

NITROUS OXIDE IN WORKPLACE ATMOSPHERES  
(PASSIVE MONITOR)



Method Number: ID-166

Matrix: Air

ACGIH Threshold Limit Value (TLV): 50 ppm Time Weighted Average (TWA)

NIOSH Recommended Exposure Limit (REL): 25 ppm TWA

OSHA PEL: None

Collection Device: Landauer or other nitrous oxide passive monitor

Recommended Minimum dose: 25 ppm-hrs (claimed by manufacturer)

Working range: 25 to 9,000 ppm-hrs (claimed by manufacturer)

Analytical Procedure: Samples are thermally desorbed and analyzed by infra-red (IR) spectroscopy by the manufacturer.

Validation Level\*: 10 to 500 ppm

Detection Limit  
Quantitative: 2 µg (claimed by manufacturer)

Precision and Accuracy

Validation Range, ppm:	12.5 to 500	25 to 110	25 to 500
CV <sub>2</sub> :	0.135	0.093	0.080
Average recovery, %:	98.7	93.1	103.1
CV <sub>(pooled)</sub> (12.5 to 500 ppm*):	0.084 (includes 3 ranges pooled above)		
Bias (12.5 to 500 ppm*):	-0.047 (includes 3 ranges pooled above)		
Overall Error:	±21.5% (12.5 to 500 ppm*)		

Method Classification: Validated Method

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Industrial Hygienist (field data): Ed Zimowski (OSHA Health Response Team)

Date (date revised): 1985 (May, 1994)

\* @ 25 °C and 760 mmHg

\*\* Normally the range will only include 0.5, 1, and 2 times PEL; due to large anticipated range of air concentration results and two different exposure limits (50 and 25 ppm) data is included for a wider range of concentrations.

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Commercial manufacturers and products mentioned in this method are for descriptive use only and do not constitute endorsements by USDOL-OSHA. Although this method discusses a specific commercial product used for measuring nitrous oxide, similar products from other sources can be substituted. Substitution is allowed provided validation procedures are conducted to determine sampling and analytical efficacy.

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## 1. Introduction

This method describes the sample collection of airborne nitrous oxide (N<sub>2</sub>O). Passive samples are taken in the breathing zone of workplace personnel, and analysis is performed using thermal desorption/infrared (IR) spectroscopy. The analysis is performed by the manufacturer of the passive dosimeter at the manufacturer's laboratory.

- 1.1 The effects of occupational exposure to N<sub>2</sub>O are still uncertain. However, there is sufficient concern to warrant positive steps to control the airborne levels of N<sub>2</sub>O in workplaces, such as medical, dental and veterinary facilities. The National Institute for Occupational Safety and Health (NIOSH) apparently recommended a Time Weighted Average (TWA) concentration of 50 ppm when N<sub>2</sub>O is used in dental offices, and 25 ppm when it is used during anesthetic administration (5.1). This has been recently clarified as a 25 ppm TWA REL (5.2) regardless of site. The reference to 50 ppm was considering what is feasible using engineering and other controls in dental offices. Scavenger systems in dental operatories are less efficient in capturing N<sub>2</sub>O due to the oral dental operations being performed.

In the past, N<sub>2</sub>O, the most commonly used anesthetic agent, could only be sampled by gas bags, evacuated containers, or syringes and subsequently analyzed by IR (5.1). Recently, R.S. Landauer, Jr. and Company (Glenwood, IL) introduced a passive diffusion monitor for N<sub>2</sub>O. These passive monitors have been evaluated in field studies and were shown to compare favorably with an IR gas analyzer [(5.3) and also see Addendum to this method]. Other passive systems are available for N<sub>2</sub>O and can be substituted in this method provided validation procedures are conducted to assure precise and accurate determinations are possible. NIOSH has published a very rigorous procedure (5.4) for validating passive monitors after this evaluation was performed.

An OSHA laboratory evaluation was conducted over a broad range of N<sub>2</sub>O concentrations to determine if the Landauer passive monitor is acceptable for use by OSHA industrial hygienists for determining N<sub>2</sub>O in work environments. In addition, a short field evaluation was performed by the OSHA Health Response Team (see Addendum for further information).

## 1.2 Principle of the Method

The Landauer nitrous oxide monitor (NITROX) is a diffusion type air monitoring badge assembly worn in the breathing zone of personnel to evaluate potential exposure to N<sub>2</sub>O gas. Nitrous oxide gas is adsorbed on the selected adsorbent material (molecular sieve), sent to the laboratory and thermally desorbed and analyzed by the manufacturer using IR. Both an active cartridge sample collected by drawing air through the cartridge with a calibrated sampling pump, (referred to as "active samples" in this report), and a passive monitor sample which requires no sampling pump to collect the sample (referred to as "passive samples" in this report) were taken. Both use the same proprietary sorbent material. This report presents data on both sampling procedures.

## 1.3 Advantages and Disadvantages

- 1.3.1 This method has adequate sensitivity for measuring workplace atmosphere concentrations of N<sub>2</sub>O.
- 1.3.2 The sampling procedure for this method involves no liquid and mechanical pumps. A somewhat bulky direct-reading instrument is not used and pre- and post-calibration is not necessary.
- 1.3.3 One disadvantage is the requirement that the monitor is analyzed at the manufacturer's laboratory, which does not allow for immediate results as given by a direct-reading instrument. Quality control is dependent mainly on the manufacturer; this makes it difficult for those laboratories which prefer to conduct their own quality control program. It is recommended that users occasionally prepare spiked samples to assure adequate quality control.

## 1.4 Method Performance

A synopsis of the method performance is presented below. Further information can be found in Section 4.

1.4.1 This method was validated over the concentration range of 10 to 500 ppm.

1.4.2 The quantitative detection limit was 2 µg N<sub>2</sub>O (manufacturer claim).

1.4.3 The validation ranges, the coefficients of variation (CV<sub>2</sub>), and average recoveries are:

Validation Range, ppm:	12.5 to 500	25 to 110	25 to 500
CV <sub>2</sub> (pooled):	0.135	0.093	0.080
Average recovery, %:	98.7	93.1	103.1

Using data derived from 5 sample sets (12.5, 25, 50, 110 ppm, and one 500 ppm set) the total pooled CV<sub>2</sub>, Bias, and Overall Error are:

$$CV_{(\text{pooled})} = 0.084; \quad \text{Bias} = -0.047; \quad \text{Overall Error} = \pm 21.5\%$$

1.4.4 Samples can be stored at ambient (20 to 25 °C) temperature on a lab bench for a period of 30 days. Results show the mean sample recovery after 30 days of storage was within ±10% of results at Day 2.

## 1.5 Interferences

No known interferences were reported by the manufacturer.

