

QUALITY ASSURANCE/QUALITY CONTROL DOCUMENTATION SERIES

**TITLE CALIBRATION OF OPTICAL MONITORING SYSTEMS
(IMPROVE PROTOCOL)**

TYPE STANDARD OPERATING PROCEDURE

NUMBER 4200

DATE JULY 1993

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1.0 PURPOSE AND APPLICABILITY

This standard operating procedure (SOP) outlines the steps for calibration of optical monitoring instruments operated according to IMPROVE Protocol. Optical monitoring instruments are calibrated periodically to verify an instrument's performance, assure quality data capture, and minimize data loss by measuring an instrument's output in response to well-defined and controlled operating conditions.

The two types of optical monitoring instruments currently operating in the IMPROVE visibility monitoring network are ambient nephelometers and transmissometers. Calibration of ambient nephelometers is required under any of the following circumstances:

- Upon acceptance testing of a new instrument.
- Upon installation in the field.
- Prior to any corrective action, service, or maintenance to any portion of the instrument that would change the instrument's response to specified input conditions.
- At weekly intervals.

Calibration of transmissometers is required under the following circumstances:

- Upon acceptance testing of a new instrument.
- Prior to installation in the field.
- Immediately following removal of the instrument from the field.
- Following any corrective action, servicing, or maintenance that could affect the instrument's operational performance.

Nephelometer and transmissometer calibration results are used to:

- Convert raw measurement values to appropriate engineering units.
- Evaluate the instrument's performance and estimate the precision and accuracy of the instrument for specific operational periods.

The following technical instructions (TIs) provide detailed information regarding specific calibration procedures:

- TI 4200-2000 *Calibration of Optec NGN-2 Nephelometers (IMPROVE Protocol)*
- TI 4200-2100 *Calibration of Optec LPV-2 Transmissometers (IMPROVE Protocol)*
- TI 4200-2110 *Transmissometer Lamp Preparation (Burn-in) Procedures*

2.0 RESPONSIBILITIES

2.1 PROJECT MANAGER

The project manager shall:

- Verify that nephelometer calibrations are performed as required.
- Schedule transmissometer calibrations.
- Review all calibration results with the field specialist.
- Identify inconsistencies in calibration results and initiate corrective action as required.
- Review and approve all changes to calibration procedures.
- Review transmissometer lamp inventory and status records to ensure a sufficient number of burned-in lamps are available.
- Approve purchase orders for new lamps.

2.2 FIELD SPECIALIST

The field specialist shall:

- Perform all required field calibrations.
- Document calibration results on the appropriate form.
- Review all calibration results with the project manager.
- Identify inconsistencies in calibration results and initiate corrective action as required.
- Enter calibration results in the site-specific Quality Assurance Database.

2.3 INSTRUMENT TECHNICIAN

The instrument technician shall:

- Perform a nephelometer calibration during acceptance testing and laboratory maintenance.
- Maintain a printout of nephelometer calibration results.
- Enter the calibration results in the site-specific Quality Assurance Database.
- Prepare lamps for transmissometer calibration.
- Measure pre-calibration transmissometer lamp voltages.
- Assist the field specialist in analyzing inconsistencies in calibration results.

- Prepare purchase orders for new lamps.
- Perform lamp burn-in procedures.
- Maintain the lamp inventory and status records.
- Coordinate with Optec, Inc. for replacement of lamps.

2.4 SITE OPERATOR

The site operator shall:

- Perform a nephelometer calibration every week.
- Record the results of the nephelometer calibration on the NGN-2 Nephelometer/Meteorology Log Sheet.

3.0 REQUIRED EQUIPMENT AND MATERIALS

3.1 NEPHELOMETER CALIBRATION

Required equipment and materials to calibrate nephelometer systems include:

- Calibration span gas
- A pressure regulator and adjustable flowmeter
- Calibration gas hoses and fittings
- HP200LX palmtop computer with DATACOMM software
- NEPHCOM.DCF communication configuration file
- Site maintenance forms
- Calibration forms
- TI 4200-2000, *Calibration of Optec NGN-2 Nephelometers (IMPROVE Protocol)*
- TI 4100-3100, *Routine Site Operator Maintenance Procedures for Optec NGN-2 Nephelometer Systems (IMPROVE Protocol)*

3.2 TRANSMISSOMETER CALIBRATION

Prior to calibrating a transmissometer, the lamps to be used with a specific instrument must be burned-in, to stabilize the lamp's filament position and light output. Required equipment and materials for burn-in includes:

- A supply of lamps
- Lamp ID labels

- Lamp burn-in fixture
- Power supply (13.8 VDC @ 25 amps)
- Documentation forms
- KimWipe tissues
- TI 4200-2110, *Transmissometer Lamp Preparation (Burn-in) Procedures*

