QUALITY ASSURANCE/QUALITY CONTROL DOCUMENTATION SERIES

TITLE	**CALIBRATION OF OPTICAL MONITORING SYSTEMS (IMPROVE PROTOCOL)**
TYPE	**STANDARD OPERATING PROCEDURE**
NUMBER	**4200**
DATE	**JULY 1993**

AUTHORIZATIONS		
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REVISION HISTORY			
REVISION NO.	CHANGE DESCRIPTION	DATE	AUTHORIZATIONS
1.0	Added responsibilities/equipment/methods.	October 1996	

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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

QUALITY ASSURANCE/QUALITY CONTROL DOCUMENTATION SERIES	
TITLE	**CALIBRATION OF OPTEC NGN-2 NEPHELOMETERS – TYPE 1 (IMPROVE PROTOCOL)**
TYPE	**TECHNICAL INSTRUCTION**
NUMBER	**4200-2000**
DATE	**JULY 1993**

AUTHORIZATIONS		
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REVISION HISTORY			
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1.0	Up-scale calibration using upgraded valve	March 1995	
2.0	Modify for use with palmtop computer	October 1996	
3.0	Add in-line filter / correct Rayleigh table	April 2004	

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1.0   PURPOSE AND APPLICABILITY

This technical instruction (TI) describes the calibration procedures for Optec NGN-2 nephelometers (type 1) operated according to IMPROVE Protocol. Type 1 systems operate with a Campbell Scientific 21X datalogger, and are configured for manual span calibrations. 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
    - 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 (4 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). (Suggested flowmeter is the Cole Parmer rotameter MN N014-96ST).

- Calibration gas hoses and fittings to connect the tank, regulator, flowmeter, and nephelometer (refer to Figure 3-1). The hoses must be compatible with SUVA-134a.

Optec Model NGN-2
Open Air Integrating Nephelometer

Alternate Locations for
Installing Filter Assembly

Refrigerant Hose

Cole Parmer Model N014-96ST
Rotameter

Hose Connection

Calibration Gas
Filter Assembly

Air Products
Model E11-N510B
Specialty Gas Regulator
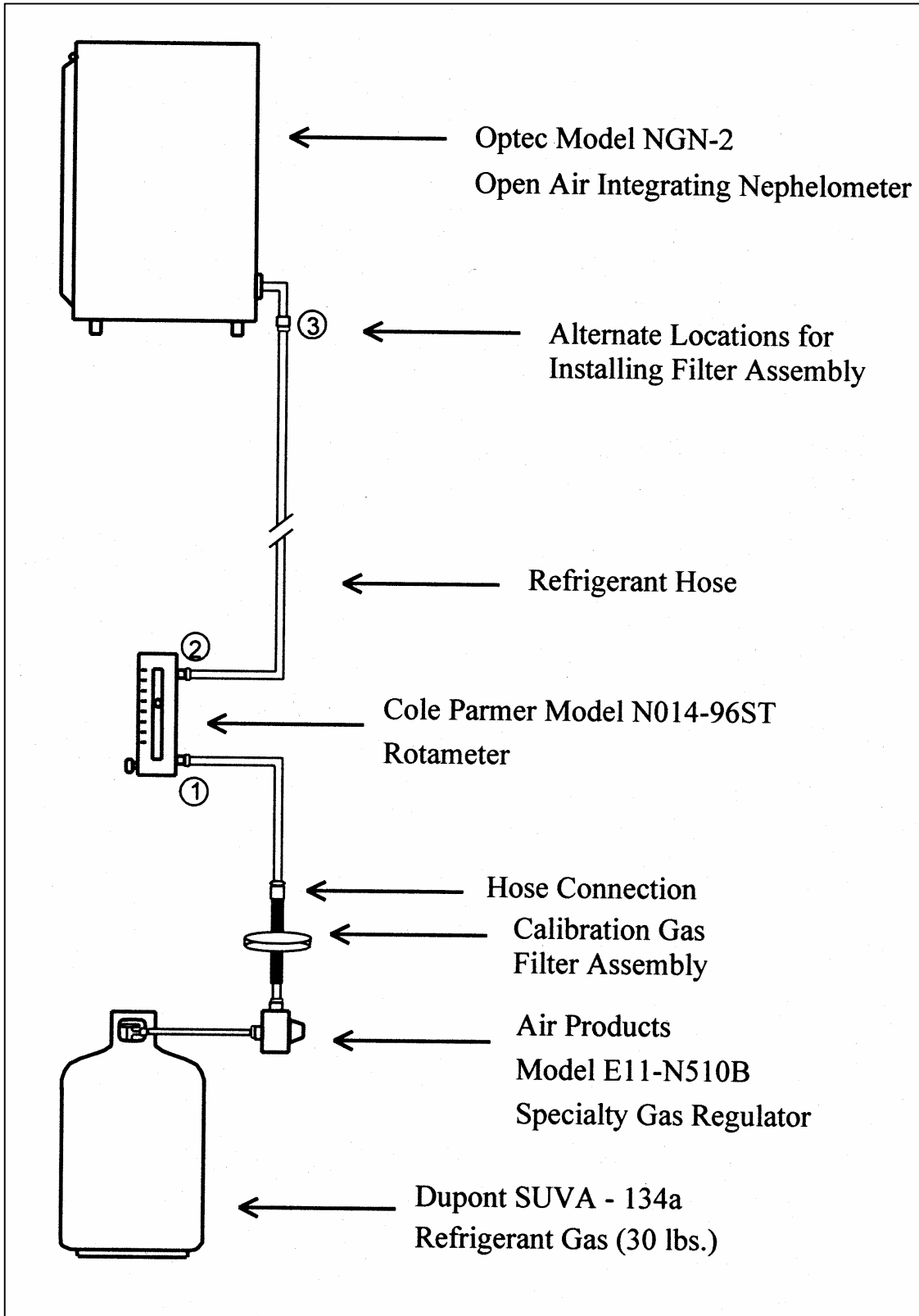
Dupont SUVA - 134a
Refrigerant Gas (30 lbs.)

