Nitric Oxide Monitor

2B Technologies, Inc.

OPERATION MANUAL

Model 400

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IDENTIFICATION RECORDS

Record the following information for future reference:

Unit serial number: _____

Warranty start date: _____
(date of receipt)

PRINTING HISTORY

New editions are complete revisions of the manual and incorporate all previous update pages and write-in instructions. This manual will be revised as necessary. Revisions can be in the form of new editions, update pages, or write-in instructions.

Revision A.....June 2004

Revision B.....January 2005

Revision C ..... April 2005

Revision D ..... April 2006

Revision E .....October 2006

Revision F .....June 2007

TRADEMARKS & PATENTS

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CONFIDENTIALITY

The information contained in this manual may be confidential and proprietary, and is the property of 2B Technologies, Inc. Information disclosed herein shall not be used to manufacture, construct, or otherwise reproduce the goods disclosed herein. The information disclosed herein shall not be disclosed to others or made public in any manner without the expressed written consent of 2B Technologies, Inc.

WARRANTY STATEMENT

2B Technologies, Inc. warrants its products against defects in materials and workmanship. 2B Technologies will, at its option, repair or replace products which prove to be defective. The warranty set forth is exclusive and no other warranty, whether written or oral, is expressed or implied. 2B Technologies specifically disclaims the implied warranties of merchantability and fitness for a particular purpose.

Warranty Periods

The warranty period is one (1) year from date of receipt by the purchaser, but in no event more than thirteen (13) months from original invoice date from 2B Technologies, Inc.

Warranty Service

Warranty Service is provided to customers through phone support, Monday - Friday, from 9:00 a.m. to 5:00 p.m., Mountain Time USA. Phone support is for trouble-shooting and determination of parts to be shipped from 2B Technologies to the customer in order to return the product to operation within stated specifications. If phone support is not efficient and effective, the product may be returned to 2B Technologies for repair or replacement. Prior to returning the product, a Repair Authorization Number (RA) must be obtained from the 2B Technologies Service Department.

Shipping

2B Technologies will pay freight charges for replacement or repaired products shipped to the customer site. Customers shall pay freight charges for all products returning to 2B Technologies.

Conditions

The foregoing warranty shall not apply to defects resulting from improper or inadequate maintenance, adjustment, calibration or operation by customer. Maintenance, adjustment, calibration or operation must be performed in accordance with instructions stated in the Nitric Oxide Monitor manual. Usage of maintenance materials purchased from suppliers other than 2B Technologies will void this warranty.

Limitation of Remedies and Liability

The remedies provided herein are the Customer's sole and exclusive remedies. In no event shall 2B Technologies be liable for direct, indirect, special, incidental or consequential damages (including loss of profits) whether based on contract, tort or any other legal theory. The Nitric Oxide Monitor manual is believed to be accurate at the time of publication and no responsibility is taken for any errors that may be present. In no event shall 2B Technologies be liable for incidental or consequential

damages in connection with or arising from the use of the Nitric Oxide Monitor manual and its accompanying related materials. Warranty is valid only for the country designated on the 2B Technologies quote or invoice.

ENGLISH

WARNING:
Any operation requiring access to the inside of the equipment, could result in injury. To avoid potentially dangerous shock, disconnect from power supply before opening the equipment.

WARNING:
This symbol,  on the instrument indicates that the user should refer to the manual for operating instructions.

WARNING:
If this instrument is used in a manner not specified by 2B Technologies, Inc. USA, the protection provided by the instrument may be impaired.

ESPAÑOL

ATENCION:
Cualquier operación que requiera acceso al interior del equipo, puede causar una lesión. Para evitar peligros potenciales, desconectarlo de la alimentación a red antes de abrir el equipo.

ATENCION:
Este símbolo,  en el instrumento indica que el usuario debería referirse al manual para instrucciones de funcionamiento.

ATENCION:
Si este instrumento se usa de una forma no especificada por 2B Technologies, Inc., USA, puede desactivarse la protección suministrada por el instrumento.

FRANÇAIS

ATTENTION:
Chaque opération à l'intérieur de l'appareil, peut causer du préjudice. Afin d'éviter un shock qui pourrait être dangereux, disconnectez l'appareil du réseau avant de l'ouvrir.

ATTENTION:
Le symbol,  indique que l'utilisateur doit consulter le manuel d'instructions.

ATTENTION:
Si l'instrument n'est pas utilisé suivant les instructions de 2B Technologies, Inc., USA, les dispositions de sécurité de l'appareil ne sont plus valables.

DEUTSCH

WARNHINWEIS:
Vor dem Öffnen des Gerätes Netzstecker ziehen!

WARNHINWEIS:
Dieses,  auf dem Gerät weist darauf hin, dab der Anwender zuerst das entsprechende Kapitel in der Bedienungsanleitung lesen sollte.

WARNHINWEIS:
Wenn das Gerät nicht wie durch die Firma 2B Technologies, Inc., USA, vorgeschrieben und im Handbuch beschrieben betrieben wird, können die im Gerät eingebauten Schutzvorrichtungen beeinträchtigt werden.

ITALIANO

ATTENZIONE:
Qualsiasi intervento debba essere effettuato sullo strumento può essere potenzialmente pericoloso a causa della corrente elettrica. Il cavo di alimentazione deve essere staccato dallo strumento prima della sua apertura.

ATTENZIONE:
Il simbolo,  sullo strumento avverte l'utilizzatore di consultare il Manuale di Istruzioni alla sezione specifica.

ATTENZIONE:
Se questo strumento viene utilizzato in maniera non conforme alle specifiche di 2B Technologies, Inc. USA, le protezioni di cui esso è dotato potrebbero essere alterate.

DUTCH

OPGELET:
Iedere handeling binnenin het toestel kan beschadiging veroorzaken. Om iedere mogelijk gevaarlijke shock te vermijden moet de aansluiting met het net verbroken worden, vóór het openen van het toestel.

OPGELET:
Het symbool,  geeft aan dat de gebruiker de instructies in de handleiding moet raadplegen.

OPGELET:
Indien het toestel niet gebruikt wordt volgens de richtlijnen van 2B Technologies, Inc., USA gelden de veiligheidsvoorzieningen niet meer.

1. *NITRIC OXIDE MONITOR INTRODUCTION*

The 2B Technologies Nitric Oxide Monitor is designed to enable accurate measurements of nitric oxide (NO) concentrations in air without the use of a calibration gas standard. The most common application is the measurement of NO in urban and regional air pollution where the concentration is a few ppb or higher. Because of the absolute nature of the measurement, the Nitric Oxide Monitor may also be used to quantify the concentrations of calibration gas standards required by other techniques such as the commonly used NO + O_3 chemiluminescence method. The highly sensitive chemiluminescence method is required when the NO concentration is $\leq$ 2 ppb. For measurements at low ppb levels and higher the Nitric Oxide Monitor has advantages over chemiluminescence of portability (small size and weight, low power consumption) and lack of requirement of a gas calibration standard. A U.S. patent has been issued (U.S. Patent No. 7,045,359, May 16, 2006) and foreign patents are pending for this new detection technique.

Theory of Operation

The principle of operation of the Nitric Oxide Monitor is based on the quantitative reaction of nitric oxide with ozone (O_3):

$$NO + O_3 \rightarrow NO_2 + O_2 + light \qquad (1)$$

This reaction has long been used as a gas phase titration for the measurement of either NO or O_3 in laboratory kinetics experiments, and the reaction is stoichiometric; i.e., one O_3 molecule is consumed for every NO molecule oxidized to NO_2 in the reaction. In the Nitric Oxide Monitor, a small concentration of ozone (~3-5 ppm) is added to the gas sample stream and the resulting decrease in concentration of ozone is measured. The change in ozone concentration is measured by the absolute method of UV absorption, and its decrease is equal to the original concentration of NO in the gas stream, provided that adequate time has been allowed for the reaction to go to completion.

Reaction 1 also is used in conventional chemiluminescence analyzers. Instead of measuring the change in ozone concentration, chemiluminescence detects the small amount of light produced in the reaction. That light is emitted by electronically excited NO_2 molecules formed in reaction 1. Chemiluminescence instruments are highly sensitive and have a very fast response time, but require frequent calibration using a gas standard. One application of the Nitric Oxide Monitor is measurement of the concentration of

NO in gas calibration standards, thereby assuring accuracy of chemiluminescence analyzers.

