flowmeters is usually part of the manufacturer's servicing program and should not be carried out by the user unless instructed by the service manual.

The oxygen flush valve receives oxygen from the pipeline inlet or cylinder regulator and directs a high unmeasured flow to the common gas outlet. With this flush valve, the anesthesiologist can flood the breathing system with a high flow of oxygen. The ANSI standard requires that the flow be between 35 to 75 liters/minute.

Anesthesia machines require regular maintenance to perform reliably. Often a machine is not inspected until there is a problem. Servicing can reduce the frequency of failures/malfunctions by replacing damaged or worn parts. Servicing of the anesthesia machine should be done by an authorized service representative and at regular intervals. Even with a routine servicing program, the user still has the responsibility for checking the machine before each use. Records should be kept of each major piece of equipment, including problems that occur, service performed, when it was performed, and by whom.

The ADA has adopted an Acceptance Program for inhalation sedation units that allow the dentist to evaluate those units being considered for purchase. In recent years, the primary emphasis has been the addition of safety features to the units that are aimed at making it difficult to administer less than 20 percent oxygen to a dental patient. The Council on Dental Materials, Instruments and Equipment for evaluation has a list of guidelines that may help the dentist in purchasing a unit acceptable to the ADA.

### The Breathing System

The breathing system allows the dentist to take an anesthetic mixture from the anesthesia machine and present this mixture to the patient. The anesthetics are conveyed to and from the patient without the disruption of the normal exchange of oxygen and carbon dioxide.

Rebreathing includes any gas that has been exhaled from which carbon dioxide may or may not have been removed. There is a tendency to associate rebreathing with carbon dioxide accumulation. However, it is possible to have partial or total rebreathing without an increase in carbon dioxide concentration. Breathing systems should prevent the accumulation of carbon dioxide, but the prevention of some rebreathing is not necessarily desirable.

The amount of rebreathing depends on three factors: the fresh gas flow, the mechanical dead space, and the design of the breathing system. The amount of rebreathing varies inversely with the total fresh gas flow. The mechanical dead space is the dead space in a breathing system occupied by gases that are rebreathed without any change in composition. This dead space may be minimized by separating inspiratory and expiratory gas streams close to the patient.<sup>21</sup> The design of the breathing system may be arranged so that there is more or less rebreathing.

### The Mapleson Breathing System

Mapleson breathing systems are a group of breathing systems characterized by the absence of directional valves to direct gases to or from the patient. Since there is no clear separation of inspired and expired gases, the composition of the inspired mixture is highly dependent on the fresh gas flows used. The most common system used in dentistry is the Mapleson D system. The Mapleson D system has a fresh gas inlet at the patient end, a length of corrugated tubing connecting the fresh gas inlet to the relief valve, a relief valve of the high-pressure type, and a reservoir bag next to the relief valve.<sup>22</sup>

### Reservoir Bag

The reservoir bag is also known as the respiratory bag, breathing bag, or, somewhat erroneously, the rebreathing bag.<sup>23</sup> Most bags are made of rubber; some are plastic. The reservoir bag has four basic functions: (1) it allows accumulation of gas during exhalation so that a reservoir of gas is available for the patient's next inspiration, thus, allowing greater economy of anesthetic gases and preventing air dilution; (2) it provides a means for the dentist to help or control respirations; (3) it can serve as a visual and tactile sensor as a monitor of a patient's spontaneous respirations; and (4) it acts to protect the patient from excessive pressure in the breathing system.<sup>24</sup>

### Breathing Tubes

Large bore, nonrigid breathing tubes, typically composed of corrugated rubber or plastic, are found in most breathing systems. The plastic tubes are often clear to permit visual observation of the interior; they are lightweight to provide less drag on the scavenging mask; and they are corrugated to prevent kinking and obstruction. The breathing tubes have two functions: to act as a reservoir in certain systems and to provide a flexible, low-resistance, lightweight connection from one part of the system to another.<sup>25</sup>



## The N<sub>2</sub>O Gas Delivery Mask

Nitrous oxide may be delivered to the patient in one of three ways: nasal masks, nasal cannulae, and full face masks. Nasal cannulae and full face masks are not routine sedation procedures in dentistry and are more typically used during emergency procedures. The nasal mask is used most often when delivering N<sub>2</sub>O and O<sub>2</sub> to the patient during dental surgery. The mask is made of a flexible rubber compound, usually a silastic rubber, which adapts to the contours of the patient's face. Nasal masks are commonly manufactured with two valves. The expiratory or relief valve permits gas to flow out of the system only. Pressure builds up in the system when the patient exhales, and the relief valve will open allowing the gas to escape into the atmosphere. The second valve is the inspiratory valve. Nasal masks are often available in three sizes; small size for children, medium for small adults, and large for large adults. Nasal masks are designed to be disconnected from the breathing hoses to allow cleaning and disinfection. Figure 27 shows the analgesia delivery system from the O<sub>2</sub> and N<sub>2</sub>O flowmeter to the mask used for patients. Figure 28 shows a common nasal mask used for nitrous oxide delivery to the patient.