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

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 – Type 1 (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
  -or-
  A laptop computer with HyperTerminal 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 – Type 1 (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, or a laptop computer with HyperTerminal software 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 or laptop 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 flowmeter input hose (bottom) to the in-line filter assembly, then 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 flowmeter adjustment knob to the OFF position (fully clockwise).

ATTACH COMPUTER

Attach the palmtop or laptop 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
COMMUNICATION
SETTINGS

HP200LX with Datacomm software
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.

SETUP
COMMUNICATION
SETTINGS (continued)

- Press **F10**.

- Verify that the palmtop computer or laptop 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**.

Laptop with HyperTerminal Software
Perform the following steps to establish communications with the nephelometer:

- Turn the computer on.

- Open the HyperTerminal program. HyperTerminal comes with all versions of Windows operating systems and is located in the Windows Start Menu, Programs/Accessories/ Communications.

- Follow the on-screen prompts for the area code entry and connect using the port that will be connected to the nephelometer directly.

- Verify that the com port configuration settings are correct:

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

- If the com port configuration settings are not correct, update the parameter with the proper setting.

OPEN A DATA FILE

HP200LX with Datacomm software
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.

OPEN A DATA FILE
(continued)

- Type the desired *filename* into the entry box using the following format: **C:_Dat*sitemmyy*.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 nay reason, be sure to use a different file name.

- Press **<Enter>**.

Laptop with HyperTerminal software
Perform the following steps to save a data file:

- Select **Transfer**, then **Capture Text**.

- Click **Browse** to select the area to save to, and type the desired *filename* into the entry box using the following format: C:\path*sitemmyy*.dat, where *site* is the site abbreviation, *mm* is the month, and *yy* is the year. 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 or laptop 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

PERFORM A MANUAL
CALIBRATION (continued)

- 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 computer 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 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) ½ 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.

PERFORM A MANUAL
CALIBRATION (continued)

- Disconnect the supply hose between the flowmeter 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.

STOP FILE CAPTURE

HP200LX with Datacomm software
Perform the following steps to stop file capture:

- After obtaining a valid calibration, press **F5** to close the capture file. The bottom status bar on the palmtop should indicate: CAPTURE.

- Press **Menu**, highlight Quit, and press **<Enter>** .

- Press the Filer key on the computer, 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 the 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.

STOP FILE CAPTURE
(continued)

Laptop with HyperTerminal software
Perform the following steps to stop file capture:

- Select **Transfer**, then under Capture Text select **Stop**.

- Use Windows Explorer to find the save file and open the file
  with WordPad to verify that the data were captured.

- Close the viewed file.