Calibration of LPV-2 transmissometers is performed at the Fort Collins Transmissometer Test Facility. Equipment and materials required at the test facility include:

- Tracking transmissometer (LPV-2 transmissometer installed to monitor light transmission measurements over a path parallel and adjacent to the calibration path)
- Tracking nephelometer (NGN-2 nephelometer installed to monitor ambient scattering measurements adjacent to the calibration path)
- Campbell 21X datalogger and solid state storage modules
- Serial printer
- Digital voltmeter (4 1/2 digit)
- Neutral Density Filters (NDFs)
- Assorted calibration apertures
- Power supplies (12 volts DC)
- Cleaning supplies (for windows and transmissometer optics)
- Calibration documentation forms
- TI 4200-2100, *Calibration of Optec LPV-2 Transmissometers (IMPROVE Protocol)*

Analysis and review of transmissometer calibration data requires the following:

- IBM-compatible 386/486 computer system with VGA and 80 megabyte hard disk
- Campbell Scientific datalogger support software
- ARS calibration support software

4.0 METHODS

This section includes two (2) major subsections:

- 4.1 Nephelometer Calibrations
- 4.2 Transmissometer Calibrations

4.1 NEPHELOMETER CALIBRATIONS

Nephelometer calibration includes performing a clean air zero calibration and a span calibration. Calibration may be simple or complete:

- Simple calibration: A single zero and a single span value generally obtained by the site operator during routine servicing.
- Complete calibration: A series of zero and span values generally obtained during acceptance testing, installation, removal, laboratory servicing, or audit of the nephelometer by the field specialist or instrument technician.

4.1.1 Simple Calibration

Simple calibration of NGN-2 nephelometers occurs during any of the following checks:

- Site operator initiated zero and span checks performed weekly
- Remote, telephone modem initiated zero and span checks
- Field specialist initiated zero and span checks

Simple calibration of NGN-2 nephelometers includes:

- Clean air zero consisting of the average of 10 one-minute readings of particle-free air.
- Span consisting of the average of 10 one-minute readings of a span gas with known scattering properties.

The results of a simple calibration must be recorded on the appropriate documentation form and entered into the site-specific Quality Assurance Database.

4.1.2 Complete Calibration

Complete calibration of NGN-2 nephelometers are generally performed by the field specialist or instrument technician during servicing in the field or in the laboratory. Complete calibrations include:

- Twenty (20) 1-minute clean air zero readings
- Twenty (20) 1-minute span readings
- Recording of ambient temperature, relative humidity, and barometric pressure

The results of a complete calibration must be recorded on the appropriate calibration form and entered into the site-specific Quality Assurance Database.

4.1.3 Instrument Adjustment

Nephelometers must not be adjusted during calibration. Unadjusted calibration values are required for evaluating the performance and estimating the precision and accuracy of nephelometers. If the nephelometer cannot be calibrated, refer to the appropriate troubleshooting standard operating procedure and technical instruction.

4.2 TRANSMISSOMETER CALIBRATIONS

Transmissometer calibration includes pre-calibration preparation of lamps and the actual transmissometer calibration.

4.2.1 Lamp Preparation

Preparation of lamps prior to transmissometer calibration includes:

- Purchasing and visually inspecting lamps upon receipt
- Burning-in the lamps
- Visually inspecting burned-in lamps
- Documenting lamp voltage measurements of burn-in

4.2.2 Transmissometer Calibration

Transmissometer calibration includes pre-field and post-field calibration of an operational instrument, calibration of the audit instrument, and measuring window transmittances, including:

- Uniformity test of transmissometer receiver detector
- Calibration of transmissometer with the appropriate number of lamps for the defined operating period and sample frequency. Ten (10) lamps are calibrated for annual service intervals for instruments operating according to IMPROVE protocols.
- Measuring window transmittances
- Processing preliminary calibration data
- Documenting calibration configuration, weather and visibility conditions, and lamp voltage measurements on the calibration form
- Quality assurance review of calibration data
- Entry of calibration data in to the Transmissometer Calibration Database
- Calculation of site-specific calibration numbers for each lamp
- Maintenance of calibration documentation

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1.0 PURPOSE AND APPLICABILITY

This technical instruction (TI) describes the calibration procedures for Optec NGN-2 nephelometers operated according to IMPROVE Protocol. The purpose of nephelometer calibration is to assure quality data capture and minimize data loss by:

- Performing simple calibrations every week.
- Performing simple and complete calibrations during acceptance testing, installation, removal, and annual site visits.
- Performing simple and complete calibrations during laboratory testing.

The calibration of Optec NGN-2 nephelometers includes:

- Performing a zero calibration using the nephelometer's internal air filtration system.
- Performing a span calibration using a span gas with known scattering properties, usually SUVA-134a.
- Documenting calibration results.