## 1.6 Uses and Sources (5.5)

byproduct of nylon production (5.6)  
anesthetic in dentistry and surgery  
propellant gas in food aerosols and whipped cream  
leak detection

## 1.7 Physical and Chemical Properties (5.7)

Nitrous oxide exists as colorless, nonexplosive, nonflammable gas at room temperature. The gas promotes combustion similar to oxygen and has a slightly sweet odor and taste. Ambient concentrations of N<sub>2</sub>O are produced by decomposition of nitrogen compounds found in the soil and are approximately 0.25 ppm.

Nitrous Oxide	(CAS No. 10024-97-2)
Chemical formula	N <sub>2</sub> O
Molecular weight	44.02
Melting point	-90.81 °C
Boiling point	-88.5 °C
Density	1.53 times that of air
Solubility	Soluble in alcohol, water, ether, oils, sulfuric acid
Flammability	Nonflammable, supports combustion
Synonyms	Laughing gas, nitrogen oxide*, dinitrogen monoxide, hyponitrous acid anhydride, factitious air.

\* Unfortunately, nitrous oxide has been confused with nitric oxide (NO) resulting in disastrous consequences.

## 1.8 Toxicology (5.7)

Information listed within this section is a synopsis of current knowledge of the physiological effects of N<sub>2</sub>O and is not intended to be used as a basis for OSHA policy. More information regarding toxicity can be found in reference 5.7.

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Previously, N<sub>2</sub>O was considered a simple asphyxiant. Current data indicates a causal relationship in producing bone marrow depression and granulocytopenia, potential teratogenicity and spontaneous abortion. Nitrous oxide-induced bone marrow depression and granulocytopenia appear reversible. Nitrous oxide has been implicated in also producing neurotoxic, hepatic, and renal effects. Neurotoxic effects such as numbness, tingling, and weakness have been demonstrated in early studies and NIOSH has based their 25 ppm REL on decreased audiovisual performance noted when subjects were exposed to 50 ppm N<sub>2</sub>O (5.1). Biological systems most susceptible to N<sub>2</sub>O toxicity are reproductive, hematologic, and the nervous system. Evidence for physiological risk to indicate short-term exposures warrant STEL or Ceiling Limits has not been adequately demonstrated (5.7).

## 2. Sampling

- 2.1 Follow the manufacturer's instructions regarding usage. These should be provided to every user. Record sample start and stop times, and sample identification numbers.
- 2.2 A pump is not used and sampling commences as soon as the upper cap is removed. Remove the upper cap and place in the breathing zone of the employee.

**Note: The manufacturer has indicated that the monitor can be placed under the top layer of surgical gowns or scrubs without affecting the sampling uptake. Losses of approximately 10% have been noted under three layers of clothing placed in test chambers. This method has not evaluated the ability for the sampler to perform under such conditions; however, there is obviously a potential for bloodborne pathogen contamination of the dosimeter during sampling. Side-by-side sampling (placing a monitor inside and outside different surgical gowns for a statistically significant number of employees) during actual work procedures may need to be performed to assure the sample uptake rate is not adversely affected.**



**Individuals conducting sampling in areas where bloodborne pathogen exposure is possible will refer to OSHA Instruction CPL 2-2.60 (Office of Occupational Medicine, Directorate of Technical Support, Occupational Safety and Health Administration). Individuals will take universal precautions to avoid contamination of personnel and equipment. All equipment (this includes sampling devices) will be decontaminated prior to shipment to any facility as deemed necessary by the Office Director.**

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- 2.3 Plan on sampling for a period of up to 8 hours to determine TWA exposures. Remove the dosimeter from the employee and place the cap tightly on the NITROX Dosimeter to cease sampling.
- 2.4 Write down any pertinent sampling information on the OSHA 91A and request analysis for nitrous oxide (N<sub>2</sub>O).
- 2.5 Wrap sample seals lengthwise on each dosimeter tube after sampling and ship samples and paperwork to the OSHA Salt Lake Technical Center (SLTC) for sample tracking. Compliance officers for OSHA do not have to ship the dosimeters to Landauer, Inc. The OSHA-SLTC will track the samples and relay the results immediately after receipt to the compliance officer.
- 2.6 Always include a blank dosimeter with every set of N<sub>2</sub>O samples.
- 2.7 Bulk and wipe samples are inappropriate for this method. Leak testing of the delivery systems for N<sub>2</sub>O should be conducted using an appropriate direct-reading IR or other suitable instrument.

## 3. Analysis

Sample analysis is proprietary and is conducted by the manufacturer. Samples are thermally desorbed and analyzed by IR spectroscopy. Results are reported back to the person submitting samples as ppm TWA and ppm-hours N<sub>2</sub>O.

#### 4. Backup Data

This method has been validated for a concentration range of 10 to 500 ppm N<sub>2</sub>O. The method validation was conducted near the ACGIH TLV of 50 ppm N<sub>2</sub>O and the NIOSH REL of 25 ppm. In addition, a high concentration (500 ppm) expected in some operations was also examined.

The validation consisted of the following experiments and discussion:

1. A preliminary analysis of 20 active samples was performed (10 samples each at 0.5 × and 1 × TWA TLV) to evaluate and to check the generation system.
2. A sampling and analysis of 70 active samples (mixed concentration from 10 to 500 ppm N<sub>2</sub>O) collected from dynamically generated test atmospheres at 60% RH to determine the precision and accuracy of the manufacturer.
3. A sampling and analysis of 38 passive monitors (mixed concentration from 10 to 500 ppm N<sub>2</sub>O) collected from dynamically generated test atmospheres at 60% RH to determine precision and accuracy analyzed by the manufacturer.
4. An evaluation of storage stability at room (20 to 25 °C) temperature for 20 collected samples.
5. An evaluation of reverse diffusion for the monitors.
6. High humidity tests for Landauer active cartridges and Landauer passive monitors.
7. Comparison of sampling methods: Active cartridges versus passive monitors.
8. Summary.

#### Evaluation Protocol

Tests were performed on a minimum of six monitors for each concentration level evaluated at relative humidities of 60% and a temperature of 25 °C, which were considered typical environmental conditions for operating rooms. The evaluation consisted of the following major experiments: precision and accuracy, storage stability, reverse diffusion, high humidity and comparison of methods.

#### 4.1 Preparation and Monitoring of Nitrous Oxide Concentrations

##### 4.1.1 Concentration of cylinder of neat nitrous oxide:

A cylinder of neat N<sub>2</sub>O was used for these experiments. The concentration of N<sub>2</sub>O had been certified by the manufacturer as USP grade N<sub>2</sub>O. This concentration was used as the "true" cylinder concentration, and was used to prepare known concentrations of N<sub>2</sub>O.