Figure 1 is a schematic diagram of the Nitric Oxide Monitor. Here we trace the gas flow through the instrument beginning at the bottom of the diagram. A miniature air pump, Air Pump #1, draws sample air into the instrument at a flow rate of 0.8-1.6 L/min. The gas sample passes through a miniature solenoid valve which alternately directs the flow through a NO scrubber or bypass, a Nafion tube (DewLine™), a mass flow meter to measure the Sample Flow, and then into an overflow tee which vents part of the air sample. The Nafion tube equilibrates the humidity of the sample air with that inside the instrument case, assuring that the humidity is the same in scrubbed and unscrubbed air samples. A fraction of the sample air (typically 600 cc/min) is drawn from the overflow tee by Air Pump #2, which pumps the scrubbed or unscrubbed sample air into the reference absorption cell. In the Reference Cell UV light intensity, I_{ref}, is measured at 254 nm using a low pressure mercury lamp and photodiode. The purpose of the reference cell is to correct for ambient ozone. Needle Valve #1 (accessed on the lower back of the instrument case) is used for rough adjustment of the flow rate through the reference cell (when in Manual Mode). Fine adjustment of this flow rate is made by the microprocessor by pulse width modulating the speed of Air Pump #2. Following the reference cell, a small flow of ozonized air is added to the sample air stream. (Ozone production and its measurement are discussed below.) The flow rate of ozone/air is regulated by Needle Valve #2, and is set to produce a flow of typically 20-30 cc/min. This flow constitutes typically less than 5% of the total flow rate.

The sample air containing added ozone next passes through a coiled reactor, which provides adequate reaction time (typically 3.5-4.5 s) for nearly all NO in the sample to react with ozone via reaction 3 above. As discussed below correction is made in the software for lack of complete reaction. That correction is typically less than 2%. The sample air, now depleted in ozone by the amount of NO originally present in the air sample, next passes through the Detection Cell where UV light intensity is again measured. From there the air stream passes through an Ozone Scrubber where O_3 is catalytically converted to O_2, through a Mass Flow Meter where the Total Flow Rate is measured, and to the instrument case. The state of Solenoid Valve #1 is switched every 10 seconds in order to measure light intensities for sample air, I_{ref} and I, and scrubbed sample air, $I_{ref,o}$ and I_o. The values of I_{ref}, I, $I_{ref,o}$ and I_o are used to calculate the concentration of NO in the original air sample, as discussed in detail below. In addition to a small correction for incomplete reaction, a correction is made for the small amount of dilution of the NO concentration by the added ozonized air based on flow rate measurements.

Ozone is produced by pumping ambient air through a Pyrex tube containing a low pressure mercury lamp. The lamp has a fused silica window that passes highly energetic atomic emission near 185 nm in addition to the resonant emission at 254-nm. The wavelengths near 185-nm are absorbed by molecular oxygen (O_2) to produce oxygen atoms (O). Those oxygen atoms rapidly attach to O_2 via a termolecular reaction to form O_3:

$$O_2 + h\nu \rightarrow 2\ O \tag{2}$$

$$O + O_2 + M \rightarrow O_3 + M \tag{3}$$

Here, $h\nu$ indicates a photon of light having a wavelength near 185 nm, and M is any molecule, principally N_2, O_2, Ar and H_2O in air. The molecule M catalyzes the combination of O and O_2 by removing excess translational energy. As noted above, the flow rate of ozone/air is controlled by needle valve #2 (accessed on the upper back of the instrument case). The ozone concentration should be adjusted to be in the range 3-5 ppm to maintain high precision of the measurements. As discussed below, when in Auto Mode, the instrument automatically adjusts the ozone concentration to be very near 4 ppm by pulse modulation of the ozone source lam intensity.

Flow rates and the actual ozone concentration produced are measured in a cycle at the beginning of an analysis by modulating solenoid valve #2. This valve either allows the ozone/air mixture to enter the stream of gas being analyzed or diverts it to an ozone scrubber. Alternating the states of solenoid valve #2 results in a square-wave modulation of the ozone concentration reaching the detection cell.

The ozone reagent and nitric oxide concentrations are measured based on the transmission of light passing through 15-cm long absorption cells fitted with quartz windows. As discussed above, reagent ozone concentration is measured by modulating solenoid valve #2, and sample NO concentration is measured by modulating solenoid valves #1. A low-pressure mercury lamp is located on one side of the absorption cells, and photodiodes are located on the opposite side. The photodiodes have built-in interference filters centered on 254 nm, the principal wavelength of light emitted by the mercury lamp. Shorter wavelengths of light that could produce ozone are absorbed by the low-grade quartz envelope of the lamp itself and by the window of the detection cell, which passes 254-nm but not 185-nm light.

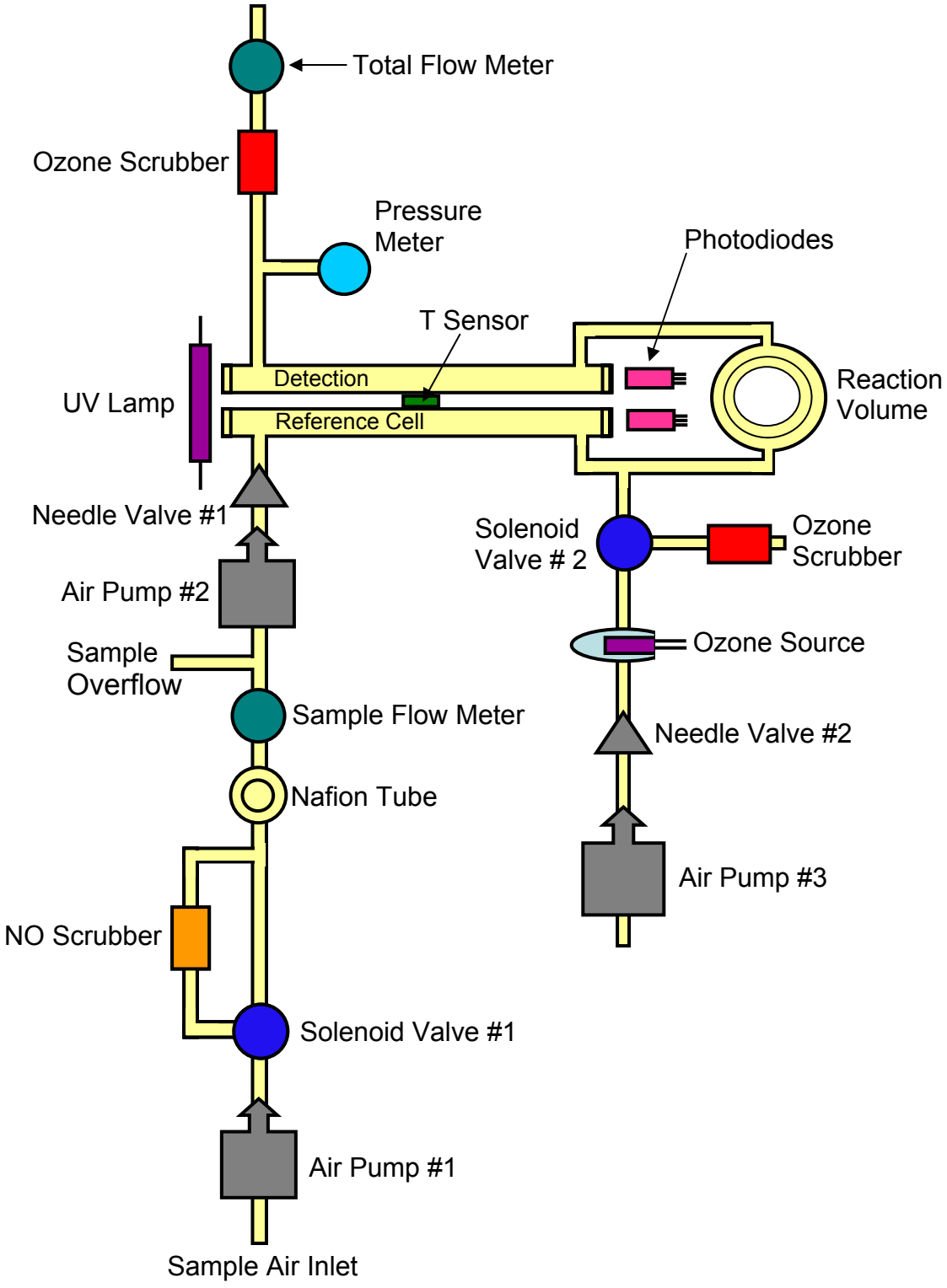

Figure 1. Schematic diagram of the Nitric Oxide Monitor. The actual plumbing configuration may vary from this schematic diagram.