2.0 RESPONSIBILITIES

2.1 PROJECT MANAGER

The project manager shall:

- Verify that simple calibrations are performed by the site operator according to the required schedule, and during:
 - Acceptance testing of a new instrument
 - Installation or removal of a nephelometer by ARS staff
 - Laboratory maintenance
 - Annual or audit site visits
- Verify that complete calibrations are performed during:
 - Acceptance testing of a new instrument
 - Installation or removal of a nephelometer by ARS staff
 - Laboratory maintenance
 - Annual or audit site visits

2.2 FIELD SPECIALIST

The field specialist shall:

- Perform a simple calibration and a complete calibration during any site visit.
- Document the results of both calibrations on the annual site visit documentation form.
- Enter the calibration results in the site-specific Quality Assurance Database.

2.3 INSTRUMENT TECHNICIAN

The instrument technician shall:

- Perform a simple calibration and a complete calibration during acceptance testing and laboratory maintenance.
- Maintain a printout of the results of both calibrations.
- Enter the calibration results in the site-specific Quality Assurance Database.

2.4 SITE OPERATOR

The site operator shall:

- Perform a simple calibration every week.
- Record the results of the simple calibration on the NGN-2 Nephelometer/Meteorology Log Sheet.

3.0 REQUIRED EQUIPMENT AND MATERIALS

A span gas calibration system, which includes the following materials, is required for all calibrations:

- Calibration span gas, (typically a 30 lb. non-refillable tank of DuPont SUVA-134a refrigerant)
- A pressure regulator capable of providing tight regulation at low pressure (2 psi) and an adjustable flowmeter compatible and calibrated for use with the span gas are required for providing optimum span gas supply to the NGN-2 nephelometer. (Suggested regulator - Air Products MN E11-N510B. A suggested flowmeter (rotameter) is the Cole Parmer MN N014-96ST).
- Calibration gas hoses and fittings to connect the tank, regulator, rotameter, and nephelometer (see Figure 3-1). The hoses must be compatible with SUVA-134a.