- 4.1.2 Samples from the cylinder of N<sub>2</sub>O (spikes were delivered to molecular sieve) were sent to Landauer Company for analysis and verification of the cylinder concentration. Landauer reported a concentration of 100.2% N<sub>2</sub>O. (Refer to Table 1)

## 4.2 Generation Apparatus:

4.2.1 The generation apparatus used provided a means of generating dynamic test atmospheres. The block diagram of the major components in the dynamic generation system is shown in Figure 1. The system consists of six essential elements:

- a) a flow-temperature-humidity control system,
- b) a N<sub>2</sub>O gas generating system (including a mass flow controller),
- c) a mixing chamber,
- d) an active sampling manifold,
- e) a monitor exposure chamber and
- f) an IR analyzer used as a continuous monitor.

A detailed description of the generation system can be found in references 5.8. and 5.9.

4.2.2 Preliminary experiments were conducted with two sets of active samplers in order to determine if the generation system was working properly. These results are reported in Table 2.

## 4.3 On-line Monitoring of Gas Concentrations

A MIRAN 103 gas analyzer was used as an on-line continuous monitor of generated N<sub>2</sub>O gas concentrations. Calibration of the analyzer was performed by employing a closed-loop circulating system following the procedure described in the MIRAN 103 operating manual (5.10). The calibration curve was obtained by plotting the N<sub>2</sub>O concentration in ppm vs. peak height in mm (from the recorder connected to the IR. The IR used had a 4.5 micron nitrous oxide filter).

## 4.4 Sampling and Analysis

4.4.1 **Sampling:** Known (theoretical) concentrations of N<sub>2</sub>O were prepared by dilution of the certified N<sub>2</sub>O with purified compressed air using mass flow controllers, with a manufacturer's reported accuracy of  $\pm 2\%$ . These theoretical concentrations (as calculated from the flow dilutions) were also independently verified by the manufacturer (R.S. Landauer, Jr. and Company) from active samples submitted for analysis. Good agreement was found between the active and theoretical sampling results (Table 3).

4.4.2 **Analysis:** All samples, (active cartridges and passive monitors) were collected, sealed and sent to the manufacturer for analysis.

## 4.5 Precision and Accuracy

The precision and accuracy data were obtained by exposing groups of at least six samples (both active cartridges and passive monitors) to known concentrations of N<sub>2</sub>O. A broad range of concentrations and a variety of sampling periods were used. These test results are presented in Tables 3 and 4. The coefficients of variation, CV<sub>2</sub>, and the average recoveries for exposed monitors for three ranges of the NIOSH and ACGIH proposed exposure limits from (1) 0.5 to 20 times the 25 ppm limit, (2) 0.5 to 2 times the 50 ppm limit, and (3) 0.5 to 10 times the 50 ppm limit. (Note: The 20 times concentrations were anticipated in actual workplace environments). These results were compared to active samplers taken side-by-side and recoveries were determined based on the active sampler results.

Concn Range, ppm*	CV <sub>2</sub> , %		Ave. Recovery, %	
	Active	Passive	Active	Passive
12.50-500.00	4.9	13.5	99.3	98.7
25.00-110.00	2.2	9.3	99.0	93.1
25.00-500.00	5.1	8.0	101.8	103.1

\*(@ NTP = 25 °C, & 760 mmHg)

Using data derived from 5 sample sets (12.5, 25, 50, 110 ppm, and one 500 ppm set) the total pooled CV<sub>2</sub>, Bias, and Overall Error are:

$$CV_{(\text{pooled})} = 0.084; \text{ Bias} = -0.047; \text{ Overall Error} = \pm 21.5\%$$

#### 4.6 Storage Stability

A study was conducted to assess the stability of the passive monitors when stored at laboratory ambient temperature. Four sets, each containing four to six passive monitors, were exposed to a N<sub>2</sub>O concentration of 25 ppm. Each set was analyzed by the Landauer Company after various periods of storage ( 2, 7, 15, and 30 days). Table 5 presents the results of this study which according to the manufacturer's analysis shows that the mean of samples stored for 30 days are within  $\pm 10\%$  of the mean of the passive monitors that were analyzed after 2 days.

#### 4.7 Reverse Diffusion

Two sets of passive monitors were used for a reverse-diffusion study. The first set of six monitors was exposed at 500 ppm N<sub>2</sub>O gas, 60% RH, and 25 °C for 2 hours. The second set of six monitors was exposed under the same conditions as the first set except that the monitors were exposed continuously for another four hours in air which contained no N<sub>2</sub>O. As shown in Table 6, the difference between the means of the two sets in terms of ppm-hour is less than 8%. These results indicate that reverse diffusion would not be a significant problem for at least an 8-hour sampling period.

#### 4.8 High Humidity

An experiment was conducted to determine if high humidity (90% RH, 25 °C) had an effect on sample collection by the passive monitors.

4.8.1 Procedure: Because the primary and back-up adsorbent cells in the passive monitor contained the same adsorbent material as the active cartridge, two separate tests were performed for active and passive samples.

4.8.2 Four sets of active samples were taken for a variety of sampling times at a flowrate of between 10 and 20 cc/min. Each set contained five samples.

4.8.3 Six passive monitors were simultaneously exposed for 7 hours according to the procedure described in Appendix A.

4.8.4 All active and passive samplers were sent to the manufacturer for analysis.

4.8.5 Results: The results of this high humidity study are shown in Tables 7 and 8 for active and passive samples, respectively. As can be seen, the results of all active samplers indicate that no significant changes are found among them for sampling times of 30, 60, 100, and 120 minutes. Table 8 also shows that passive monitors can accurately and precisely measure known N<sub>2</sub>O challenges at relative humidities of 60 and 90% and N<sub>2</sub>O concentrations as high as 500 ppm for an 8-hour shift.

#### 4.9 Comparison of Landauer Active Sampling and Passive Monitor Methods for N<sub>2</sub>O:

A study was conducted to compare the performance of Landauer active cartridge samplers with that of Landauer passive monitors for determining N<sub>2</sub>O concentrations at 25 °C and 60% RH. All active cartridges and passive monitors were exposed simultaneously using the same environmental conditions. Table 9 summarizes the data for comparison of these two sampling methods. As shown, the pooled coefficients of variation CV<sub>2</sub> (pooled) are 4.9 and 13.5% with average recoveries in terms of percentage (%) over the concentration range studied of 99.3 and 98.7% for active cartridges and passive monitors, respectively.

#### 4.10 Summary and Conclusion:

The Landauer N<sub>2</sub>O monitors offer significant advantages over traditional methods, particularly in the area of convenience. The monitors show good accuracy and precision except at the lowest concentration of 12 ppm where the mass collected is very close to the detection limit claimed by the manufacturer. The CVs of monitors over concentrations from 25 to 500 ppm are less than ±10%. The average recoveries in comparison with the active cartridges are close to 100%.