- Close the HyperTerminal program.

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

$$m = \frac{C_{span} - C_{zero}}{S_{span} - S_{zero}} \quad and \quad b = C_{zero} - m * S_{zero}$$

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 A-1. Curves will vary between instruments.

For the measured calibration values displayed in Figure A-1, of 35 counts for clean air and 200 counts for Freon-12:
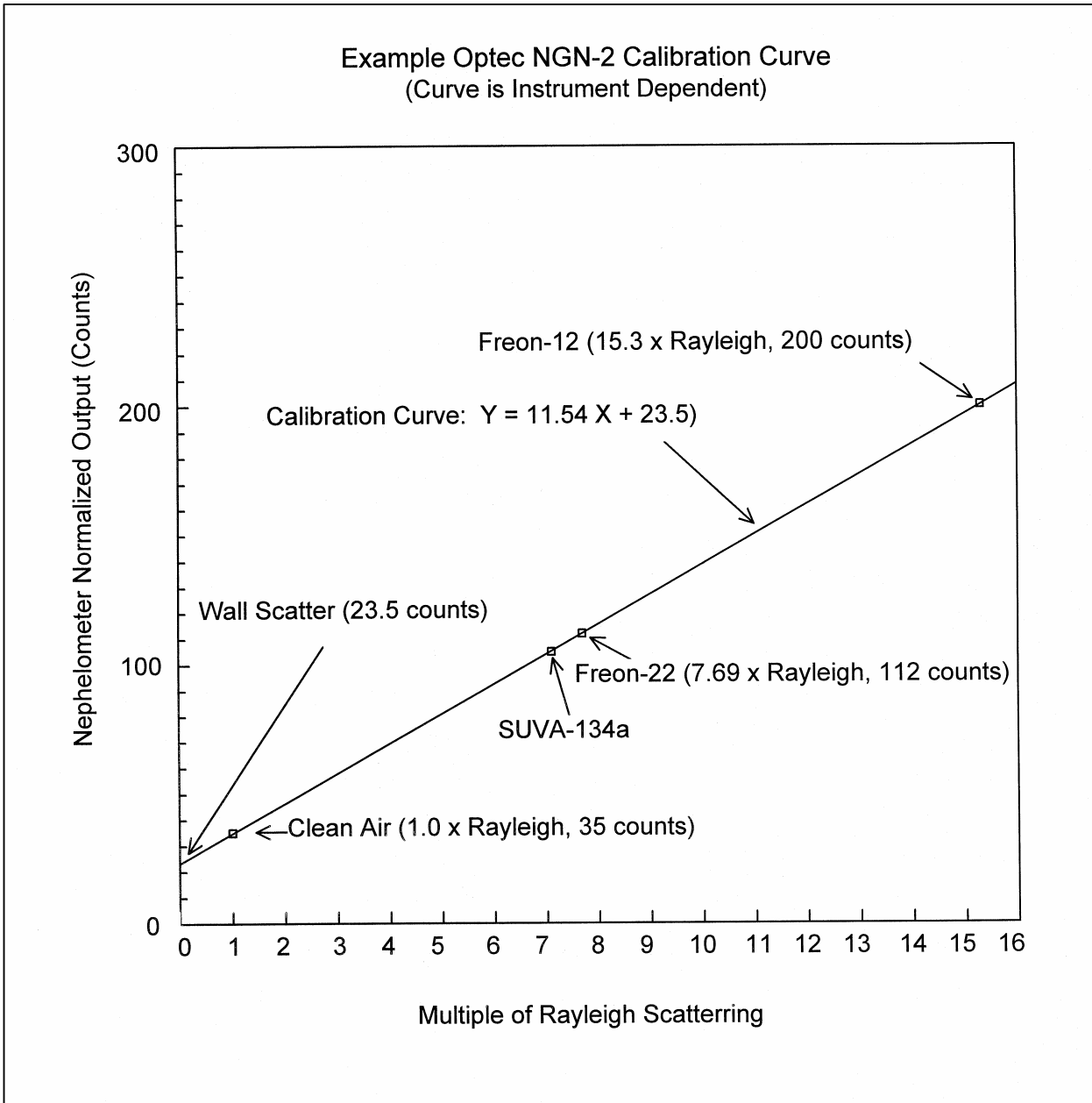
$$m = 11.54 \quad and \quad b = 23.5$$

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

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).