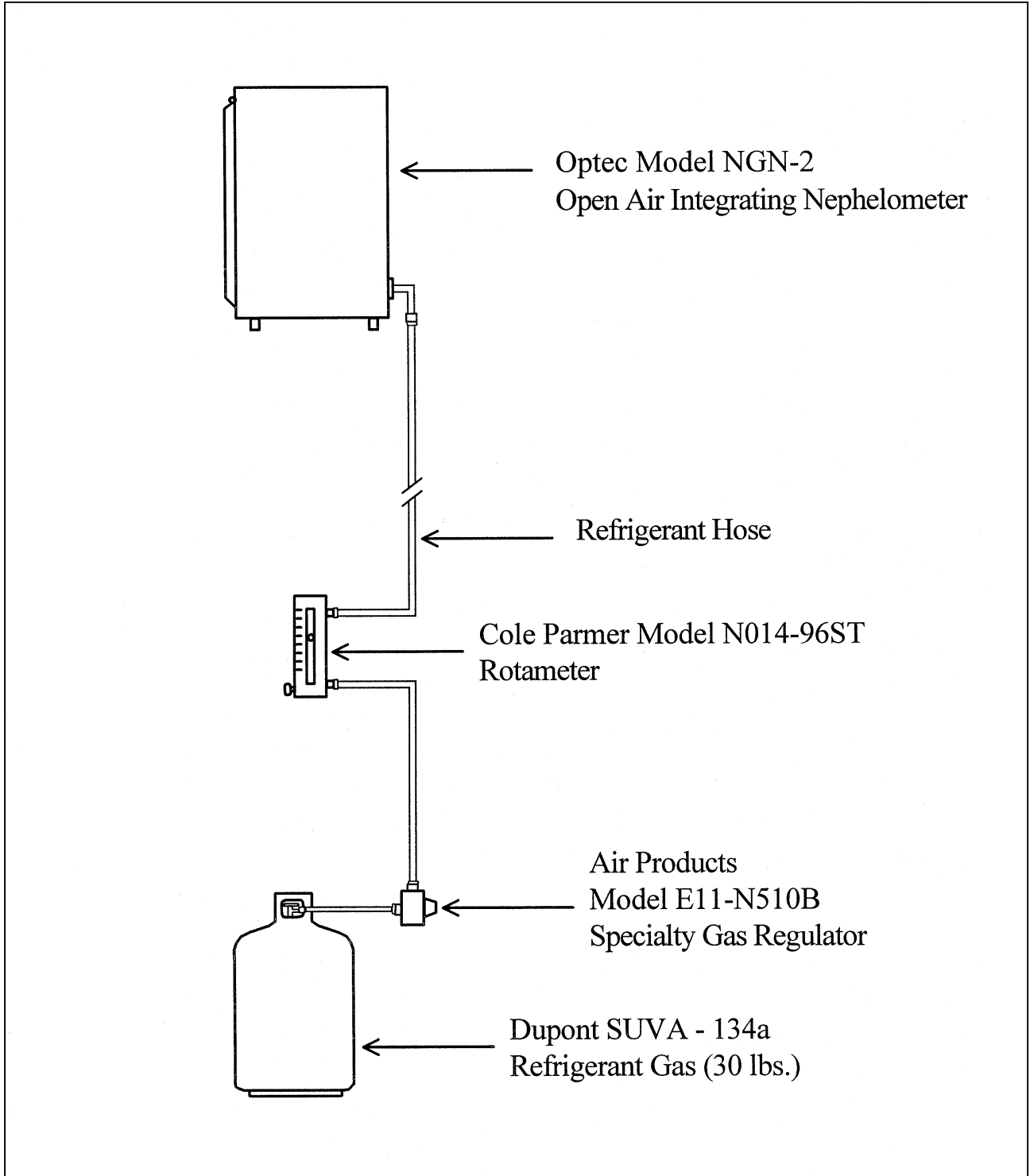


Figure 3-1. Manual Span Gas Calibration/Audit Configuration for the Optec NGN-2 Nephelometer.

The following additional materials are required to perform a simple calibration:

- TI 4100-3100, *Routine Site Operator Maintenance Procedures for Optec NGN-2 Nephelometer Systems (IMPROVE Protocol)*
- NGN-2 Nephelometer/Meteorology Log Sheet (site operator only)
- NGN-2 Nephelometer Annual Site Visit Documentation Form (field specialist only)

The following additional equipment and materials are required to perform a complete calibration:

- HP200LX palmtop computer with DATACOMM software
- NEPHCOM.DCF communications configuration file
- Computer-to-nephelometer support system interface cable

4.0 METHODS

The two methods of calibrating Optec NGN-2 nephelometers are the simple calibration and the complete calibration. Simple calibrations are initiated by site operators and field specialists to check the operation of the nephelometer system. Complete calibrations are performed by the field specialist or instrument technician during installations, removals, and laboratory testing. These methods are discussed in the following two (2) major subsections:

- 4.1 Simple Calibration
- 4.2 Complete Calibration

4.1 SIMPLE CALIBRATION

Simple calibration of NGN-2 nephelometers occurs during any of the following checks:

- Site operator initiated zero and span checks
- Remote, telephone modem initiated zero and span checks
- Field specialist initiated zero and span checks

Simple calibration of NGN-2 nephelometers includes:

- Span consisting of ten (10) minutes of gas introduction, then an average of ten (10) 1-minute readings of a span gas with known scattering properties.
- Clean air zero consisting of five (5) minutes of internal air filtering, then an average of ten (10) 1-minute readings of particle-free air.

Detailed instructions for performing simple calibrations are included in TI 4100-3100, *Routine Site Operator Maintenance Procedures For Optec NGN-2 Nephelometer Systems (IMPROVE Protocol)*.

Record the results of the simple calibration on the Optec NGN-2 Nephelometer/Meteorology Log Sheet (site operator) or the NGN-2 Nephelometer Annual Site Visit Documentation Form (field specialist).

4.2 COMPLETE CALIBRATION

Complete calibration of NGN-2 nephelometers occurs during any of the following:

- Acceptance testing of a new instrument
- Installation or removal of a nephelometer by ARS staff
- Laboratory maintenance
- Annual or audit site visits

The HP200LX palmtop computer is used by the field specialist to control nephelometer functions and log calibration data during a complete calibration of the NGN-2 nephelometer. Complete calibration includes the following:

- Nephelometer power-on-self-test (POST) information
- Twenty (20) 1-minute clean air zero readings
- Twenty (20) 1-minute span readings

Procedures for initiating a complete calibration include:

- Attaching the span gas system to the nephelometer
- Attaching the palmtop computer to the nephelometer support system
- Executing the specific procedures outlined below.

Specific procedures are detailed as follows:

ATTACH SPAN GAS SYSTEM

Attach the span gas system to the nephelometer as follows:

- Connect the regulator input hose to the calibration gas tank outlet connector.
- Connect the rotameter input hose (bottom) to the calibration gas regulator output connector.
- Connect the span gas hose from the nephelometer to the output connector (top) of the rotameter.
- Turn the rotameter adjustment knob to the "OFF" position (fully clockwise).

ATTACH
PALMTOP
COMPUTER

Attach the palmtop computer to the nephelometer support system (field calibration) or directly to the nephelometer (lab calibration) using the appropriate interface cable. The cable must be attached to the bottom of the datalogger at the connector labeled "Terminal" (AMP-A directly behind the connector labeled "Phone").