Before administering anesthesia, it is necessary to check all equipment to make sure it is functional, calibrated, and leak proof. Figure 29 shows the potential leak sources in the anesthesia delivery system. The anesthesia machine must be turned on before gases can flow. Before gas supplies are inspected, all flow control valves should be closed by turning them clockwise. In hospital and large dental operatories, the hose should be securely connected to the machine. Pressure gauges should be checked to make sure that proper pressures are available. If the machine is equipped with an oxygen pressure failure alarm, it should be checked for proper function according to the manufacturer's instructions. The flowmeter should be examined with no gas flow to make certain that the indicator is in the 0 position. Each flow control valve should be opened and closed slowly while the indicator is observed as it rises and falls within the tube. The flowmeter ball should rotate freely.

Testing the machine for leaks is normally performed separately from the test for leaks in the breathing system.<sup>26</sup> Testing for leaks by pressurizing the breathing system frequently will not detect leaks in the high pressure components of the machine. Most machines are equipped with unidirectional check valves, either near the common outlet or in a vaporizer. A pressure gauge (a standard sphygmomanometer) is attached to the common gas outlet or the fresh gas hose. The flow control valve of a flowmeter on the machine is opened slowly until the pressure on the gauge reaches 30 cm H<sub>2</sub>O (22 millimeters of Mercury). The flow is lowered until a static equilibrium between the gas flow and the leak has been established; usually at a pressure of 30 cm H<sub>2</sub>O. Test for leakage at the yoke is recommended. After cylinder pressures have been checked and the valves closed, the cylinder pressure gauges are observed for 2 to 5 minutes. A drop in pressure of more than 50 psig shows significant leakage.

Figure 27. An analgesia delivery system from the  $O_2$  and  $N_2O$  flowmeters to the mask used for patients.