<u>Example</u>

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

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

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

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

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.

<u>Example</u>

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

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

b_{scat} is then calculated as:

$$
\begin{aligned}
b_{scat} \quad &= \quad 6.63 * 0.01162 \\
b_{scat} \quad &= \quad 0.077\ \text{km}^{-1}
\end{aligned}
$$

5)   Dataloggers 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.

Table A-1

Rayleigh Scatter in km^{-1} as a Function of Altitude

Altitude (m)	Wavelength			
	UV (405)	Blue (450)	Green (550)	Red (630)
0	0.03952181	0.02593026	0.01162000	0.00674986
100	0.03915788	0.02569148	0.01151300	0.00668770
200	0.03879395	0.02545271	0.01140600	0.00662555
300	0.03843003	0.02521394	0.01129900	0.00656340
400	0.03806610	0.02497517	0.01119200	0.00650124
500	0.03770217	0.02473639	0.01108500	0.00643909
600	0.03733824	0.02449762	0.01097800	0.00637693
700	0.03697432	0.02425885	0.01087100	0.00631478
800	0.03661039	0.02402008	0.01076400	0.00625262
900	0.03624646	0.02378130	0.01065700	0.00619047
1000	0.03588254	0.02354253	0.01055000	0.00612831
1100	0.03554242	0.02331938	0.01045000	0.00607023
1200	0.03520230	0.02309623	0.01035000	0.00601214
1300	0.03486218	0.02287308	0.01025000	0.00595405
1400	0.03452206	0.02264992	0.01015000	0.00589596
1500	0.03418194	0.02242677	0.01005000	0.00583787
1600	0.03384182	0.02220362	0.00995000	0.00577978
1700	0.03350170	0.02198047	0.00985000	0.00572170
1800	0.03316159	0.02175732	0.00975000	0.00566361
1900	0.03282147	0.02153416	0.00965000	0.00560552
2000	0.03248135	0.02131101	0.00955000	0.00554743
2100	0.03216844	0.02110571	0.00945800	0.00549399
2200	0.03185553	0.02090041	0.00936600	0.00544055
2300	0.03154262	0.02069511	0.00927400	0.00538711
2400	0.03122971	0.02048981	0.00918200	0.00533367
2500	0.03091680	0.02028451	0.00909000	0.00528023
2600	0.03060389	0.02007921	0.00899800	0.00522678
2700	0.03029098	0.01987391	0.00890600	0.00517334
2800	0.02997807	0.01966861	0.00881400	0.00511990
2900	0.02966516	0.01946331	0.00872200	0.00506646
3000	0.02935225	0.01925801	0.00863000	0.00501302
3100	0.02903934	0.01905271	0.00853800	0.00495958
3200	0.02872644	0.01884741	0.00844600	0.00490614
3300	0.02841353	0.01864211	0.00835400	0.00485270
3400	0.02810062	0.01843681	0.00826200	0.00479925
3500	0.02778771	0.01823152	0.00817000	0.00474581
3600	0.02747480	0.01802622	0.00807800	0.00469237
3700	0.02716189	0.01782092	0.00798600	0.00463893
3800	0.02684898	0.01761562	0.00789400	0.00458549
3900	0.02653607	0.01741032	0.00780200	0.00453205
4000	0.02622316	0.01720502	0.00771000	0.00447861
4100	0.02591025	0.01699972	0.00761800	0.00442517
4200	0.02559734	0.01679442	0.00752600	0.00437172
4300	0.02528443	0.01658912	0.00743400	0.00431828
4400	0.02497152	0.01638382	0.00734200	0.00426484

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QUALITY ASSURANCE/QUALITY CONTROL DOCUMENTATION SERIES

TITLE	**CALIBRATION OF OPTEC NGN-2 NEPHELOMETERS – TYPE 2 (IMPROVE PROTOCOL)**
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1.0   PURPOSE AND APPLICABILITY

This technical instruction (TI) describes the calibration procedures for Optec NGN-2 nephelometers (type 2) operated according to IMPROVE Protocol. Type 2 systems operate with a Campbell Scientific 23X datalogger, and can be configured for manual or automatic span calibrations. The purpose of nephelometer calibration is to assure quality data capture and minimize data loss by:

- Performing automatic simple calibrations every week.

- Performing manual simple calibrations during monthly site visits.