SETUP DATACOMM
COMMUNICATION
SETTINGS

Perform the following steps to establish communications with the nephelometer:

- Turn the computer "ON."
- Press the **MORE** key.
- Close all active applications except "FILER." (To close an application, highlight the icon for that application and press **F6**).
- After all applications (except "FILER") have been closed, highlight the "DATACOMM" icon and press **F5** or **ENTER**.
- Press the "MENU" key.
- Move the cursor to "CONNECT" and press **ENTER**.
- Move the cursor down to "SETTINGS" and press **ENTER**.
- Press **O** to list stored configuration files.
- Use the "TAB" key to move the cursor to the listed files. Then highlight the nephelometer communication configuration file NEPHCOM.DCF.
- Press **F10**.
- Verify that the palmtop computer configuration settings are correct:

Baud:	9600	Data Bits:	8
Interface:	Com1	Stop Bits:	1
Parity:	None		

- If the palmtop computer configuration settings are not correct, use the "TAB" key to move the cursor from one parameter (e.g., Baud) to another parameter (e.g., Parity) and then move the cursor to the proper setting for that parameter.
- When the settings are correct, press **F10**.

OPEN A
DATA FILE

Perform the following steps to open a data file:

- Press the **MENU** key.

- Move the cursor to "CONNECT" and press **ENTER**.
- Press **F5**.
- Press the **BACKSPACE** key to clear the filename entry box.
- Type the desired filename into the entry box using the following format: "**C:_DAT\SITEMMY.Y.DAT**," where "SITE" is the site abbreviation, "MM" is the month and "YY" is the year.

NOTE: "STOPCAP" should be indicated on the bottom status bar on the palmtop. Note that if you have to start over for any reason, be sure to use a different file name.

- Press **ENTER**.

PERFORM A MANUAL CALIBRATION

Perform the following calibration steps:

- Reset the nephelometer by interrupting power to the nephelometer (press the red reset button on the datalogger panel).
- Quickly press **^C** several times to get the nephelometer prompt (>).
- Press **ENTER** once to get a clean line.
- If the nephelometer will not respond, disconnect the palmtop computer cable from the datalogger system. Install the circular connector adapter between the cable and the datalogger system and repeat the two preceding steps.
- Press **FN** (function) and **ZOOM** (spacebar) to see all of the printed lines.
- Verify that the nephelometer settings, date, and time are correct:

SN (serial number) = #
Run Mode = 3
Intervals = 72
Date and Time = current date and time
Auto Span = 1
Baud Rate = 1200
Auto Test = 1

- Document any incorrect nephelometer settings.
- Verify that the nephelometer is set to local standard time. If the time is not correct, reset the nephelometer clock by entering the correct hour and minute. Note that the nephelometer uses a 24-hour clock (e.g., 4:30 pm would be entered as 16 hours, 30 minutes).

- When the nephelometer date, time, and configuration settings are correct, enter **POST** at the nephelometer prompt. The current nephelometer settings will be displayed on the palmtop screen and written to the open capture file.
- Manually perform the POST functions by typing the following commands, and pressing the "ENTER" key after each command:

DOOR OPEN
LAMP-ON
FAN ON
FAN OFF
SOL ON
SOL OFF
VALVE ON
VALVE OFF
PUMP ON
PUMP OFF

- Close the nephelometer door by typing **DOOR CLOSE**.
- Turn pump on by typing **PUMP ON**.
- Type **1 TO INTEG**.
- Type **1 20** (minutes in the field) **DO WORK LOOP**.
- After the clean air calibration cycle is complete, perform a span gas calibration. Before turning the gas on, verify that the flowmeter is turned "OFF" (fully clockwise). Turn the span gas tank valve (counter-clockwise) 1/2 turn and set the regulator to 4 psi.
- Turn the nephelometer valve on by typing **VALVE ON** and slowly adjust the flowmeter to 20 mm.
- Type **1 20** (minutes in the field) **DO WORK LOOP**.
- After the span calibration is finished, turn the span gas tank valve off.
- Disconnect the supply hose between the rotameter and tank.
- Close the flowmeter (fully clockwise).
- Perform POST calibration functions by typing the following commands (press the "ENTER" key after each command):

DOOR OPEN
FAN ON
LAMP OFF
SOL ON
VALVE OFF

To remove SUVA gas from the measurement chamber, let the instrument run for approximately five minutes, and type the following commands (press the "ENTER" key after each command):

PUMP OFF
FAN OFF
SOL OFF
DOOR CLOSE

- Press **FN** (function) and **ZOOM** (spacebar) to see the bottom status bar.
- After obtaining a valid calibration, press **F5** to close the capture file. The bottom status bar on the palmtop should indicate "CAPTURE."
- Then press **MENU**
- Highlight "QUIT" and press **ENTER**
- Press the "FILER" key on the palmtop, then press **F5**. Type or highlight the correct path, (e.g., C:_DAT). Type or highlight the correct file name and enter.
- Press **F8** "VIEW" to verify that the data were captured.
- Use the arrow keys to move through the entire file
- Press **F8** to close the viewed file.
- Press **MENU**, highlight "QUIT," and press **ENTER** to close file.
- Press **MENU**, highlight "QUIT," and press **ENTER** to close applications and return to the opening screen.
- Turn the computer off and remove the cables.