For the measurement of ozone reagent concentration, the intensity of light at the Detection Cell photodiode is measured in NO-scrubbed sample air that has no ozone added (I_o) and in NO-scrubbed sample air that has ozone added (I). The ozone concentration is given by the Beer-Lambert Law:

$$C = \frac{1}{\sigma l} \ln\left(\frac{I_o}{I}\right) \tag{4}$$

where l is the path length (15 cm) and σ is the absorption cross section for ozone at 254 nm (1.15 x 10^{-17} cm^2 $molecule^{-1}$ or 308 atm^{-1} cm^{-1}), which is known with an accuracy of approximately 1%. The concentration of ozone reagent is measured each time the instrument is turned on and can be remeasured at any time by briefly pressing the select switch on the front panel. As discussed below, one can also schedule measurements and readjustments of the total flow rate and ozone concentration. Reagent ozone is measured to be certain that sufficient ozone is present to cause nearly complete reaction with NO in the sampled air and for the purpose of making a small correction for incomplete reaction. After an ozone measurement and adjustment cycle, the instrument automatically enters NO Measurement Mode and continues to measure NO until 1) the instrument is powered off, 2) the operator uses the select button to remeasure and adjust ozone, or 3) a scheduled ozone measurement occurs.

For NO measurements, I_o and $I_{o,ref}$ are measured when NO-scrubbed air is passing through both absorption cells, and I and I_{ref} are measured when unscrubbed air is passing through both absorption cells. Equation 4 is used to calculate ambient ozone in the reference cell, $C_{O3,ref}$, and ambient O_3 minus ambient NO in the detection cell, $(C_{O3\text{-}NO})_{det}$. Ambient NO concentration is then calculated by subtraction of the two measurements:

$$C_{NO} = C_{O_3,ref} - \frac{F_{total}}{F_{total} - F_{ozone}} \left(C_{O_3-NO}\right)_{\text{det}} \tag{5}$$

where $F_{total}/(F_{total}-F_{ozone})$ is correction factor (typically less than 5%) for dilution of the sample gas by the addition of ozone/air to the Detection Cell. F_{ozone} is determined by measuring the total flow rate with and without ozone added; i.e., by

Application of equation 4 gives ozone and nitric oxide concentrations in units of molecules/cm^3. The pressure and temperature within the absorption

cell are measured using miniature sensors in order to calculate the total concentration of gas molecules. This allows nitric oxide and ozone concentrations to be expressed as mixing ratios in parts-per-billion by volume (ppb):

$$X(ppb) = C\left(\frac{T(K)}{273.16}\right)\left(\frac{1012.95}{P(mbar)}\right)10^9 \quad (6)$$

Note that the abbreviations ppb and ppm refer throughout this manual to volume/volume or mole/mole ratios.

Finally, a small correction (~1%) for incomplete reaction is made to the measured NO concentration based on the reagent ozone concentration and reaction time (determined by total volumetric flow rate and reactor volume).

In principle, the measurement of ozone by UV absorption requires no external calibration; it is an absolute method. However, non-linearity of the photodiode response and associated electronics can result in a small measurement error. Therefore, each Nitric Oxide Monitor is itself calibrated against a nitric oxide standard gas, the concentration of which is periodically verified by a 2B Technologies Nitric Oxide Calibrator, whose calibration is traceable to a NIST standard. The corrections for offset and slope are recorded in the instrument Birth Certificate and on a calibration sticker that can be viewed by removing the top cover of the instrument. These calibration parameters are entered into the microprocessor prior to shipment. It is recommended that the instrument be returned to 2B Technologies for recalibration at least once annually.

NITRIC OXIDE MONITOR SPECIFICATIONS

Power Requirements ..... 11-14 V DC, nominally 0.9 A at 12 V, 11 watt

Dimensions ..... 3.5” x 8.3” x 11.6”

Weight ..... 6.4 lbs (2.9 kg)

*Precision (10-s measurements)** ..... higher of 2.5 ppb or 2%

*Precision (1-min averaging)** ..... higher of 1 ppb or 1%

Accuracy ..... higher of 2.5 ppb or 2%

Data Transmission…….. 4800 baud, 8 bits, no parity, 1 stop bit

2. OPERATION

Please read all the following information before attempting to install the Nitric Oxide Monitor. For assistance, please call 2B Technologies at (303)273-0559 or email techsupport@twobtech.com.

NOTE:

Save the shipping carton and packing materials that came with the Nitric Oxide Monitor. If the Nitric Oxide Monitor must be returned to the factory, pack it in the original carton. Any repairs as a result of damage incurred during shipping will be charged.

Shipping Box Contents

Open the shipping box and verify that it contains the following:

1. Model 400 Nitric Oxide Monitor
2. 110-240V AC 50-60Hz Power Adapter
3. Cigarette Lighter Adapter
4. Battery Wire Connector
5. Serial Port Cable
6. Zeroing Cartridge
7. CD Containing Nitric Oxide Manual
8. Birth Certificate and Calibration data

If anything is missing or obviously damaged, contact 2B Technologies immediately.

Operation of the Nitric Oxide Monitor

To operate the Nitric Oxide Monitor, connect it to an external power source and turn the instrument on by flipping the front panel power switch. The instrument requires a 12 V DC source which can be supplied by the 110-220 V AC power adapter provided or external battery. The power source should be capable of supplying at least 2.5 amperes of current at 12 V (30 watts).

Once turned on, the instrument will display:

2B Technologies

where "x.xx" is the version number of the software installed on the microprocessor. After powering up, the instrument will begin a 20-minute WARMUP mode. During this period a count down of time in minutes and seconds will appear on the display. If the instrument was previously warmed up, the warmup period can be skipped by briefly pressing ("clicking") the SELECT switch (black knob on front panel labeled "Select").

Following warmup, the instrument will enter the **PARAMETER ADJUSTMENT MODE**, during which time the total flow rate, F_{total}, and ozone reagent concentration are adjusted to be in range. The total flow is first adjusted, followed by the ozone concentration. After the flow rate is adjusted to be in the range 580-620 cc/min, the ozone concentration will be displayed along with flow rate, temperature and pressure every 10 seconds; for example:

O3= 4537 F= 610
T= 28.2 P= 997.7

where ozone concentration is in ppb, F is the total volumetric flow rate in cm^3/min, T is the temperature in the chosen units (^oC or K) and P is the pressure in the chosen units (Torr or mbar).

For accurate measurements of NO with the greatest precision, the total flow rate should be in the range 550-650 cc/min and the ozone concentration should be in the range 3000-5000 ppb. When in automatic (Auto) mode, the instrument will attempt to adjust the flow rate to be in the narrower range of 580-620 cc/min by pulse wide modulation of air pump #2 and adjust the ozone concentration to the narrower range of 3800-4200 ppb by pulse width modulation of the ozone source lamp.

The first three ozone measurements are spurious and will be reported as the ozone value previously stored in memory. After every set of 3 ozone measurements, the ozone source intensity is adjusted in an attempt to bring the ozone concentration into the range 3800-4200 ppb. Once the ozone concentration is both in range and stable, the instrument will skip to NO Measurement Mode (**NO Mode**). After 30 ozone measurements (5 minutes), the instrument will skip to **NO Mode** even if the ozone concentration is not in range. Also, the user can skip to NO Mode at any time during ozone measurements by momentarily pressing the select switch. When skipping to

NO Mode, the most recently measured ozone concentration will be stored in memory and displayed until the Parameter Adjustment Mode is next entered.

In the NO measurement mode, the first five readings are spurious and are reported as 0. After another 5-10 measurements the reported NO concentrations should be stable and after 20-30 measurements the average standard deviation of ten sequential measurements should be ±2.5 ppb or better.