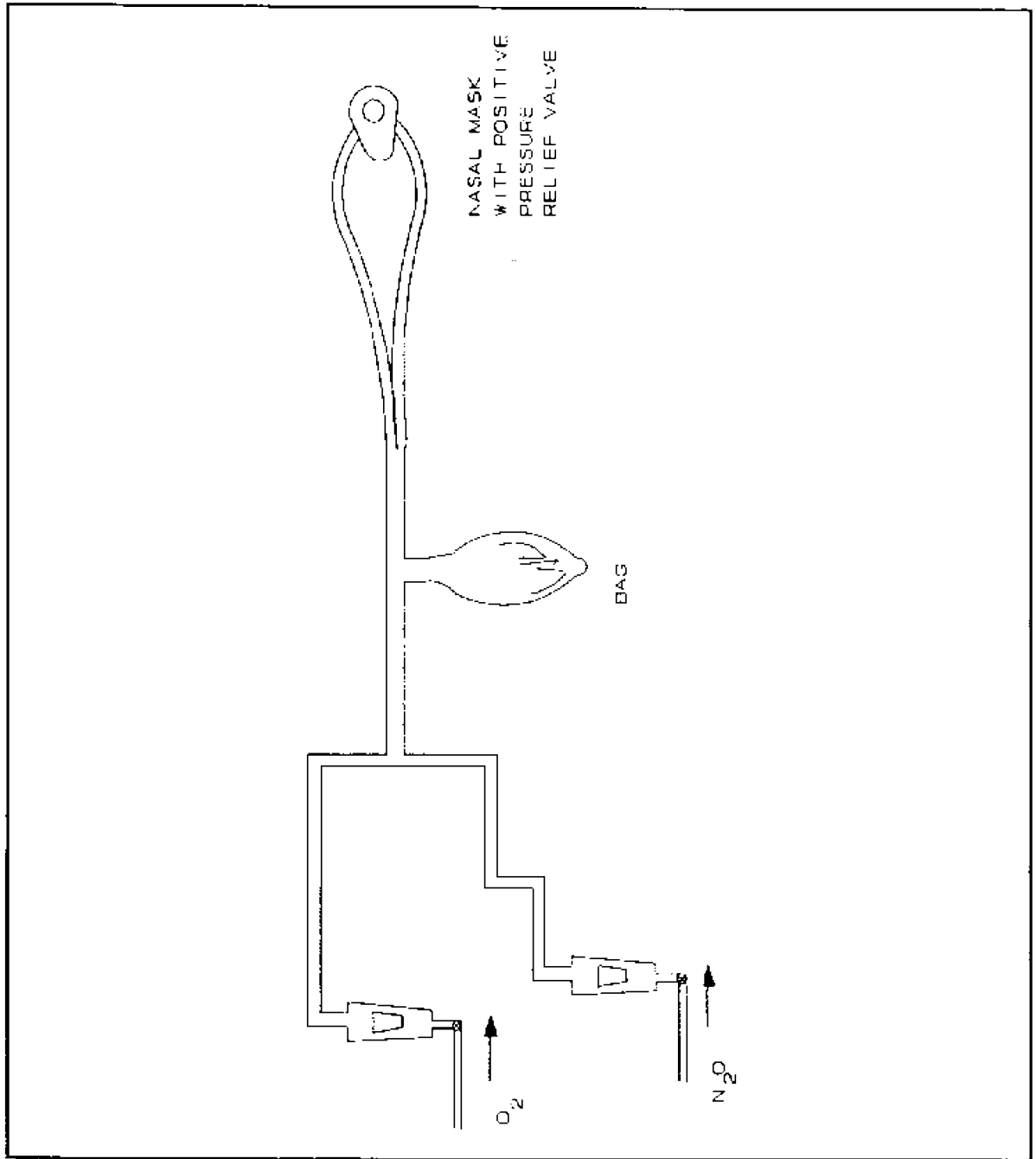


Figure 28. A common nasal mask used for nitrous oxide delivery to the patient.