The monitors show excellent stability after exposure. There were no significant differences between monitors analyzed after two days (Note: This is the minimum time required to send to the manufacturer for analysis) and monitors analyzed after 30 days. There is no evidence to show that the reverse diffusion and high humidity can affect the performance of the monitor over an 8-hour shift. One disadvantage is the manufacturer requirement to have monitors analyzed at the manufacturer's laboratory.

## 5. References

- 5.1 National Institute for Occupational Safety and Health (NIOSH): *Criteria for a Recommended Standard - Occupation Exposure to Waste Anesthetic Gases and Vapors*, (DHEW/NIOSH Pub. No. 77-140 77) Cincinnati, OH: NIOSH, 1977.
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- 5.9 Occupational Safety and Health Administration Analytical Laboratory: Evaluation of 3M Formaldehyde Monitors (Model 3751) by J.C. Ku (Product Evaluation no. ID-139). Salt Lake City, UT: OSHA Analytical Laboratory, 1982.



5.10 Wilks Scientific Corp: *Miran 103 (Gas Analyzer) Operating Manual*, South Norwalk, CT: Wilks Scientific Corporation, no publication date given.

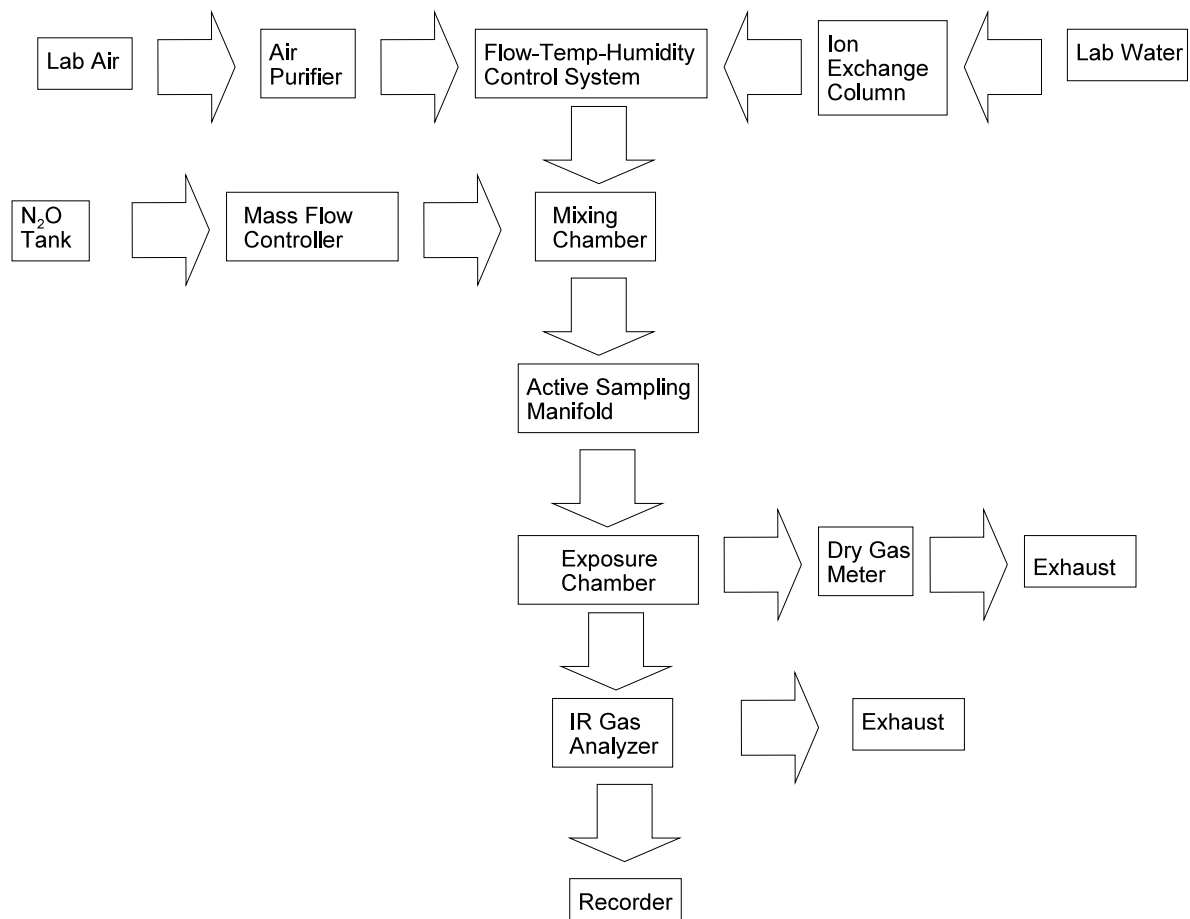


Figure 1. Block Diagram of the Major Components in a Dynamic Generation System

Table 1  
Concentration of Neat Nitrous Oxide

No.	µL Spiked	µg Taken	µg Found	Statistical	Analysis
S01	100	156.28	155.89	n	10
S02			152.54	Mean, µg	154.11
S03			149.41	Std Dev, µg	5.00
S04			142.86	CV <sub>1</sub> , %	3.2
S05			157.53	Purity, %	98.8
S06			155.52		
S07			155.78		
S08			160.00		
S09			157.74		
S10			156.78		
S11	50	78.14	75.96	n	10
S12			78.00	Mean, µg	77.98
S13			71.46	Std Dev, µg	3.12
S14			78.12	CV <sub>1</sub> , %	4.0
S15			80.64	Purity, %	99.8
S16			77.53		
S17			76.17		
S18			79.32		
S19			79.39		
S20			83.16		
S21	250	392.44	395.21	n	4
S22			414.38	Mean, µg	395.61
S23			376.64	Std Dev, µg	15.41
S24			396.21	CV <sub>1</sub> , %	3.9
S25			LIA	Purity, %	100.8
S26	100	156.97	163.76	n	5
S27			162.85	Mean, µg	160.47
S28			160.99	Std Dev, µg	3.03
S29			156.70	CV <sub>1</sub> , %	1.9
S30			158.07	Purity, %	102.2
S31	50	78.02	78.64	n	10
S32			81.11	Mean, µg	77.49
S33			80.26	Std Dev, µg	3.25
S34			80.59	CV <sub>1</sub> , %	4.2
S35			79.32	Purity, %	99.3
S36			75.00		
S37			74.05	CV <sub>1</sub> (pooled)	3.7%
S38			79.43	Av. Purity	100.2%
S39			74.26		
S40			72.23		

LIA = Lost in analysis

Table 2  
Preliminary Experiments  
Checking the Generation System Using Landauer Active Sampling Cartridges  
(60% RH and 25 °C)