Procedure for Adjusting the Flow rate and Ozone Concentration Needle Valves: If the instrument cannot adjust either the flow rate or the ozone concentration to be in range by pulse width modulation of the pump and lamp, adjustments to the needle valves may be required:

1. Depress select switch while powering the instrument on, and continue to depress the select switch until the service menu appears.
2. Choose **Tst** and then **Flw**. The instrument will now set the duty cycles of both the Ozone Flow pump and the ozone source to 70%. Ozone Flow rate (**O3F**) Total Flow rate (**TF**) and Sample Flow rate (**SMPF**) will be continuously displayed.
3. Adjust the Ozone Flow rate to be in the range 20-30 cc/min using the recessed needle valve for Ozone Flow on the back of the instrument. Only a fraction of a turn should be required.
4. Adjust the Total Flow rate to be in the range 580-620 cc/min using the recessed needle valve for Total Flow on the back of the instrument. Again, only a fraction of a turn should be required.
5. The Sample Flow rate should be greater than 700 cc/min. If an NO_2 Converter is being used, the sample flow rate should be in the range 900-1000 cc/min. The needle valve for this adjustment is inside the instrument next to the Sample Flow pump.
6. Exit the Menu and go to **Parameter Adjustment Mode**. The instrument should now be able to automatically bring the Total Flow rate into the range 580-620 cc/min and the ozone concentration into the range 3800-4200 ppb.

Scheduling of Flow Rate and Ozone Measurement Adjustments

The instrument can be set to readjust (“tweak”) the flow rate and ozone concentration at frequencies of 1 time per day or 4 times per day. To do this, go to the Service Menu by powering the instrument on while depressing the select switch. Choose **Sch** from the Service Menu and set the **O3 Adj Freq** to

0, 1 or 4. When set to 0, the instrument will return to **Parameter Adjustment Mode** only manually (by a click of the Select switch) or after experiencing a power interruption. When set to 1, **Parameter Adjustment Mode** will be entered every 24 hours following the time this parameter is set. When set to 4, **Parameter Adjustment Mode** will be entered every 6 hours following the time this parameter is set.

Collecting Data over the Serial Port

Measured parameters may be continuously collected on a computer from the serial port of the Nitric Oxide Monitor. To transmit data to a computer over the serial port in real time, connect the NO Monitor to the serial port of the computer using the 9-pin serial cable provided. If your computer does not have a serial port, you can connect via its USB port by use of a serial-to-USB port adaptor. Activate your data acquisition software; e.g., Hyperterminal (available on most Windows®-based computers) or Tera Term Pro. Tera Term Pro is freeware that can be downloaded at

http://hp.vector.co.jp/authors/VA002416/teraterm.html

Tera Term Pro has the advantage over Hyperterminal that the buffer may be set to up to 10,000 lines of data as compared to a buffer limit of 500 lines for Hyperterminal. However, if one logs to a text file, the buffer is not a limitation. Data logged to a file (or copied from the computer screen and pasted into a text file) may be opened in Microsoft Excel (or another spread sheet program) where they may be converted to formatted data in columns by defining delimiters (commas and carriage returns) for data manipulation and graphing. The ozone or nitric oxide mixing ratio (ppb), internal cell temperature (^{o}C), cell pressure (mbar), total flow rate, sample flow rate, date, and time are sent as comma-delimited ASCII text to the serial port (4800 baud, 8 bits, no parity, 1 stop bit) every 10 seconds, 1 minute, 5 minutes, or 1 hour, depending on the averaging time selected from the microprocessor menu. Time is provided in 24-hour (military) format, and the date is given in European style (day/month/year).

In addition to data lines, messages are written to the serial port to describe the functions being performed. A complete Parameter Adjustment Mode cycle followed by output of NO measurements produces the following lines of data, for example:

BEGIN NEW NO PARAMETER ADJUSTMENT
Setting Total Flow Rate
Flow = 619 cc/min *New flow rate*

S = 1.02, Z = -2, Fm1 = 1.12, Fm2= 1.01 *Calibration parameters applied*
Signal Photodiode voltage = 0.98 V *Should be in the range 0.7 – 2.4 v*
Reference Photodiode Voltage = 1.23 V *Should be in the range 0.7 – 2.4 v*
Automatic control of flow and ozone concentrations *In Auto mode*
Measure Ozone Concentration and Flow Rates *Start ozone measurements*
O3, Temp, Press, TotFlow *Header for O_3 data stream*
data line 1
data line 2
date line 3
……..
data line 30

Ozone = 4513 ppb *Final measured O_3 concentration*
Incomplete Reaction Correction Factor = 1.038 *Should be in range 1.00-1.15*

If the ozone concentration remains within range (3800-4200 ppb) for 3 sequential measurements, the instrument will exit NO Parameter Adjustment Mode and enter NO Measurement Mode. Upon exiting, the percent duty cycle used for flow and ozone control will be transmitted over the serial port as, for example:

Flow Duty Cycle = 66%
Ozone Duty Cycle = 43%

The instrument will then begin measuring NO concentration and write to the serial port:

Measure NO Concentration *Start measuring NO concentration*
Avg: 10 s/rdg *Averaging time selected in menu*

NO, Temp, Press, Flow, Sample Flow 1, Total Flow 1, Sample Flow 2, Total Flow 2, Ozone, Date, Time

Header for NO data stream

data line 1
data line 2
data line 3
……..

Nitric oxide data will continue to be output until the Select Switch is used to enter the Menu or the Parameter Adjustment mode.

As an example, a typical data line for NO reads:

20.3,35.3, 990.6,1360,603,1348,602,4027,15/11/06,18:31:27

where:

NO = 20.3 ppb
Cell temperature = 35.3 ^{o}C (if ^{o}C units have been selected)
Cell pressure = 990.6 mbar (if mbar units have been selected)
Sample Flow Rate (I measurement) = 1360 cc/min (volumetric)
Total Flow Rate (I measurement) = 603 cc/min (volumetric)
Sample Flow Rate (Io measurement) = 1348 cc/min (volumetric)
Total Flow Rate (Io measurement) = 602 cc/min (volumetric)
Ozone Concentration = 4027 ppb
Date = 15 November 2006
Time = 6:31:27 pm

Using the Menu to Change Instrument Parameters

The Menu may be accessed to log and transmit data, choose the averaging time, change the calibration parameters, turn the backlight of the LCD on and off and choose units for pressure and temperature. The Service Mode also may be accessed via the Menu to test the lamp, output raw data from both absorption cells, turn the automatic parameter adjustment mode on and off, and schedule automatic parameter adjustment.

The **Menu** is accessed by using the Select switch on the front panel. Navigation within the **Menu** is summarized in Fig. 2. Momentary depressions ("clicks") of the Select switch change the instrument mode from **Warmup** to **Parameter Adjustment Mode** to **NO Mode** and back to **Parameter Adjustment Mode**. Depressing the Select switch for a time longer than about 1 second accesses the **Menu**. Within the **Menu**, rotating the select switch moves a blinking cursor back and forth between the four submenus, **Dat**, **Avg**, **Cfg** and **Svc**. To enter a submenu, position the cursor under the first letter of the submenu name and "click" (quickly press and release) the Select switch. To move up one level in the menu move the underline cursor to the left arrow (←) and click the Select switch.

In general, horizontal navigation within the menu and submenus is achieved by rotating the Select switch, clicking on a submenu title allows movement downward in the menu, and clicking on the return symbol (left arrow, ←), provides movement up one level in the menu.