- 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 the nephelometer and datalogging system are running automatic calibrations every seven (7) days, as scheduled.

- 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
  - 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:

- Verify that the automatic calibration system is operating properly.

- Perform a simple calibration at monthly site visits.

- 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 (4 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). (Suggested flowmeter is the Cole Parmer rotameter MN N014-96ST).

- Calibration span gas inlet and outlet valves and inlet and outlet relays.

- Calibration gas hoses and fittings to connect the tank, regulator, flowmeter, and nephelometer (refer to Figure 3-1). The hoses must be compatible with SUVA-134a.
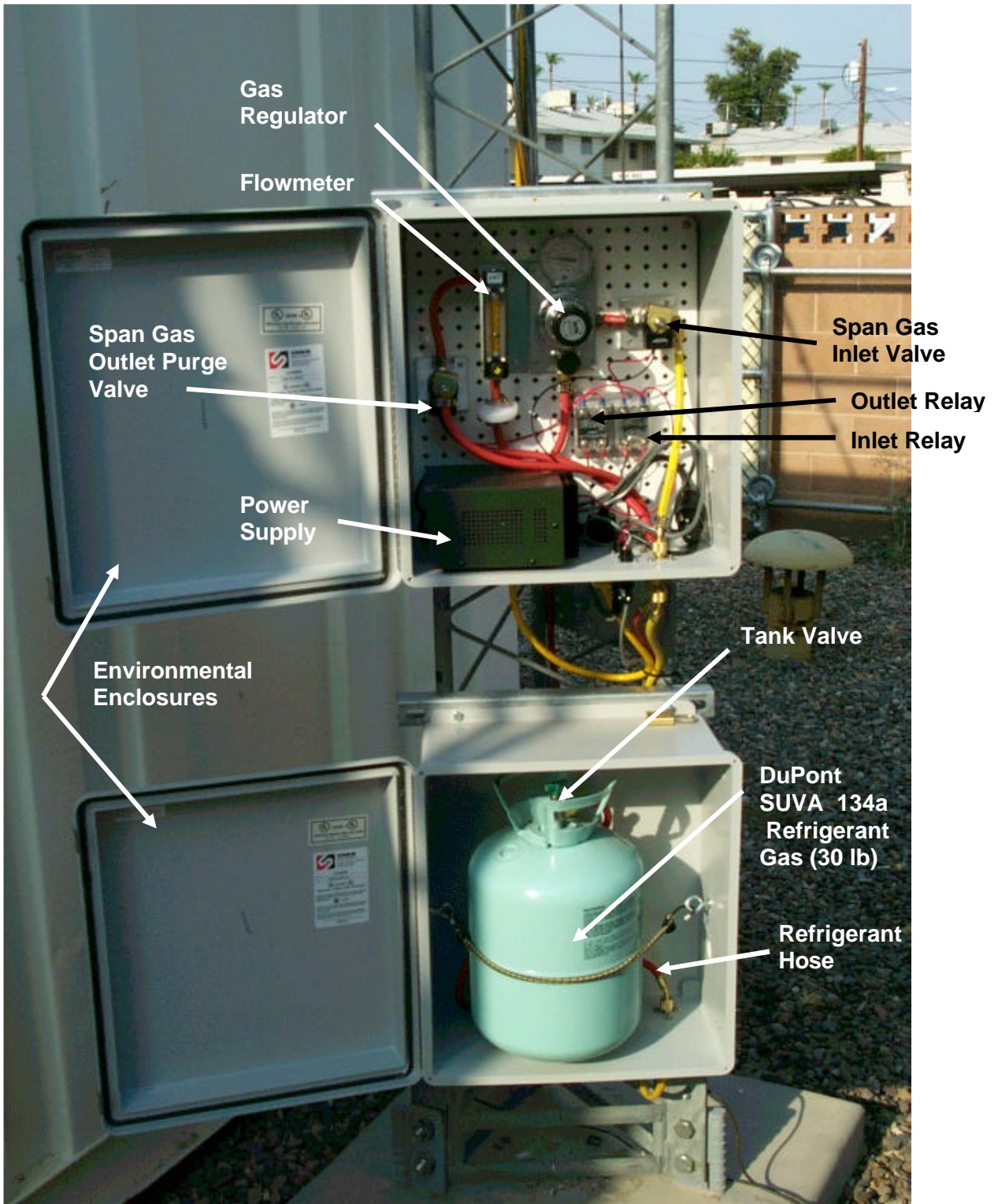
Figure 3-1.   Automatic Span Gas Calibration System
for the Optec NGN-2 Nephelometer (Type 2).