Sample No.	Air Vol L	Mass Found $\mu\text{g}$	N <sub>2</sub> O Conc		Statistical	Analysis
			mg/m <sup>3</sup>	ppm**		
G01	0.926	70.76	76.41	49.11	n	7
G02	0.838	62.52	74.61	47.95	Mean, ppm	46.60
G03	1.132	86.31	76.25	49.01	Std Dev, ppm	2.50
G04	1.227	84.88	69.18	44.46	CV <sub>2</sub> , %	5.37
G05	0.892	Lost	In	Analysis	Theor. ppm**	50.00
G06	1.395	Lost	In	Analysis		
G07	1.266	86.22	68.10	43.77		
G08	1.722	129.17	74.97	48.19		
G09	1.835	230.67	125.71*	80.79*		
G10	1.328	90.28	67.98	43.69		
G11	0.925	60.49	65.39*	42.03*	n	8
G12	0.840	57.12	68.00*	43.71*	Mean, ppm	25.55
G13	1.134	46.96	41.41	26.62	Std Dev, ppm	0.83
G14	1.220	47.27	38.75	24.90	CV <sub>2</sub> , %	3.26
G15	0.869	33.64	38.71	24.88	Theor. ppm**	25.00
G16	1.386	55.33	39.92	25.66		
G17	1.255	49.89	39.75	25.55		
G18	1.697	71.23	41.97	26.98		
G19	1.850	71.86	38.84	24.97		
G20	1.295	50.05	38.65	24.84		

\* Excluded from statistical analysis

\*\* (@ NTP = 25 °C & 760 mmHg)

Table 3  
Precision and Accuracy for  
Landauer N<sub>2</sub>O Active Sampling Cartridges  
(60% RH and 25 °C)

Sample No.	Air Vol L	Mass Found $\mu\text{g}$	N <sub>2</sub> O Conc		Statistical	Analysis
			mg/m <sup>3</sup>	ppm*		
GA21	1.087	182.52	167.91	107.11	n	10
GA22	0.974	168.84	173.34	110.59	Mean, ppm	109.52
GA23	1.480	259.09	175.06	111.68	Std Dev, ppm	1.79
GA24	1.619	276.27	170.64	108.86	CV <sub>2</sub> , %	1.63
GA25	0.948	164.83	173.87	110.91	Recovery, %	99.6
GA26	0.924	158.07	171.07	109.13	Known ppm*	110.00
GA27	0.826	141.31	171.08	109.14		
GA28	1.255	213.18	169.86	108.36		
GA29	1.369	229.90	167.93	107.13		
GA30	0.813	143.06	175.97	112.26		
GA31	1.380	100.25	72.64	46.84	n	10
GA32	1.248	89.30	71.55	46.14	Mean, ppm	46.21
GA33	1.894	132.55	69.98	45.12	Std Dev, ppm	1.15
GA34	2.076	145.29	69.99	45.12	CV <sub>2</sub> , %	2.50
GA35	1.186	86.93	73.30	47.26	Recovery, %	92.4
GA36	1.380	103.13	74.73	48.18	Known ppm*	50.00
GA37	1.248	91.26	73.13	47.15		
GA38	1.886	133.06	70.55	45.49		
GA39	2.071	143.07	69.08	44.54		
GA40	1.199	85.94	71.68	46.21		

Sample No.	Air Vol L	Mass Found µg	N <sub>2</sub> O Conc		Statistical	Analysis
			mg/m <sup>3</sup>	ppm*		
GA41	1.855	30.90	16.66	10.66	n	10
GA42	1.666	29.07	17.45	11.17	Mean, ppm	10.86
GA43	2.530	41.82	16.53	10.58	Std Dev, ppm	0.34
GA44	2.770	46.00	16.61	10.63	CV <sub>2</sub> , %	3.10
GA45	1.590	26.35	16.57	10.60	Recovery, %	86.9
GA46	1.862	31.79	17.07	10.92	Known ppm*	12.50
GA47	1.665	28.38	17.05	10.91		
GA48	2.534	42.47	16.76	10.72		
GA49	2.766	46.24	16.72	10.70		
GA50	1.615	29.42	18.22	11.66		
GA51	1.462	56.71	38.79	24.97	n	10
GA52	1.312	51.87	39.54	25.45	Mean, ppm	25.52
GA53	1.994	78.39	39.31	25.31	Std Dev, ppm	0.51
GA54	2.184	84.56	38.72	24.93	CV <sub>2</sub> , %	2.00
GA55	1.261	50.01	39.66	25.53	Recovery, %	101
GA56	1.474	57.61	39.08	25.16	Known ppm*	25.00
GA57	1.313	49.30	37.55	24.17		
GA58	1.990	79.98	40.19	25.87		
GA59	2.176	85.16	39.14	25.19		
GA60	1.271	51.18	40.27	25.92		
GA61	1.868	75.39	40.36	25.82	n	10
GA62	1.663	69.32	41.68	26.67	Mean, ppm	26.30
GA63	2.535	104.86	41.36	26.47	Std Dev, ppm	0.63
GA64	2.761	115.33	41.77	26.73	CV <sub>2</sub> , %	2.40
GA65	1.612	68.20	42.31	27.07	Recovery, %	105
GA66	1.876	75.36	40.17	25.70	Known ppm*	25.00
GA67	1.661	69.49	41.84	26.77		
GA68	2.520	101.02	40.09	25.65		
GA69	2.745	108.27	39.44	25.24		
GA70	1.589	66.66	41.95	26.84		
GA71	0.449	384.19	855.66	554.23	n	9
GA72	0.380	339.62	893.74	578.90	Mean, ppm	545.24
GA73	0.571	Lost	In	Analysis	Std Dev, ppm	20.81
GA74	0.631	539.83	855.52	554.14	CV <sub>2</sub> , %	3.82
GA75	0.420	346.56	825.14	534.47	Recovery, %	109
GA76	0.447	366.97	820.96	531.76	Known ppm*	500.00
GA77	0.380	335.39	882.61	571.69		
GA78	0.566	470.86	831.91	538.85		
GA79	0.630	505.07	801.70	519.28		
GA80	0.415	335.62	808.72	523.83		
GA81	0.887	749.03	844.45	546.14	n	19
GA82	0.762	618.65	811.88	525.07	Mean, ppm	516.59
GA83	1.140	923.64	810.21	523.99	Std Dev, ppm	41.36
GA84	1.264	1063.36	841.27	544.08	CV <sub>2</sub> , %	8.01
GA85	0.824	642.26	779.44	504.09	Recovery, %	103
GA86	0.448	<1*			Known ppm***	500.00
GA87	0.381	330.03	866.22	560.22		
GA88	0.570	351.88	617.33	399.25	CV <sub>2</sub> (pooled), %	4.64
GA89	0.630	527.51	837.32	541.52	Ave. Recovery, %	99.6
GA90	0.430	343.36	837.26	541.62		
GA91	1.800	1294.23	719.02	465.01		
GA92	1.525	1178.50	772.79	499.79		
GA93	2.287	2093.73	915.49	592.08		
GA94	2.522	2095.36	830.83	537.33		
GA95	1.635	1264.97	773.68	500.37		
GA96	1.499	1104.59	736.88	476.57		
GA97	1.270	1031.42	812.14	525.24		
GA98	1.902	1513.91	795.96	514.77		
GA99	2.101	1719.76	818.54	529.38		
GA100	1.356	1024.56	755.57	488.66		