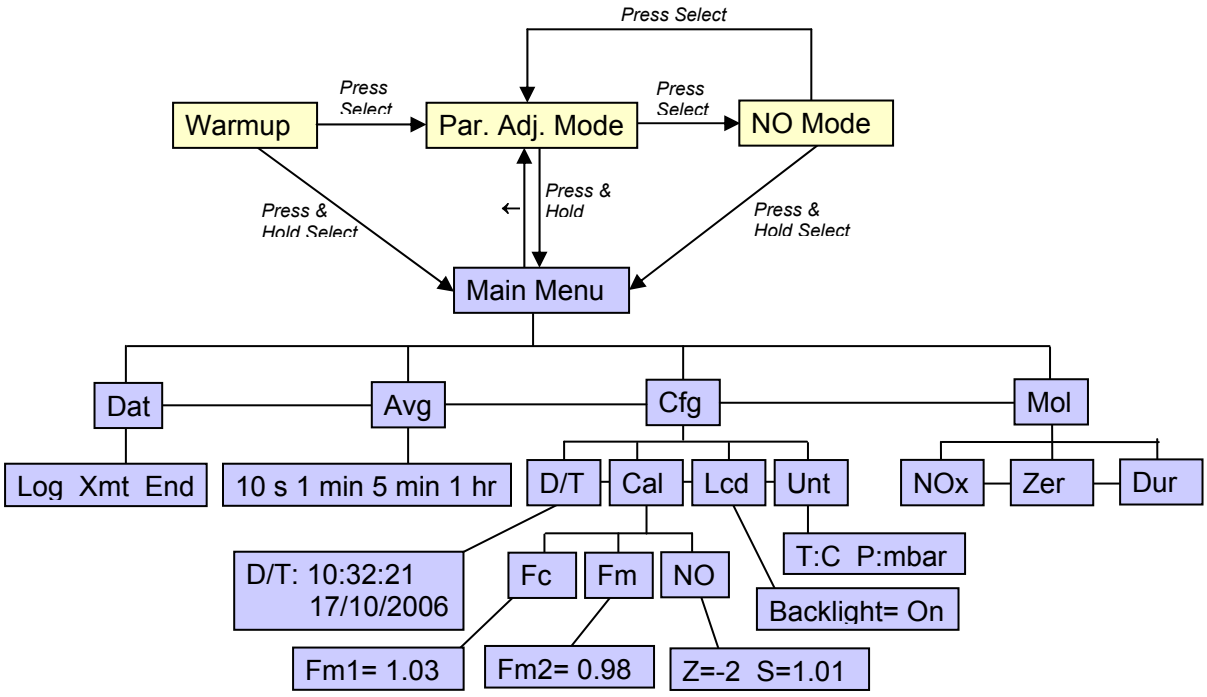

Figure 2. Navigation chart for the NO Monitor menu.

Data Averaging and Data Logging Using the Menu

The NO Monitor reports new measurements of the NO concentration every 10 s. You may choose to average these data within the instrument for periods of 1 min, 5 min and 1 hour. Also, data lines may be stored in the instrument's internal data logger. Up to 10,240 data lines containing the log number, NO mixing ratio, internal temperature, internal pressure, total flow rate, date and time may be stored in internal memory, corresponding to an operational time of 1.2 days with no averaging. Averaging times of 1 min, 5 min and 1 hr also may be selected from the menu, thereby allowing the instrument to operate for more than 1 week, 1 month and 1 year, respectively, before filling the memory. For virtually unlimited data storage, we recommend the flash memory option, which is also available as an upgrade.

To Log Data

To reach the **Menu**, hold in the Select button until **Menu** is displayed. Then release the button. The panel will now display:

Menu
Dat Avg Cfg Mol ←

where **Dat**, **Avg**, **Cfg** and **Lmp** are submenus that may be selected. A blinking cursor will show across the **D** of the **Dat** submenu. The Select switch may be rotated clockwise or counterclockwise to position the cursor over the first letter of one of the other submenus. To select a particular submenu, move the cursor to the first letter of a submenu and click the Select switch. To exit the menu and begin making measurements again, select and click on the left arrow (←).

Select the **Dat** submenu from the Main Menu using the Select button. The display will now show:

Data Menu
Xmt Log End ←

To start logging data, rotate the Select switch to move the cursor to the first letter of **Log** and click to select the logging mode. You will then be asked whether you want to overwrite the data stored in the logger:

Overwrite Data?
No Yes ←

If you select **Yes** and start logging, all data previously stored in the logger will be irretrievably lost. If you have data in the logger that you want to keep, be sure to download it using the **Xmit** function before starting logging. If you are ready to start logging, then select **Yes** by positioning the cursor and clicking. Either selection will return you to the **Main Menu**. To start data acquisition, select ← and click.

The NO Monitor will then alternately display: 1) the O_3 mixing ratio, internal temperature and internal pressure and 2) the NO mixing ratio and log number. For example, the display might read:

O3= 4135 F= 603
T=25.6 P=989.7

where the ozone concentration most recently measured is 4135 ppb (4.135 ppm), the total volumetric flow rate is 603 cc/min, the cell temperature is 25.6 ^{o}C (if ^{o}C units are selected), and the cell pressure is 989.7 mbar (if mbar units are selected). After 5 seconds (midway between 10-s measurement cycles), as an example, the display will be replaced by:

NO= 56.7 ppbv

Log= 193:0

where **NO** is most recently measured NO cocentration, and the log number is 193.

If averaging has been selected, the ozone value (**O3**) will be replaced by **AVG**, which is the most recently calculated average value of NO, and the first screen will read for example:

AVG= 57.3 F= 603
T=25.6 P=989.7

The second screen (5 seconds later) will display for example:
:

NO= 56.7 ppbv
Log= 193:4

where NO is the most current 10-s measurement of NO. Again 193 refers to the most recent log number. The "4" in 193:4 refers to the number of 10-s data points that have been measured so far for inclusion in the next average to be displayed and logged. If 10-s averaging is used (i.e., no averaging), this number will always be 0. If 1-min averaging is used, this number will increment from 0 to 5; for 5-min averaging, the number will increment from 0 to 29; and for 1-hr averaging, it will increment from 0 to 359. This number is displayed so that the user will know how many more 10-s measurements need to be made before a new average is displayed and logged.

If there is a power failure while the instrument is in the logging mode, logging will resume after power is restored. A note of

Data Interrupt - Time Error < 60s

will be written to the logger prior to writing the first new data line. In the case of a power failure, as many as 10 data lines may be lost because the microprocessor writes to the logger memory in groups of 10 lines. All data residing only in the volatile memory of the microprocessor are lost when power is interrupted. Also, the start time for logging of additional data following a power interruption will be accurate only to the nearest minute (or nearest hour when Avg = 1 hr).

The instrument can accommodate multiple data interruptions due to power failures. For example, one can purposely switch the instrument off, move to another location and restart logging simply by turning the instrument

back on. Data sets will be separated by the data interrupt message. However, as mentioned above, start times will be accurate only to the nearest minute (or hour if 1 hr averaging is chosen). If more accurate measurements of time are required, it is recommended that an external clock be used to assign an accurate time to the log number of the first data line following a purposeful power interruption. The incremental times between data lines are exact (i.e., 2 s, 10 s, 1 min, 5 min and 1 hr).

Note: Once logging has started, you should not enter the menu, except to end logging. Entering the menu stops data acquisition, which is treated in the same way as a power failure; i.e., when logging is resumed, the start time for the new data will be accurate only to the nearest minute (nearest hour if 1-hr averaging is being used). In particular, you should not change the averaging time or turn the external inputs on or off while in the logging mode, as the earlier data stored in the logger memory will not be retrieved correctly.

To Stop Logging Data

Hold the Select button in to obtain the **Menu**. Go to the **Dat** submenu by clicking on **Dat**. Choose and click on the **End** function. This will end data logging. You may now transmit the data to a computer by clicking on **Xmt** (see below). You may transmit the data as many times as you want. Alternatively, you may return to the **Menu** by clicking on ←. The stored data will reside in memory (even when new measurements are being made) and can be transmitted using the **Xmt** function at a later time. However, all stored data are lost once logging is started again using the **Log** function. Thus, you should always transmit your data to a computer before restarting logging.

If you fail to **End** logging prior to transmitting the data using the **Xmt** function, the instrument will automatically execute the **End** function for you before transmitting the data.

To Transmit Logged Data to a Computer Using the Serial Port

Connect the serial port of the instrument to the serial port of your computer using the cable provided. Enable a data acquisition program on the computer such as Microsoft Hyperterminal Terra Term Pro (see above). Hold down the Select button to obtain the **Main Menu**. Go to the **Dat** submenu by clicking on **Dat**. Next, click on **Xmt**. The message “Logged Data” will be

written to the serial port, followed by a carriage return and all of the lines of logged data. After all data are transmitted, the message "End Logged Data" and a carriage return are written. After transmission is complete, you can return to any position in the menu or resume NO measurements. The logged data continues to reside in memory and be available for transmission until a new data log is started.

To Average Data

Hold down the Select button to obtain the **Menu**. Select and click on **Avg** to obtain the **Avg** menu:

Avg Menu
10s 1m 5m 1h ←

Use single clicks to move the cursor to **10s**, **1m**, **5m** or **1h** for averaging times of 10s (no averaging), 1 min, 5 min or 1 hr, respectively. Then click on the averaging time you want to use. To return to the Main Menu, click on **←.** To exit the Main Menu and start acquiring data, click on ← again.

While in averaging mode, the current 10-s measurement is displayed alternately with the average value, as discussed above. Averaged data may be logged, thereby greatly extending the length of time that the data logger can be used.