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

- TI 4100-3105, *Routine Site Operator Maintenance Procedures for Optec NGN-2 Nephelometer Systems – Type 2 (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
  -or-
  A laptop computer with HyperTerminal software

- Nephcom.dcf communications configuration file

- Computer-to-nephelometer support system interface cable

4.0   METHODS

The three methods of calibrating Type 2 Optec NGN-2 nephelometers are the automatic simple calibration, the manual simple calibration, and the complete calibration. Automatic simple calibrations are set up to be initiated by the datalogging and control subsystem on a weekly basis (every seven days as scheduled). Manual simple calibrations are initiated by site operators and field specialists to check the operation of the nephelometer system while on site. Complete calibrations are performed by the field specialist or instrument technician during installations, removals, and laboratory testing. These methods are discussed in the following three (3) major subsections:

4.1   Automatic Simple Calibration
4.2   Manual Simple Calibration
4.3   Complete Calibration

4.1   AUTOMATIC SIMPLE CALIBRATION

Automatic simple calibrations of NGN-2 nephelometers occur every seven (7) days at the scheduled time, once they are scheduled by the site operator or field specialist. Detailed instructions for scheduling the automatic simple calibrations are included in TI 4100-3105, *Routine Site Operator Maintenance Procedures for Optec NGN-2 Nephelometer Systems – Type 2 (IMPROVE Protocol)*.

Automatic 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.

Results of the automatic simple calibration are recorded by the Campbell 23X datalogger.

4.2   MANUAL SIMPLE CALIBRATION

Manual 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

Manual calibration of NGN-2 nephelometers includes the same measurement readings and procedures as in automatic simple calibration (see Section 4.1):

- 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 4100-3105, *Routine Site Operator Maintenance Procedures for Optec NGN-2 Nephelometer Systems – Type 2 (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).

4.3   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 or a laptop computer with HyperTerminal software 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 or laptop computer to the nephelometer support system.

- Executing the specific procedures outlined below.

Specific procedures are detailed as follows:

ATTACH SPAN GAS SYSTEM

For laboratory calibration, attach the span gas system to the nephelometer as follows:

- Connect the regulator input hose to the calibration gas tank outlet connector.

- Connect the flowmeter 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 flowmeter.

- Turn the flowmeter adjustment knob to the OFF position (fully clockwise).

For field calibration, the span gas system is already connected to the nephelometer.

ATTACH COMPUTER

Attach the palmtop or laptop 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 serial connection on the connector panel on the bottom of the datalogger enclosure.

SETUP COMMUNICATION SETTINGS

HP200LX with Datacomm software
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**).

SETUP
COMMUNICATION
SETTINGS (continued)

- 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**.

Laptop with HyperTerminal software
Perform the following steps to establish communications with the nephelometer:

- Turn the computer on.

- Open the HyperTerminal program. HyperTerminal comes with all versions of Windows operating systems and is located in the Windows Start Menu, Programs/Accessories/ Communications.

- Follow the on-screen prompts for the area code entry and connect using the port that will be connected to the nephelometer directly.

- Verify that the com port configuration settings are correct:

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

- If the com port configuration settings are not correct, update the parameter with the proper setting.

OPEN A DATA FILE

HP200LX with Datacomm software
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*sitemmyy*.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 nay reason, be sure to use a different file name.

- Press **<Enter>**.

Laptop with HyperTerminal software
Perform the following steps to save a data file:

- Select **Transfer**, then **Capture Text**.

- Click **Browse** to select the area to save to, and type the desired *filename* into the entry box using the following format: C:\path*sitemmyy*.dat, where *site* is the site abbreviation, *mm* is the month, and *yy* is the year. 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 pressing ***6A0** to enter the port locations. Then press **1** to turn the nephelometer off and **1** again to restart the nephelometer.

- 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 or laptop computer cable from the datalogger system. Install the null modem adapter between the cable and the datalogger system and repeat the two preceding steps.

PERFORM A MANUAL
CALIBRATION (continued)

- 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 computer 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 field) **DO WORK LOOP**.

PERFORM A MANUAL
CALIBRATION (continued)

- After the clean air calibration cycle is complete, perform a span gas calibration by entering **2** and **3** on the 23X keypad to open the solenoid valves.