DOCUMENTING THE CALIBRATION

Place a printout of the calibration results in the instrument-specific nephelometer maintenance log book. An example of the printout is shown in Figure 4-1. Enter the results in the site-specific Quality Assurance Database.

RTL CPM VERSION - FOR OPTEC SBC
COPYRIGHT 1992
OPTEC, INC. NGN-2 OPERATING SYSTEM
VERSION: NEPH1056
SN = 21
RUN MODE = 3
INTERVALS = 72
DATE & TIME (YR-MO-DAY HR-MIN) = 960509 1641
AUTO SPAN (1 ON / 0 OFF) 1
STORED BAUD RATE = 1200
AUTO TEST (1 ON / 0 OFF) = 1
TOTAL RUN TIME = 4037 HOURS
CSUM = 23 ROMTOP = 23

Column												
1	2	3	4	5	6	7	8					
>LAMP-ON PUMP ON T TO INTEG												
>1	15	DO	WORK	LOOP	1	131	4005	65	1	23.66	960509	1642
1	124	3989	62	1	1	23.72	960509	1643				
1	123	3978	61	1	1	23.78	960509	1644				
1	116	3971	58	1	1	23.81	960509	1645				
1	120	3968	60	1	1	23.78	960509	1646				
1	120	3967	60	1	1	23.84	960509	1647				
1	118	3967	59	1	1	23.81	960509	1648				
1	117	3967	59	1	1	23.84	960509	1649				
1	119	3967	60	1	1	23.84	960509	1650				
1	114	3967	57	1	1	23.87	960509	1651				
1	118	3967	59	1	1	23.84	960509	1652				
1	121	3968	61	1	1	23.90	960509	1653				
1	117	3973	59	1	1	23.95	960509	1654				
1	117	3979	58	1	1	23.92	960509	1655				
1	120	3985	60	1	1	23.95	960509	1656				
>VALVE ON												
>1	15	DO	WORK	LOOP	1	144	3979	72	1	24.13	960509	1702
1	189	3980	95	1	1	24.19	960509	1703				
1	220	3982	110	1	1	24.22	960509	1704				
1	233	3983	117	1	1	24.28	960509	1705				
1	241	3984	121	1	1	24.34	960509	1706				
1	244	3986	122	1	1	24.39	960509	1707				
1	245	3988	122	1	1	24.42	960509	1708				
1	246	3991	123	1	1	24.51	960509	1709				
1	246	3993	123	1	1	24.54	960509	1710				
1	246	3995	123	1	1	24.57	960509	1711				
1	247	3997	123	1	1	24.60	960509	1712				
1	248	3999	124	1	1	24.69	960509	1713				
1	246	4000	123	1	1	24.75	960509	1714				
1	246	4001	123	1	1	24.78	960509	1715				
1	248	4002	124	1	1	24.86	960509	1716				
>LAMP OFF PUMP OFF VALVE OFF												

Column	Description
1	Status: 1 = ambient air measurement
	2 = clean air calibration
	3 = span gas calibration
	4 = lamp low or burned out
	5 = rain
	6 = chopper motor failure
	7 = span/clean air calibration in process
	(D/A channel-2 output only)
	8 = fog level reached
2	Raw scattered light value
3	Raw lamp brightness value
4	Normalized scattered light value
5	Integration time in minutes
6	Temperature (°C)
7	Year-Month-Day
8	Hour-Minute using 24-hour clock

Figure 4-1. Example Optec NGN Nephelometer Calibration Results Printout.

APPENDIX A

**Optec NGN-2
Clean-Air Zero and Span Gas
Nephelometer Calibration Calculations**

**Optec NGN-2
Clean-Air Zero and Span Gas
Nephelometer Calibration Calculations**

- 1) Calibration of the nephelometer allows conversion of the reading in counts to b_{scat} . This is a two-step process:
 - The nephelometer reading in counts is converted to multiples of Rayleigh; and
 - The calculated multiple of Rayleigh is multiplied by the Rayleigh coefficient (specific for each elevation) to provide b_{scat} .
- 2) Two calibration points are required (see accompanying Optec NGN-2 Manual Calibration Procedures): 1) A clean air (Rayleigh) value obtained by recirculating air through the nephelometer's internal clean air filter, and 2) an upscale span value obtained by introducing a gas of known scattering properties to the nephelometer chamber.
- 3) Nephelometer response to scattering can be represented by the linear equation $y = mx + b$ where:

y = normalized nephelometer reading in counts
 m = slope of calibration line
 x = multiple of Rayleigh scattering
 b = nephelometer wall scattering in counts

m and b are calculated as follows:

$$m = \frac{C_{\text{span}} - C_{\text{zero}}}{S_{\text{span}} - S_{\text{zero}}} \text{ and } b = C_{\text{zero}} - m \times S_{\text{zero}}$$

where

C_{span} = nephelometer counts during upscale span calibration (in counts)
 C_{zero} = nephelometer counts during clean air calibration (in counts)
 S_{span} = span gas multiple of Rayleigh scattering (e.g., F12 = 15.3)
 S_{zero} = clean air multiple of Rayleigh scattering (always 1.0)

An example calibration curve is provided as Figure 1. Curves will vary between instruments.

For the measured calibration values displayed in Figure 1 of 35 counts for clean air and 200 counts for Freon-12:

$$m = 11.54 \text{ and } b = 23.5$$

Solving the calibration equation for x yields:

$$x = (y - b) / m$$

This equation can be used to determine multiples of Rayleigh scattering (x) given a normalized nephelometer reading (y).

Example

Assuming a normalized nephelometer reading of 100 counts and the calibration values depicted in Figure A-1, solve for x:

$$\begin{aligned} x &= (y - b) / m \\ &= (100 - 23.5) / 11.54 \\ &= 6.63 \text{ multiples of Rayleigh} \end{aligned}$$

- 4) The nephelometer reading can be converted to b_{scat} as follows:

$$b_{\text{scat}} = \text{multiples of Rayleigh} * \text{Rayleigh coefficient}$$

The Rayleigh coefficient is a function of the elevation of the site. Table A-1 lists Rayleigh coefficients at various elevations and at various wavelengths. The NGN-2 nephelometers measure scattering at a wavelength of 550 nm.

Example

Assuming an elevation of sea level, the Rayleigh coefficient at a wavelength of 550 nm is:

$$b_{\text{ray}} = 0.01162 \text{ km}^{-1}$$

b_{scat} is then calculated as:

$$b_{\text{scat}} = 6.63 * 0.01162$$

$$b_{\text{scat}} = 0.077 \text{ km}^{-1}$$

- 5) Data loggers that have a $y = mx + b$ option can perform the calculations necessary to calculate b_{scat} directly using the last zero and span calibration values and the site-specific Rayleigh coefficient.

Example Optec NGN-2 Calibration Curve
(Curve is Instrument Dependent)