To Change the Calibration Parameters

The NO Monitor is calibrated at the factory, and calibration factors are entered to make the instrument read accurately over the range 0 to 1,000 ppb. The user may wish to recalibrate the instrument from time to time and change the calibration parameters. However, it is recommended that the NO Monitor be returned to 2B Technologies for recalibration at least once per year.

To change the calibration parameters, select **Cfg** from the **Menu** and **Cal** from the **Cfg** submenu. The following submenu with the values of the current calibration parameters will then appear:

Cal Menu
Fm1 Fm2 NO ←

The parameters **Fm1** and **Fm2** are calibration factors for the two flow meters to make them read correctly in terms of volumetric flow. These parameters are set in the factory and should not be changed unless you have independently

calibrated the flow meters. Factory values of the calibration parameters Fm1 and Fm2 are recorded in the instrument's Birth Certificate are typically in the range 0.8-1.2. Selecting **NO** allows one to enter a submenu for entering the slope (S) and offset (Z) calibration parameters. For example, the **NO** submenu might read:

Cal NO Menu
Z= -2 S= 1.02 ←

Here Z is the additive offset correction applied (in this case -2 ppb) and S is the multiplicative slope correction factor applied (in this case 1.02) to the raw data. For example, if the instrument reads an average of 3 ppb when sampling NO-scrubbed air (and with the calibration factors set to Z=0 and S=1.00), the value of Z should be set to –3. If after correction for the zero, the instrument consistently reads 2% low for a NO calibration standard, the value of S should be set to 1.02.

A few words of caution: Compressed air cylinders often contain traces of NO, so it is necessary to use an external NO scrubber when measuring the zero of the instrument. Also, calibration standards frequently decline in concentration with time and may provide inaccurate results.

When the **Cal Menu** first appears, an underline cursor will be beneath the **Z**. Depressing the Select switch will change this cursor to a blinking dark cursor that covers the **Z**. When the cursor is blinking, you can change the value of the selected parameter by rotating the Select switch (clockwise to increase and counter-clockwise to decrease). Once the desired value is chosen, click the Select switch to store that value in memory; the cursor will now return to an underline. You may now move the underline cursor to **S** by rotating the Select switch and click on **S** to enable change of the slope calibration parameter. To exit the **NO** calibration menu move the underline cursor to ← and press the Select switch.

To Set the Time and Date

From the **Main Menu**, select the **Cfg** submenu. Next, select the **D/T** submenu. The display will read, for example:

D/T: 14:32:21 ←
17/10/2006

meaning that it is 21 seconds after 2:32 p.m. on October 17, 2006 (military time and European date). To change a number in the date and time, rotate the Select switch to underline the numeral you want to change. A single click then causes a blinking cursor to cover that numeral. The number can then be changed by rotating the Select switch. Once the number is correct, click on the Select switch to turn off the blinking cursor. You may now rotate the Select switch to choose another numeral to change. Once the time and date is correct, clicking on ← will set the internal clock to that time and return the display to the **Cfg** menu. As in setting a digital watch, the seconds should be set in advance of the real time since the clock starts to run again only when the set time is entered; in this case by clicking on ←.

To Turn the Display Light On and OFF

Selecting **Lcd** from the **I/O Menu** allows you to turn the light of the front panel display on and off. To conserve power, use the Select switch to set the **Lcd** submenu to **OFF**.

To Change the Units for Internal Temperature and Pressure

From the **Cfg** menu, select **Unt** to give the following submenu, for example:

Units Menu
T:C P:mbar ←

Rotating the Select switch will cycle the underline cursor between temperature (**T**) and pressure (**P**). Temperature units may be selected as either Kelvin (**K**) or Celsius (**C**) by first clicking to obtain the blinking cursor and then rotating the Select switch to obtain the desired units. Pressure units may be selected as either **torr** or **mbar**. A click on ← returns the display to the **Cfg** menu.

Service Menu

The **Svc** menu is reached by holding in the select switch while powering on the instrument:

Svc Menu
Adm Tst Aut Sch ←

An Administrative Mode may be selected under the **Adm** submenu. In this mode, the serial output of the instrument displays raw data for the reference and detection cells. The reference cell measures the degree of ozone

interference in ambient air. When in Administrative Mode, a typical serial output line might be:

-20.5,55.6,33.2,28.7,995.6,1301,598,1247,599,10/09/06,14:52:10

Here, the reference channel, which detects ambient ozone only, reads -20.5 ppb. A higher ozone reading will produce a larger negative reading. The value 55.6 is the raw measurement of the concentration in ppb of NO in the detection cell. The value 33.2 is the final value for NO concentration output to LCD and over the serial port. It is not simply the sum of the two channels, but includes corrections for dilution by the ozone flow, incomplete reaction of NO with ozone, and the slope and offset calibration factors. The final value of NO concentration also involves a complex averaging process of the raw data from the two channels. The value 28.7 is the temperature in the chosen units, 995.6 is the pressure in the chosen units, and 607 is the total volumetric flow rate (measured mass flow rate corrected for temperature and pressure of the detection cell). The data and time are the final two entries in the data line. Another characteristic of the Administrative Mode is that there is no automatic exit from the Parameter Adjustment Mode. One can only exit by clicking the Select switch to enter NO Mode. Thus, if one wants to change the settings of the needle valves, as discussed earlier, it is desirable to enter the Administrtive Mode first.

Lamp Test

A diagnostic lamp test is provided in the **Lmp** submenu of the Service menu. When first entering the **Lmp** submenu, the voltage measured by the photodiode detectors are displayed. For best performance these voltages should be in the range 0.7-2.5 volts. For detector voltages less than about 0.7 volts, the data may be noisy due to insufficient light intensity to make precise measurements. If the voltage is zero, the lamp is not ignited and is either burned out or not receiving 5V from the circuit board. For voltages above 2.5 volts, the A/D converter is saturated and the measured ozone and NO concentrations will be spurious. This could happen if the instrument is very hot so that the lamp output is too bright.

Immediately following display of the detector voltage, the instrument starts measuring an “effective” NO concentration without switching the solenoid valve on and off. This is an electronic zero and should after a few readings settle down to ± a few ppb. If either value is outside the range -10 to +10, the instrument may not be operating correctly. The display also gives a standard deviation of the electronic zero. For best measurement precision (low noise), the standard deviations should be not greater than ±3.

To exit the **Lmp** test mode, hold in the Select switch and release to return to the **Main Menu**.

The **Aut** (for “automatic”) submenu is used to turn automatic control of flow rate and ozone concentration on and off. For normal operation the Aut should be set to **On**. The **Sch** (for “schedule”) submenu is used to set the frequency of automatic entry into the Parameter Adjustment Mode where the total flow rate and ozone concentration are adjusted. Uses of both of these submenus are discussed earlier in this manual.

3. MAINTENANCE/TROUBLESHOOTING

The Nitric Oxide Monitor is designed to be nearly maintenance free. The only components that require routine maintenance are the ozone and NO scrubbers, which should be changed at least once every six months of operation.

If the instrument fails to operate correctly, common problems can be identified and corrected using Table I below. If the problem cannot be corrected, the instrument may be returned to 2B Technologies for service. Please phone or email in advance for shipping instructions. Often, the problem with the instrument can be diagnosed over the phone and corrections or repairs made without returning the instrument to the factory. Before contacting 2B Tech, it is helpful if you can make a few observations. These include:

1) **What are the ozone concentration, NO concentration, temperature, pressure and flow rate displayed by the instrument on the front panel?**

2) **What is the voltage output for the 2 photodiodes?** These should fall in the range 0.7 to 2.4 V. Enter the Service Mode by selecting **Svc** in the menu. Choose the **Lmp** submenu. The voltages of the signal and reference photodiodes will be briefly displayed. The instrument will then measure the electronic offsets and standard deviations of the two detection cells. The offsets should be near zero and the standard deviations (preceded by "±") should be less than 3 ppb in both channels.

3) **Is air being drawn into the instrument?** Hold your finger over the air inlet to determine whether there is suction.

4) **What is the average value of NO measured when the NO scrubber is attached to the inlet (i.e., the instrument zero)?**

5) **How noisy is the instrument?** Calculate the standard deviation of 10 sequential measurements with the external NO scrubber in place.