- 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 off the solenoid valves by resetting Ports 2 and 3 to **0** using the 23X keypad.

- 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.

STOP FILE CAPTURE

HP200LX with Datacomm software
Perform the following steps to stop file capture:

- After obtaining a valid calibration, press **F5** to close the capture file. The bottom status bar on the palmtop should indicate: CAPTURE.

- Press **Menu**, highlight Quit, and press **<Enter>** .

- Press the Filer key on the computer, 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.

STOP FILE CAPTURE
(continued)

- Press **Menu**, highlight Quit, and press **<Enter>** to close the 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.

Laptop with HyperTerminal software
Perform the following steps to stop file capture:

- Select **Transfer**, then under Capture Text select **Stop**.

- Use Windows Explorer to find the save file and open the file with WordPad to verify that the data were captured.

- Close the viewed file.

- Close the HyperTerminal program.

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

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

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 A-1. Curves will vary between instruments.

For the measured calibration values displayed in Figure A-1, of 35 counts for clean air and 200 counts for Freon-12:
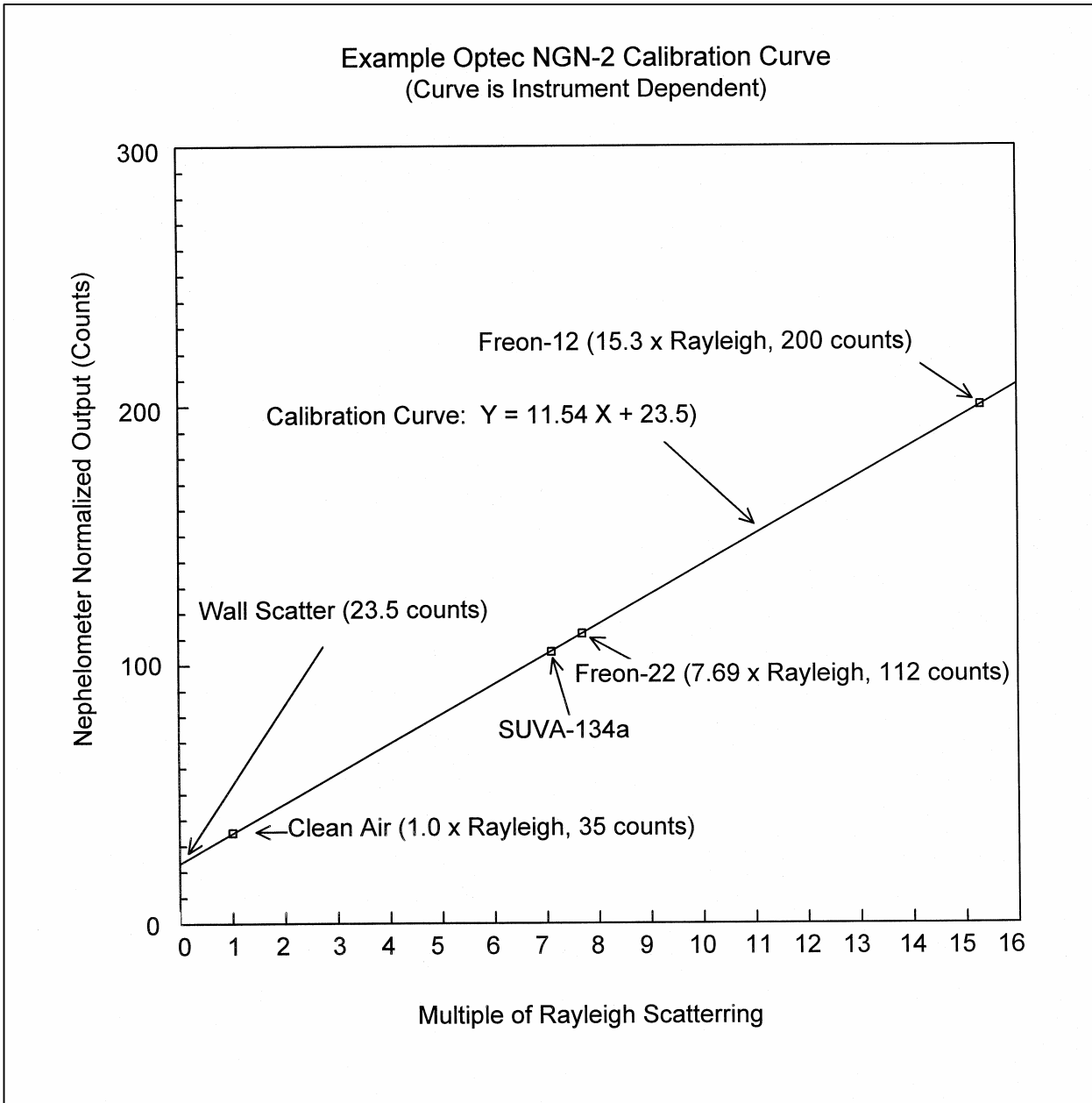
$$m = 11.54 \ and \ b = 23.5$$