\* Excluded from statistical analysis

\*\* The environmental conditions of 90% RH and 25 °C were used.  
 \*\*\* (@ NTP)

Table 4  
 Precision and Accuracy for Landauer N<sub>2</sub>O Passive Monitors  
 (60% RH and 25 °C)

Known ppm**	Samp Time Min	Sample No.	N <sub>2</sub> O Conc'n		Statistical	Analysis
			µg	ppm**		
12.50	420	GP25	3.21	7.28	n	6
		GP26	3.13	7.10	Mean, ppm	9.58
		GP27	5.50	12.47	Std Dev, ppm	2.72
		GP28	4.11	9.23	CV <sub>2</sub> , %	28.3
		GP29	3.50	7.94	Recovery, %	88.2
		GP30	5.90	13.38		
25.00	420	GP41	11.51	26.11	n	6
		GP42	9.16*	20.78	Mean, ppm	23.44
		GP43	11.59	26.29	Std Dev, ppm	2.40
		GP44	9.23*	20.93	CV <sub>2</sub> , %	10.20
		GP45	10.34	23.45	Recovery, %	89.0
		GP46	10.18	23.09		
50.00	420	GP19	22.68	51.84	n	6
		GP20	17.97	41.08	Mean, ppm	45.60
		GP21	17.00	38.86	Std Dev, ppm	5.47
		GP22	19.49	44.55	CV <sub>2</sub> , %	11.99
		GP23	22.83	52.19	Recovery, %	98.7
		GP24	19.72	45.10		
110.00	300	GP13	34.36	105.68	n	6
		GP14	34.52	106.17	Mean, ppm	103.89
		GP15	32.69	100.54	Std Dev, ppm	3.54
		GP16	35.08	107.89	CV <sub>2</sub> , %	3.40
		GP17	33.92	104.32	Recovery, %	94.9
500.00	120	GP51	86.26	622.50	n	5
		GP52	79.16	571.26	Mean, ppm	610.79
		GP53	86.40	623.51	Std Dev, ppm	24.66
		GP54	87.78	633.46	CV <sub>2</sub> , %	4.00
		GP55	Lost In	Analysis	Recovery, %	112.00
		GP56	83.59	603.23		
500.00	420	GP63	248.88	570.63	n	8
		GP64	211.05	483.90	Mean, ppm	569.30
		GP65	249.34	571.69	Std Dev, ppm	36.45
		GP66	256.96	589.16	CV <sub>2</sub> , %	6.40
		GP67	252.45	578.82	Recovery, %	110.2
		GP68	254.77	584.14		
		GP69	248.93	570.75		
		GP70	263.99	605.28		

\* Some N<sub>2</sub>O found in backup cartridge.

\*\* (@ NTP)

<u>Concentration Range, ppm*</u>	<u>CV<sub>2</sub>(pooled), %</u>	<u>Avg. Recovery, %</u>
12.50 - 500.00	13.5	98.7
25.00 - 110.00	9.3	93.1
25.00 - 500.00	8.0	103.1

\* (@ NTP)

Table 5  
 Storage Stability for Landauer N<sub>2</sub>O Passive Monitors  
 (60% RH and 25 °C)

Known ppm**	Sample Age Days	Sample No.	N <sub>2</sub> O Found ppm	Statistical	Analysis
25.00	2	GP41	26.11	n	6
		GP42	20.78*	Mean, ppm	23.44
		GP43	26.29	Std Dev, ppm	2.40
		GP44	20.93	CV <sub>2</sub> , %	10.20
		GP45	23.45		
		GP46	23.09		
25.00	7	GP31	25.02	n	5
		GP32	24.74	Mean, ppm	26.64
		GP33	30.75	Std Dev, ppm	2.53
		GP34	25.29	CV <sub>2</sub> , %	9.50
		GP35	27.41		
25.00	15	GP36	21.80	n	5
		GP37	25.04	Mean, ppm	25.16
		GP38	29.58	Std Dev, ppm	3.37
		GP39	22.02	CV <sub>2</sub> , %	13.4
		GP40	27.34		
25.00	30	GP47	22.75	n	4
		GP48	22.75	Mean, ppm	21.58
		GP49	20.53	Std Dev, ppm	1.35
		GP50	20.30	CV <sub>2</sub> , %	6.26

\* Some N<sub>2</sub>O found in backup cartridges.

\*\* (@ NTP)

Table 6  
Reverse Diffusion for Landauer N<sub>2</sub>O Passive Monitors

Exposure Time Hrs	Sample No.	N <sub>2</sub> O Conc'n			Statistical	Analysis
		µg	ppm*	ppm-hour		
2	GP51	86.26	622.50	1245.0	n	5
	GP52	79.16	571.26	1142.5	Mean, ppm-hrs	1221.6
	GP53	86.40	623.51	1247.0	Std Dev, ppm-hrs	49.3
	GP54	87.78	633.46	1266.9	CV <sub>2</sub> , %	4.0
	GP55	Lost	In	Analysis		
	GP56	83.59	603.23	1206.5		
2+4 Hrs 'Zero' Air	GP57	67.69	178.95	1073.7	n	6
	GP58	73.37	193.97	1163.8	Mean, ppm-hrs	1146.8
	GP59	74.68	197.43	1184.6	Std Dev, ppm-hrs	46.3
	GP60	73.40	194.05	1164.3	CV <sub>2</sub> , %	4.0
	GP61	69.74	184.37	1106.2		
	GP62	68.59	181.33	1188.0		

Note: 1) Ratio = Mean(second set) / Mean(first set) = 1,146.8 / 1,221.6 = 0.939

\* (@ NTP)

Table 7  
High Humidity for Landauer Active Cartridges  
(90% RH and 25 °C)(Known Conc'n = 500.00 ppm)