6) **If possible, collect data from the serial port for both the NO Parameter Adjust Mode and NO Measurement Mode and email the file to 2B at service@twobtech.com with an explanation of the problem you are experiencing with the instrument.**

If you feel comfortable working on the instrument, additional useful information can be provided by removing the top and bottom instrument covers. To do this, turn the instrument power off, remove the two screws that hold the front panel in place, then remove the black bezel by removing the four screws centered positioned at the corners of the bezel. Electrical connections to the front panel are sufficiently long to pull the front panel a few inches away from the case. The top and bottom covers are each held in place by two screws at the corners at the back of the instrument and two screws at the corners of the front of the instrument. Remove those screws, and the top and bottom covers will side off the front of the instrument. You may now reattach the front panel and bezel with the top and bottom covers removed. Annotated photographs of the inside of the instrument case and of the circuit board are given below. Now power up the instrument. Useful questions that you can quickly answer once the top and bottom covers are removed are:

1) **Is the ozone source lamp ignited?** There should be a purple glow coming from the tubing attached to the ozone source located in the top of the instrument.

2) **Is there an overflow of air?** Place your finger on the overflow tee located in the bottom of the instrument and determine whether air is going into (incorrect) or out (correct) of the overflow tee.

3) **Is there power to the board?** Measure the dc voltage on the power inlet connector shown in Figure 3-3. It should be close to 12 V.

The figures following Table I provide a "guided tour" of the instrument so that critical components and connectors may be easily identified. A list of serviceable parts is provided in Section 4 at the end of this manual.

Table I. *Troubleshooting the Nitric Oxide Monitor for performance problems.*

Problem/symptom	Likely cause	Corrective action
Instrument does not turn on.	Power not connected properly or circuit breaker tripped.	Check to see that the power adapter is supplied with 110 or 220 v ac power and that 12 v dc is reaching the circuit board.
Display is blank or nonsense.	Bad connection of display to circuit board.	Remove top cover and reconnect display to

		circuit board. Check solder connections to display.
Cell temperature reads low by several 10's of degrees.	Absent or loose connection of temperature probe cable to circuit board.	Remove top cover and check attachment of temperature sensor connector to circuit board.
Readings are noisy with standard or on external scrubber with standard deviations greater than 3.0 ppb.	Lamp is not on.	Check lamp connection to circuit board. Remove bottom cover, turn instrument on, and visually check to see that lamp turns on within a few seconds after the power switch is turned on. Return instrument for lamp replacement if lamp does not light.
	Lamp output is weak.	Measure reference and sample photodiode using **Svc** submenu. If either voltage is less than 0.9 V DC, contact 2B Tech for lamp replacement.
	Excessive vibration.	Provide additional vibration insulation for the instrument such as a foam pad.
Select switch does not work.	Cable not properly connected between select switch and circuit board.	Remove top cover and reconnect select switch cable to circuit board.
Serial port does not work.	Cable not properly connected between serial port 9-pin connector and circuit	Remove top cover and reconnect serial port cable to circuit board.

	board. Wrong serial cable used. Wrong baud rate is used.	 A “straight through” serial cable is provided. Some data collection devices require a ”cross over” cable in which pins 1 and 3 are exchanged between the two ends of the cable. Use a “cross over cable or additional connector that switches pins 1 and 3. Make sure the baud rate of your data collection device is set at 4800.
Required calibration parameters are excessively large when calibrated using a reference gas standard.	Standard incorrect. NO scrubber is contaminated or scrubbing capacity is depleted. Connecting tubing and/or absorption cells are contaminated.	NO standards are notoriously unstable and decrease in concentration with time. Try using another standard. Replace ozone scrubber. Be sure to use an inlet filter to remove particulate matter. Rinse cells and tubing with methanol and dry with zero air. Replace internal tubing with ¼” o.d., 1/8” i.d.Teflon-lined Tygon® tubing (or silicone tubing where not in sample flow path).
Instrument always reads close to zero for NO concentration.	Solenoid valve cable is not properly connected to circuit board.	Reattach solenoid valve cables to circuit board.