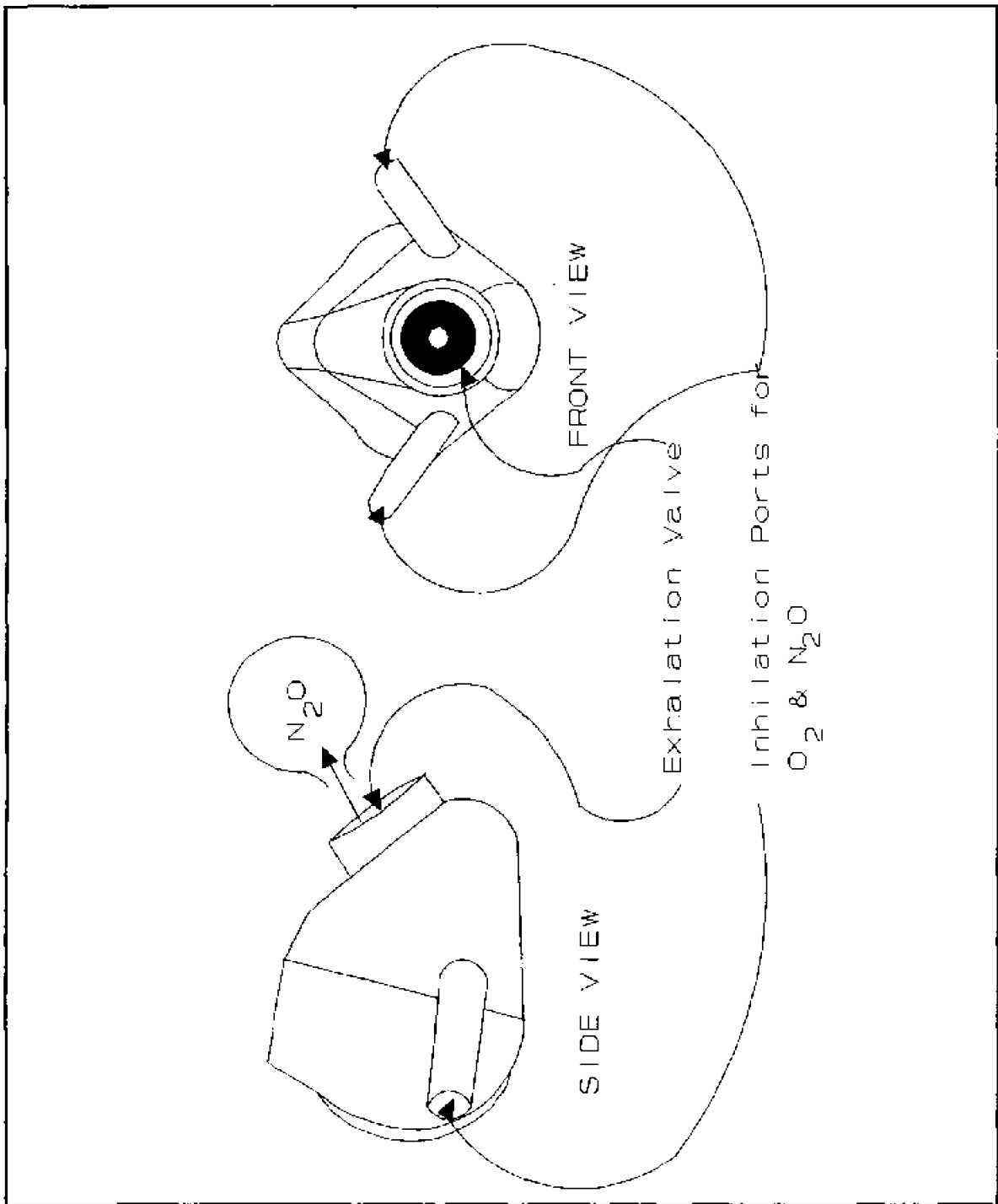
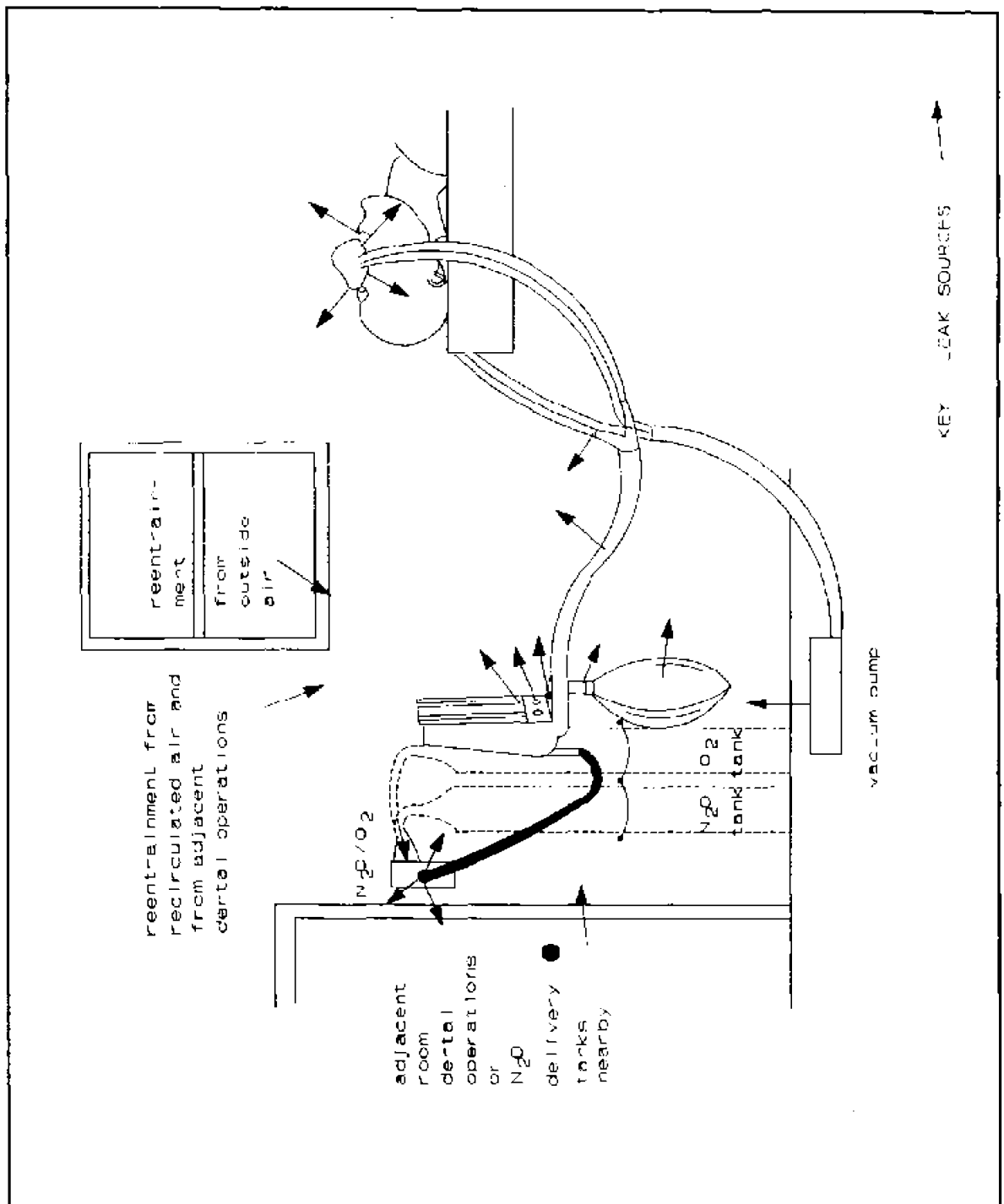


Figure 29. Sources of N<sub>2</sub>O exposure resulting from potential leaks in the anesthetic delivery system.