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

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*).

<u>Example</u>

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

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

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

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

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.

<u>Example</u>

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

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

b_{scat} is then calculated as:

$$
\begin{aligned}
b_{scat} \quad &= \quad 6.63 * 0.01162 \\
b_{scat} \quad &= \quad 0.077 \text{ km}^{-1}
\end{aligned}
$$

5) Dataloggers 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.

Table A-1

Rayleigh Scatter in km^{-1} as a Function of Altitude

Altitude (m)	Wavelength			
	UV (405)	Blue (450)	Green (550)	Red (630)
0	0.03952181	0.02593026	0.01162000	0.00674986
100	0.03915788	0.02569148	0.01151300	0.00668770
200	0.03879395	0.02545271	0.01140600	0.00662555
300	0.03843003	0.02521394	0.01129900	0.00656340
400	0.03806610	0.02497517	0.01119200	0.00650124
500	0.03770217	0.02473639	0.01108500	0.00643909
600	0.03733824	0.02449762	0.01097800	0.00637693
700	0.03697432	0.02425885	0.01087100	0.00631478
800	0.03661039	0.02402008	0.01076400	0.00625262
900	0.03624646	0.02378130	0.01065700	0.00619047
1000	0.03588254	0.02354253	0.01055000	0.00612831
1100	0.03554242	0.02331938	0.01045000	0.00607023
1200	0.03520230	0.02309623	0.01035000	0.00601214
1300	0.03486218	0.02287308	0.01025000	0.00595405
1400	0.03452206	0.02264992	0.01015000	0.00589596
1500	0.03418194	0.02242677	0.01005000	0.00583787
1600	0.03384182	0.02220362	0.00995000	0.00577978
1700	0.03350170	0.02198047	0.00985000	0.00572170
1800	0.03316159	0.02175732	0.00975000	0.00566361
1900	0.03282147	0.02153416	0.00965000	0.00560552
2000	0.03248135	0.02131101	0.00955000	0.00554743
2100	0.03216844	0.02110571	0.00945800	0.00549399
2200	0.03185553	0.02090041	0.00936600	0.00544055
2300	0.03154262	0.02069511	0.00927400	0.00538711
2400	0.03122971	0.02048981	0.00918200	0.00533367
2500	0.03091680	0.02028451	0.00909000	0.00528023
2600	0.03060389	0.02007921	0.00899800	0.00522678
2700	0.03029098	0.01987391	0.00890600	0.00517334
2800	0.02997807	0.01966861	0.00881400	0.00511990
2900	0.02966516	0.01946331	0.00872200	0.00506646
3000	0.02935225	0.01925801	0.00863000	0.00501302
3100	0.02903934	0.01905271	0.00853800	0.00495958
3200	0.02872644	0.01884741	0.00844600	0.00490614
3300	0.02841353	0.01864211	0.00835400	0.00485270
3400	0.02810062	0.01843681	0.00826200	0.00479925
3500	0.02778771	0.01823152	0.00817000	0.00474581
3600	0.02747480	0.01802622	0.00807800	0.00469237
3700	0.02716189	0.01782092	0.00798600	0.00463893
3800	0.02684898	0.01761562	0.00789400	0.00458549
3900	0.02653607	0.01741032	0.00780200	0.00453205
4000	0.02622316	0.01720502	0.00771000	0.00447861
4100	0.02591025	0.01699972	0.00761800	0.00442517
4200	0.02559734	0.01679442	0.00752600	0.00437172
4300	0.02528443	0.01658912	0.00743400	0.00431828
4400	0.02497152	0.01638382	0.00734200	0.00426484