Sample No.	Air Vol L	Mass Found µg	N <sub>2</sub> O Conc'n		Statistical	Analysis
			mg/m <sup>3</sup>	ppm**		
GA81	0.887	749.03	844.45	546.14	n	5
GA82	0.762	618.65	811.88	525.07	Mean, ppm	528.67
GA83	1.140	923.64	810.21	523.99	Std Dev, ppm	17.19
GA84	1.264	1063.36	841.27	544.08	CV <sub>2</sub> , %	3.25
GA85	0.824	642.26	779.44	504.09	Recovery, %	106
GA86	0.448	<1*			n	4
GA87	0.381	330.03	866.22	560.22	Mean, ppm	510.65
GA88	0.570	351.88	617.33	399.25	Std Dev, ppm	74.79
GA89	0.630	527.51	837.32	541.52	CV <sub>2</sub> , %	14.65
GA90	0.430	343.36	837.26	541.62	Recovery, %	102
GA91	1.800	1294.23	719.02	465.01	n	5
GA92	1.525	1178.50	772.79	499.79	Mean, ppm	518.92
GA93	2.287	2093.73	915.49	592.08	Std Dev, ppm	48.24
GA94	2.522	2095.36	830.83	537.33	CV <sub>2</sub> , %	9.3
GA95	1.635	1264.97	773.68	500.37	Recovery, %	104
GA96	1.499	1104.59	736.88	476.57	n	5
GA97	1.270	1031.42	812.14	525.24	Mean, ppm	506.92
GA98	1.902	1513.91	795.96	514.77	Std Dev, ppm	23.22
GA99	2.101	1719.76	818.54	529.38	CV <sub>2</sub> , %	4.58
GA100	1.356	1024.56	755.57	488.66	Recovery, %	101

\* Excluded from statistical analysis

\*\* (@ NTP)

Notes: (1) Sampling time taken = 60 minutes for first set, = 30 minutes for second set, = 120 minutes for third set, = 100 minutes for fourth set

(2) Sampling rate taken = 10 - 20 cc/min

Table 8  
High Humidity Test for Landauer Passive Monitors  
A Comparison Study

60% RH and 25 °C		90% RH and 25 °C	
Known N <sub>2</sub> O Conc ppm**	N <sub>2</sub> O Found ppm**	Known N <sub>2</sub> O Conc ppm**	N <sub>2</sub> O Found ppm**
500.00	622.50	500.00	570.63
	571.26		483.90
	623.51		571.69
	633.46		589.16
	Lost In Analysis		578.82
	603.23		584.14
			570.75
			605.28
n	5	n	8
Mean	610.79	Mean	569.30
Std Dev	24.66	Std Dev	36.45
CV <sub>2</sub> , %	4.04	CV <sub>2</sub> , %	6.40
Recovery, %	122	Recovery, %	114

where:

Recovery = Mean, ppm / Theoretical, ppm, i.e., for 60% RH Recovery = 611 / 500 = 122 %

\*\* (@ NTP)

Table 9  
Summary of Comparison of Methods  
Active Cartridges vs. Passive Monitors

	Active Cartridges	Passive Monitors
Theor. concn, ppm	10	10
# of samples	10	6
Mean, ppm*	10.86	9.58
Std dev, ppm	0.34	2.72
CV <sub>2</sub> , %	3.1	28.3
Recovery, %	86.9	76.6
Theor. concn, ppm	25	25
# of samples	10	6
Mean, ppm*	26.34	23.44
Std dev, ppm	0.70	2.40
CV <sub>2</sub> , %	2.6	10.2
Recovery, %	105	93.8
Theor. concn, ppm	50	50
# of samples	10	6
Mean, ppm*	46.21	45.6
Std dev, ppm	1.15	5.47
CV <sub>2</sub> , %	2.5	12.0
Recovery, %	92.4	91.2
Theor. concn, ppm	110	110.6
# of samples	10	6
Mean, ppm*	109.52	103.89
Std dev, ppm	1.77	3.54
CV <sub>2</sub> , %	1.6	3.4
Recovery, %	99.6	94.4
Theor. concn, ppm	500	500
# of samples	9	5
Mean, ppm*	545.24	610.79
Std dev, ppm	20.81	24.66
CV <sub>2</sub> , %	3.8	4.0
Recovery, %	109	122



	Active Cartridges	Passive Monitors
Theor. concn, ppm	500	500
# of samples	19	8
Mean, ppm*	516.59*	569.30*
Std dev, ppm	41.36	36.45
CV <sub>2</sub> , %	8.0	6.4
Recovery, %	103	114
CV <sub>2</sub> (pooled), %	4.9	13.5
Avg. Recovery, %	99.3	98.7

\* (@ NTP)

Note: (1) All samples, active cartridges and passive monitors, were analyzed by the manufacturer, R.S. Landauer, Jr. Co.

(2) The same environmental conditions were used for comparison

(3) The flowrates of 10 to 20 cc/min were used for active samples.

(4) The sampling times were varied from 30 to 120 minutes for active samples and from 120 to 420 minutes for passive samples.

(5) Recovery = Mean, ppm / Theoretical, ppm, e.g., for the sixth set Passive Monitor results above, Recovery = 569/500 = 114%

### Appendix A

1. Adjust the total flow rate in the dynamic generation system to determine the theoretical generated N<sub>2</sub>O concentration which is based on the flow rate controlled by the mass flow controller from the N<sub>2</sub>O gas tank.

For example:

Total flow rate = 20 L/min

N<sub>2</sub>O flow rate = 2.0 cc/min

Therefore, the theoretical N<sub>2</sub>O concentration in the generation system is equal to 100 ppm.

2. Remove each monitor from the package and record the sample number.
3. Before exposing to the exposure chamber, attach (or hang) a minimum of six monitors on the Teflon sticker.
4. Remove each cap from the head of each monitor by using a "breaking" motion and store the cap by snapping it snugly onto the base of the monitor.
5. Open the top of the exposure chamber and put the Teflon sticker with the monitors into the chamber.
6. Close and tighten the top by using a metal U-clamp to prevent leakage between the top and the chamber.
7. Simultaneously expose the monitors and the active cartridges.
8. Remove the active cartridges after 30 or 60 minutes at a flow rate of between 10 and 20 cc/min, depending on the nitrous oxide concentrations.
9. At the conclusion of the sampling period, immediately remove the sticker from the chamber and the monitors from the sticker.
10. Record the end time and total exposure time.
11. Remove each cap from the base of each monitor by using a "breaking" motion and close the monitor by snapping the cap snugly to the head.
12. Seal and pack the monitors before sending to the manufacturer for analysis.

## ADDENDUM FIELD COMPARISON OF NITROUS OXIDE SAMPLING PROCEDURES

Note: This field study was conducted by Ed Zimowski, Senior Industrial Hygienist, OSHA Health Response Team (HRT), Salt Lake City, UT. The study was performed during 1983-84.

### BACKGROUND

The adverse health effects of waste anesthetic gases and vapors have been documented for some time. Several epidemiological studies have shown an increased incidence of spontaneous abortions and congenital abnormalities in the children of both female workers and wives of male workers exposed to anesthetic gases. Studies show that exposed personnel have suffered damage to the liver and kidneys and demonstrated symptoms of possible central nervous system effects.