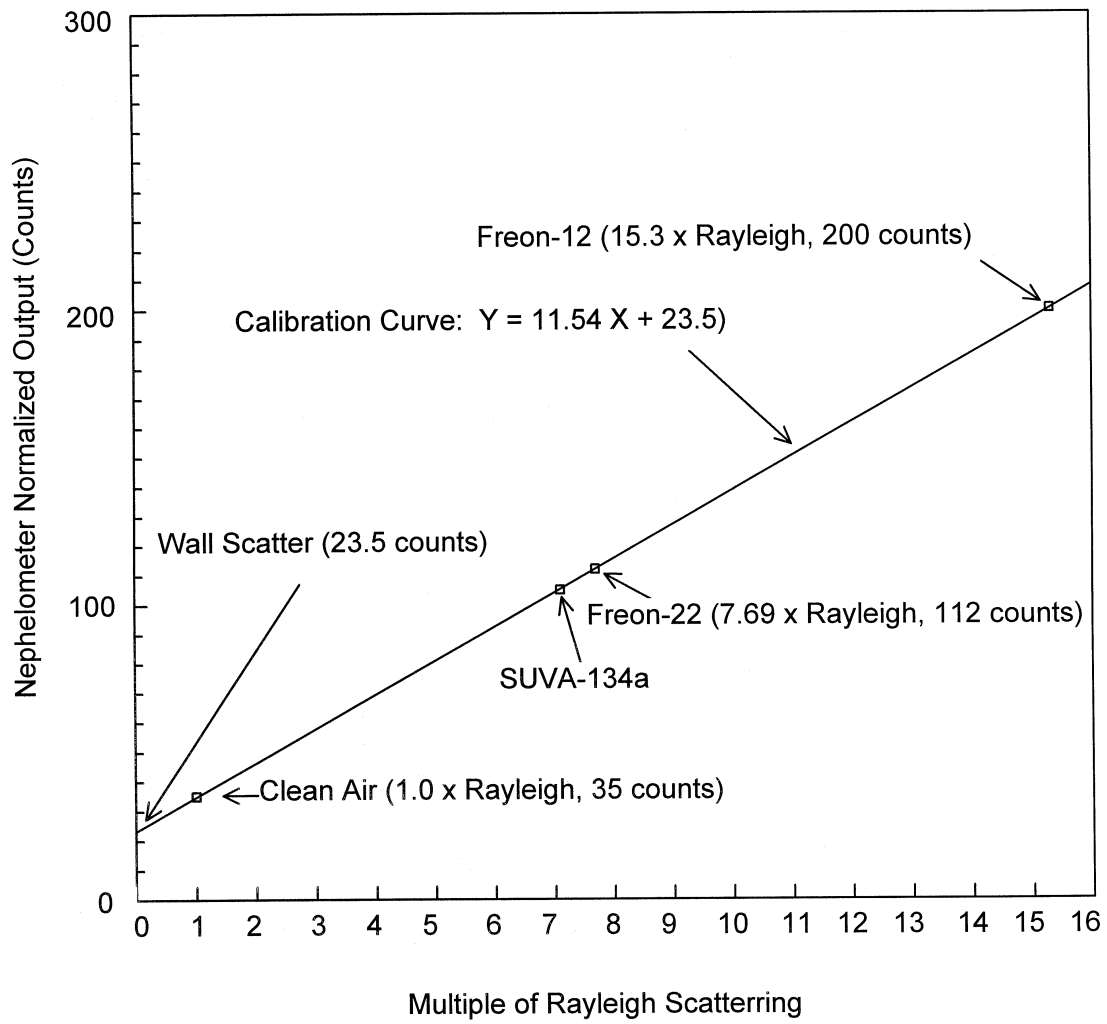


Figure A-1. Example Optec NGN-2 Calibration Curve.

Table A-1

RAYLEIGH SCATTER AS A FUNCTION OF ALTITUDE				
ALTITUDE	WAVELENGTH			
METERS/ FEET	ULTRAVIOLET 405	BLUE 450	GREEN 550	RED 630
0000/0000	.04137000	.02644000	.01162000	.00679800
100/ 328	.04025100	.02572000	.01130370	.00661200
200/ 656	.03992200	.02551000	.01121140	.00655800
300/ 984	.03959300	.02530000	.01111910	.00650400
400/ 1312	.03926400	.02509000	.01102680	.00645000
500/ 1640	.03893500	.02488000	.01093450	.00639600
600/ 1969	.03860600	.02467000	.01084220	.00634200
700/ 2297	.03827700	.02446000	.01074990	.00628800
800/ 2625	.03794800	.02425000	.01065760	.00623400
900/ 2953	.03761900	.02404000	.01056530	.00618000
1000/ 3281	.03754000	.02400000	.01055000	.00616900
1100/ 3609	.03696100	.02362000	.01038070	.00607200
1200/ 3937	.03663200	.02341000	.01028840	.00601800
1300/ 4265	.03630300	.02320000	.01019610	.00596400
1400/ 4593	.03597400	.02299000	.01010380	.00591000
1500/ 4921	.03564500	.02278000	.01001150	.00585600
1600/ 5249	.03531600	.02257000	.00991920	.00580200
1700/ 5577	.03498700	.02236000	.00982690	.00574800
1800/ 5906	.03465800	.02215000	.00973460	.00569400
1900/ 6234	.03432900	.02194000	.00964230	.00564000
2000/ 6562	.03400000	.02173000	.00955000	.00558600
2100/ 6890	.03367100	.02152000	.00945770	.00553200
2200/ 7218	.03334200	.02131000	.00936540	.00547800
2300/ 7546	.03301300	.02110000	.00927310	.00542400
2400/ 7874	.03268400	.02089000	.00918080	.00537000
2500/ 8202	.03235500	.02068000	.00908850	.00531600
2600/ 8530	.03202600	.02047000	.00899620	.00526200
2700/ 8858	.03169700	.02026000	.00890390	.00520800
2800/ 9186	.03136800	.02005000	.00881160	.00515400
2900/ 9514	.03103900	.01984000	.00871930	.00510000
3000/ 9843	.03071000	.01963000	.00862700	.00504600
3100/10170	.03038340	.01942153	.00853522	.00499239
3200/10499	.03005864	.01921424	.00844395	.00493909
3300/10827	.02973572	.01900812	.00835320	.00488609
3400/11155	.02941464	.01880317	.00826297	.00483339
3500/11483	.02909539	.01859939	.00817325	.00478099
3600/11811	.02877798	.01839678	.00808405	.00472890
3700/12139	.02846239	.01819534	.00799536	.00467710
3800/12467	.02814863	.01799507	.00790719	.00462560
3900/12795	.02783669	.01779596	.00781952	.00457440
4000/13123	.02752658	.01759801	.00773237	.00452350
4100/13451	.02721828	.01740123	.00764573	.00447290
4200/13780	.02691180	.01720560	.00755960	.00442260
4300/14108	.02660714	.01701113	.00747398	.00437259
4400/14436	.02630428	.01681782	.00738887	.00432289