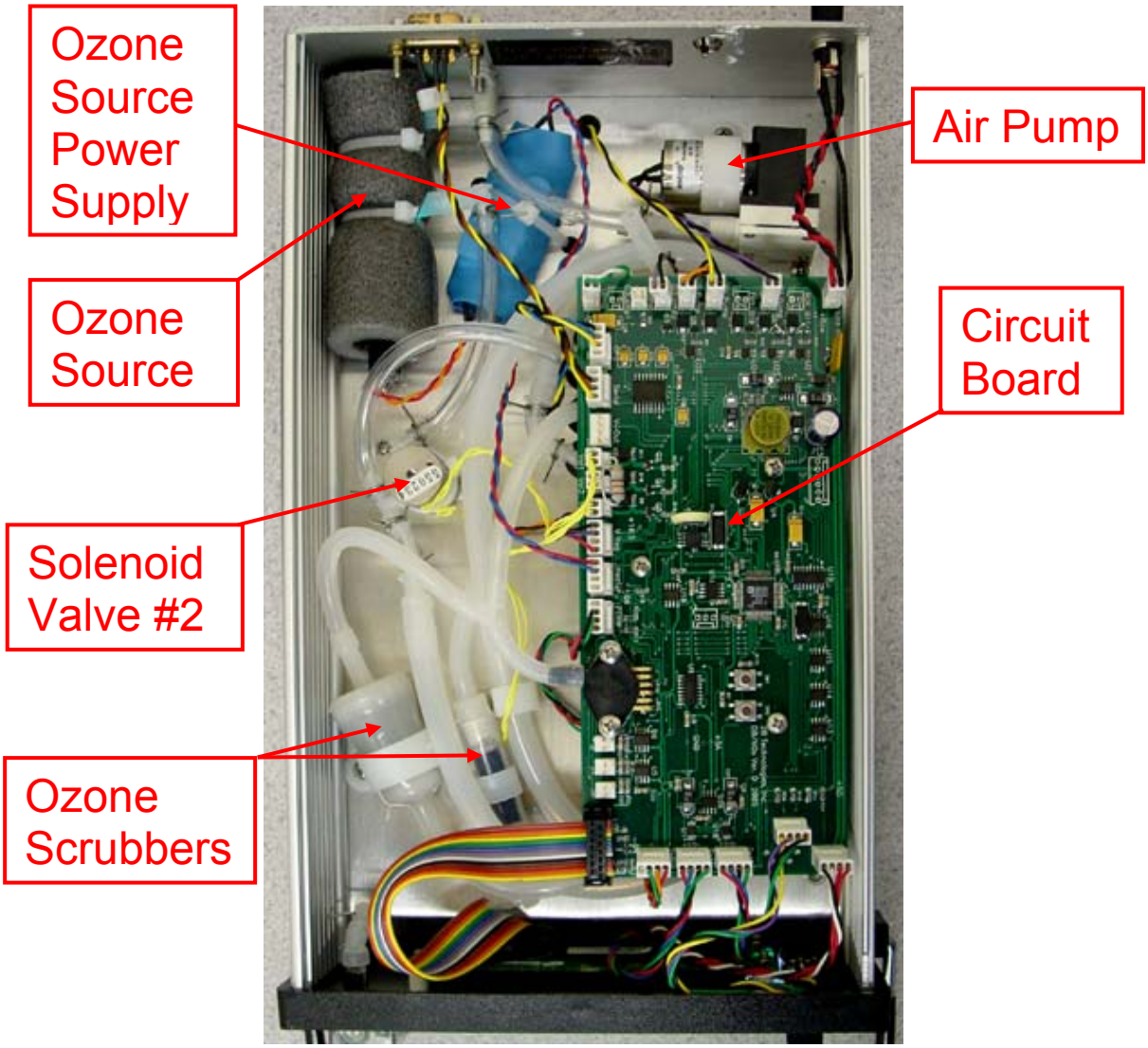

FIGURE 3-1: ***Top view of Nitric Oxide Monitor with cover removed.***

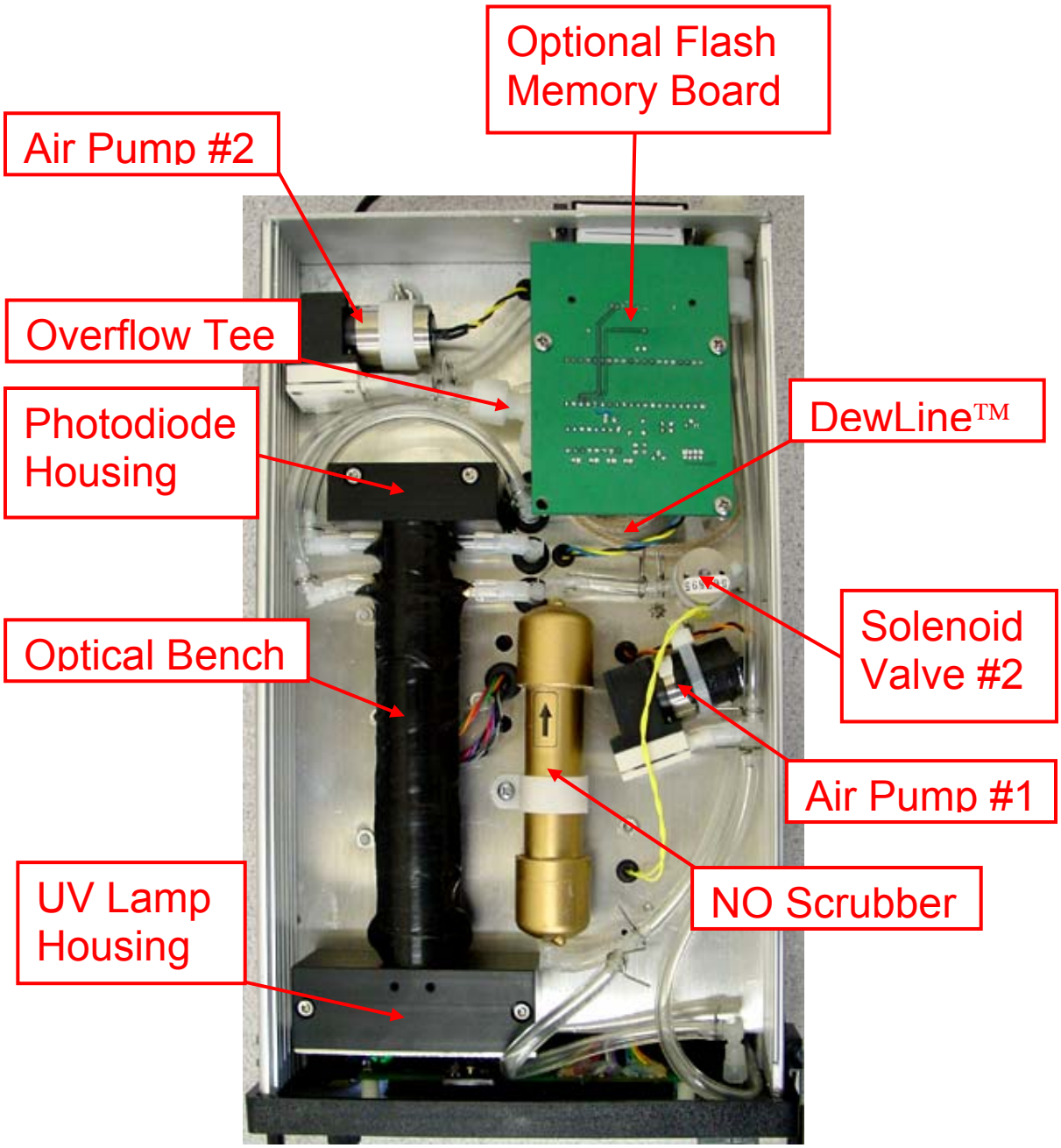

FIGURE 3-2: ***Bottom view of Nitric Oxide Monitor with cover removed. (Individual instruments may vary.)***

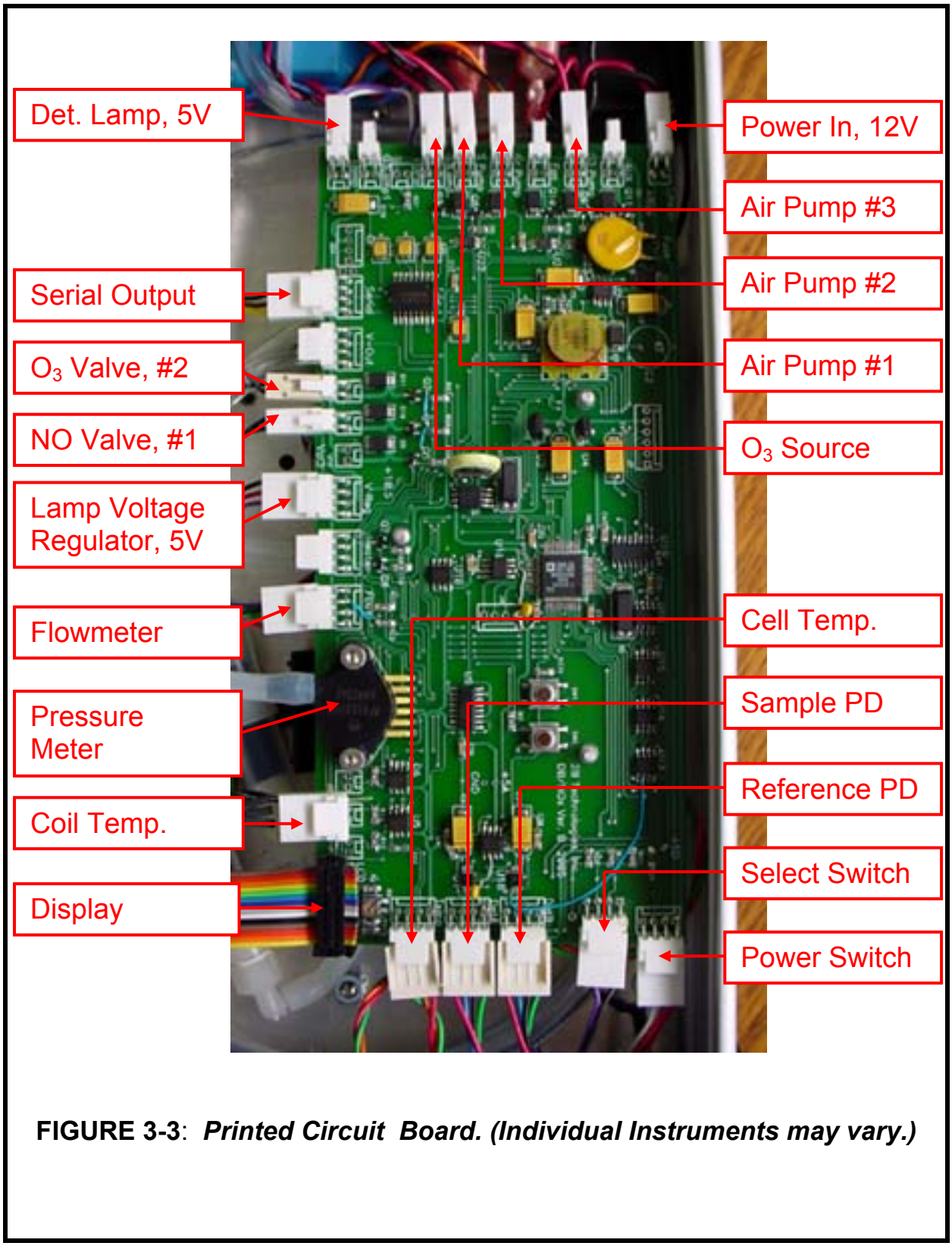

FIGURE 3-3: ***Printed Circuit Board. (Individual Instruments may vary.)***

4. PARTS LIST

The following list includes those parts that are user serviceable.

Part Number	Description
NOSCRBINT	NO scrubber (internal)
NOSCRBEXT	NO scrubber (external)
NOOZSCRBL	NO scrubber, large
NOOZSCRBS	NO scrubber, small
NOLAMP	Lamp and cable
NOVLV	Solenoid valve
NOBRD	Circuit board without microprocessor
NODSP	LCD display and cable
NOPUMPS	Air sampling pump (Air Pump #1)
NOPUMPI	Air Pumps #2 and #3
NOPDASSY	Photodiode assembly and cable
NOCELL	Absorption cell
NOPWRASSY	Power connector/circuit breaker assembly
SERCABL	Serial port cable (to computer)
SERCON	Serial port connector and cable
NO110ADP	110 V AC adapter
PWRWIR	Bare wire power cable
12VADP	12 V DC cigarette lighter adapter
TEFTYG	Teflon-lined Tygon® tubing
SILTUB	Silicone tubing
OZSOURCE	Ozone source with power supply
NDLVLV	Needle Valve