Although OSHA presently does not have a Permissible Exposure Limit for employees exposed to anesthetic gases, NIOSH has recommended a limit in *Criteria for a Recommended Standard. . . Occupational Exposure to Waste Anesthetic Gases and Vapors* published in March, 1977. NIOSH recommends that when used as the sole anesthetic agent, no worker be exposed to TWA concentrations of nitrous oxide greater than 25 ppm during anesthetic administration. With available technology, exposure levels of 50 ppm and less for nitrous oxide are attainable in dental offices. [After this study was performed the American Conference of Governmental Industrial Hygienists (ACGIH) adopted in 1989 a TWA Threshold Limit Value (TLV) of 50 ppm nitrous oxide.]

### SAMPLING PROCEDURES

Until recently, the only procedure available for monitoring employee exposure to nitrous oxide was sampling in gas sampling bags and subsequent infrared (IR) analysis using a direct reading portable infrared analyzer (OSHA has used the MIRAN IA, 1B, or 103). This normally involved pre- and post-sampling calibration of the instrument in the laboratory and shipment of the equipment to the local area office requesting the equipment. Due to the potential of the instrument losing calibration during shipment and lack of trained field personnel familiar with the equipment, it was often necessary for an HRT member to travel to the local area office to perform training and to assist the compliance officer in the inspection.

Due to the difficulties involved with monitoring employee exposure to nitrous oxide, a field comparison of sampling procedures was performed. The methods chosen for comparison included: (1) gas sampling bag collection and analysis by IR spectrophotometry, (2) Siemens Gammasonics, Inc. nitrous oxide monitor, and (3) R.S. Landauer NITROX dosimetry system. During the evaluation Siemens withdrew their dosimeter from the market.

### SAMPLING PROTOCOL

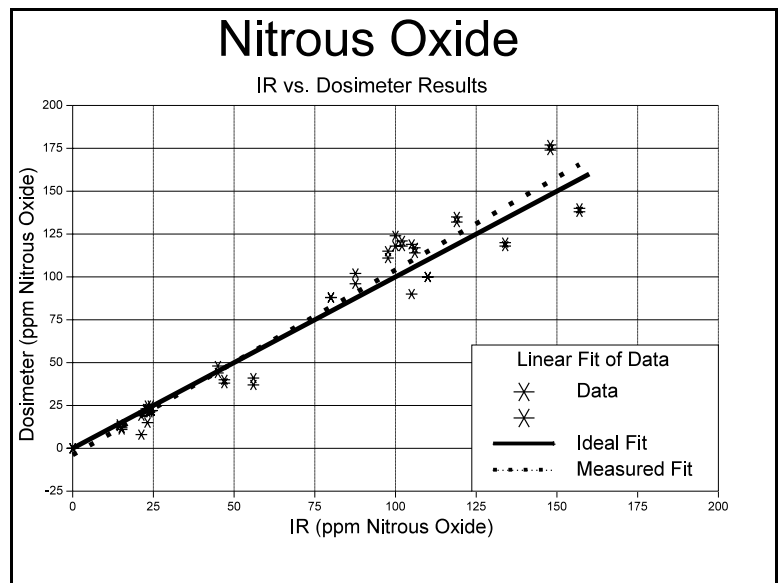
Area air samples were collected in the operatory rooms of a dental clinic by placing two Landauer dosimeters, one on either side of a piece of Tygon tubing. The Tygon tube was attached to the vacuum side of a Du Pont P125 sampling pump. The exhaust port of the pump was connected by Tygon tubing to the inlet of an evacuated 20-liter multi-layer sampling bag (Calibrated Instruments, Inc., Ardsley, NY). Area sampling was used because it allowed a wider range of concentrations to be studied. Due to the low sampling rate of the dosimeters, approximately 2 cc/min, starvation of the badges would not occur. Samples were collected for a minimum of 2 hours.

## SAMPLE ANALYSIS

The Landauer dosimeters were returned to the manufacturer for analysis because the method of analysis is proprietary. The sampling bags were analyzed on-site using a MIRAN 103 portable IR with a 4.5 micron nitrous oxide filter. The MIRAN was pre- and post-calibrated at the OSHA HRT Laboratory in Salt Lake City, UT with a Teflon calibration loop by injecting known amounts of pure nitrous oxide into the cell with a gas-tight syringe. A calibration curve was plotted using the actual concentration of nitrous oxide in the calibration loop as the abscissa and the IR scale readings as the ordinate. Each sampling bag was analyzed by attaching the inlet port to the IR and recording the scale reading. The reading was then converted to ppm at Salt Lake City's altitude (640 mmHg) using the calibration curve. This value was then converted to ppm at 760 mmHg for comparison with the passive dosimeters.

## RESULTS

The results of the comparison sampling with the passive dosimeters and the multi-layer sampling bags is shown in Figure 2. Data is shown below. The two dosimeter values represent the duplicate samples collected with each bag sample.



**Figure 4**

Nitrous Oxide Field Comparison Data (760 mmHg, 25 °C)

<u>Sampling Bag</u> <u>(ppm N<sub>2</sub>O)</u>	<u>Landauer NITROX Dosimeter</u> <u>(ppm N<sub>2</sub>O)</u>
14.6	14, 13
15.2	11, 12
21.3	8, 19
22.8	22, 23
23.2	15, 21
23.3	25, 23
23.8	21, 22
24.2	22, 25
24.5	22, 22
45	44, 48
47	40, 38
56	41, 37
80	88, 88
87.6	96, 102
97.7	115, 111
100	124, 118
102	118, 121
105	119, 90
106	117, 114
110	100
119	132, 135
134	118, 120
148	174, 177
157	140, 138

CONCLUSIONS

The Landauer NITROX passive dosimeter provides an acceptable alternative to bag sampling for monitoring employee exposure to nitrous oxide. Linear regression analysis applied to the comparison data using the sampling bag procedure as the reference provided the following information.

Correlation Coefficient	0.973
Slope	1.08
Std. Dev. of the slope	0.038
Intercept	-3.81
Std. Dev. of the intercept	3.17
Std. Dev. about the regression line	12.0

The correlation coefficient shows that the range of values studied was adequate to obtain comparison information although it could have been improved by sampling at higher levels. Because of the NIOSH Recommended Exposure Limit, it was necessary to obtain data at the low concentration values. Also, the badges are designed for 40-hour exposure monitoring of hospital and dental employees and therefore the comparative data for short term (2-4 hour) periods was important.

A full laboratory validation was performed in 1985 by the Inorganic Methods Evaluation Branch on the badges and included determination of detection limits, breakthrough, accuracy, and stability.