The oxygen failure safety valve should be tested at the beginning of the day and/or before each case. This test can be performed using either the pipelines or cylinders as the gas source. Some recommend that it be performed with both sources. A cylinder of each gas on the machine is turned on, leaving the pipeline hoses disconnected. Flows of 2 liters/min. are established on the flowmeters for each gas. The oxygen cylinder is then turned off. As the pressure of oxygen falls, the oxygen flowmeter indicator will fall. At a certain oxygen pressure, the indicators for each anesthetic gas should suddenly fall to 0. To test pipeline gases, all cylinder valves should be closed and the flow control valves opened until the cylinder pressure gauges register 0 pressure. The pipeline hoses are connected and flows established on both anesthetic gas and oxygen flowmeters. The oxygen hose is disconnected. The indicators of the anesthetic gases should fall to 0 with the oxygen indicator.

When the hoses and bag are firmly attached, leaks are minimized. To check for leaks, the relief valve is closed and the patient port of the y-piece occluded. The reservoir bag is filled using the oxygen flush until a pressure of 30-40 cm H<sub>2</sub>O water is shown on the pressure gauge. With no additional gas flow the pressure should not drop more than 5 cm H<sub>2</sub>O in 30 seconds. This corresponds to a leak of less than 50 cc/min.

The Mapleson system pressure gauge should be checked to make certain that it reads 0. System integrity is tested by occluding the patient port, closing the relief valve, and beginning the oxygen flush on the anesthesia machine to distend the bag. The bag should maintain the distension and not deflate. When the relief valve is then opened, the bag should deflate.

An assortment of masks in various sizes should be readily available in order to fit the patient and reduce potential leaks. It may be necessary to try a few mask sizes on the patient's face before finding a suitable one.

Suction equipment should be checked by placing a flowmeter with a range of 0 to 100 liters per minute in line. The suction valve should be opened fully to find the range of suction flow and then, the valve should be turned back to 45 liters per minute.

New equipment should be checked with the aid of a user's manual. It will contain assembly and installation instructions, a list of requirements, and daily checking procedures. The manual should be kept in the central department files and reviewed periodically. A copy of the daily checking procedures should be kept in the operatory with the equipment. Assembly, installation, and operation instructions should be carefully followed.

Preventive maintenance should be contracted with the respective equipment manufacturers and their trained service representative on 3- to 12-month intervals depending on frequency of use. Preventive maintenance includes inspection, testing, cleaning, lubrication, and adjustment of various components. Worn or damaged parts are to be fixed or replaced. Such maintenance can result in detection of deterioration before an overt malfunction occurs.

Recordkeeping for anesthesia equipment is often neglected. Recordkeeping is important because it provides a number of checks and balances: (1) proof that an effort has been made to keep the equipment in proper working order; (2) a means of communication with the service representative; (3) a complete, up-to-date record for each piece of equipment; (4) a written record that maintenance by a service representative was performed and shows what was done; (5) a check on the service rendered by the representative; and (6) a reminder to the user of when the equipment needs to be serviced or a component replaced. Figure 30 shows the sources of N<sub>2</sub>O exposure resulting from potential leaks in the anesthetic delivery system.

#### American Dental Association Guidelines for Scavenging Equipment

Because of the variety and quality of N<sub>2</sub>O scavenging systems and the concern for patient safety, the ADA has developed guidelines for scavenging equipment.<sup>27</sup> These guidelines, recommend that scavenging system equipment have the following characteristics: (1) be capable of providing N<sub>2</sub>O-O<sub>2</sub> flow rates that comply with or improve upon minimum concentrations indicated in current NIOSH and OSHA documents; (2) be adaptable to existing sedation, anesthesia, and exhaust systems; (3) be constructed so as not to interfere significantly with the normal breathing system and delivery of selected gas concentrations; (4) be effective regardless of the heating and air conditioning system in use; (5) be constructed to permit safe and efficient disposal of the gases; (6) be effective when more than one device is being used simultaneously; and (7) be constructed such that patient rebreathing will be insignificant.

Of two commercially available scavenging systems provided to the ADA for testing to date, only the Porter-Brown system has been fully tested and approved.<sup>27</sup> It should be noted that testing of scavenging systems by the ADA does not include meeting the NIOSH REL.

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