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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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REVISION HISTORY			
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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

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QUALITY ASSURANCE/QUALITY CONTROL DOCUMENTATION SERIES	
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1.0 PURPOSE AND APPLICABILITY

This technical instruction (TI) describes calibration procedures for Optec LPV-2 transmissometers operated in accordance with IMPROVE Protocol. The purpose of transmissometer calibration is to assure quality data capture and minimize data loss by:

- Performing pre-field calibrations prior to installing an operational instrument at a field site.
- Performing post-field calibrations immediately after an instrument is removed from a field site.
- Performing pre-audit and post-audit calibrations on the audit transmissometer before and after it is used to perform a field audit of an operational transmissometer during an annual site servicing visit.
- Performing window transmittance measurements before and after the windows are installed in the IMPROVE network.

Calibration of LPV-2 transmissometers for operation in the IMPROVE network is performed at the Fort Collins Transmissometer Calibration and Test Facility. Pre-field calibration is required prior to installing an operational instrument at a network site and includes:

- A pre-field receiver detector uniformity check.
- Pre-field calibration of an annual supply of ten transmitter lamps (eight (8) on-site operational lamps, one (1) on-site reference lamp, and one (1) primary reference lamp).
- Completing the Optec LPV-2 Transmissometer Calibration Data Form.
- Calculation of a pre-field calibration number for each lamp calibrated and preparation of a site-specific calibration memo for the instrument prior to installing the instrument in the field.

Post-field calibration is required after an operational instrument has been removed from the network, but prior to any cleaning or servicing of the instrument. Post-field calibrations include:

- A post-field receiver detector uniformity check.
- Post-field calibration of all operational lamps, the primary reference lamp, and the on-site reference lamp.
- Completing the Optec LPV-2 Transmissometer Calibration Data Form.
- Calculating a lamp brightening factor for each post-calibrated lamp.

The audit transmissometer is used to perform on-site internal field audits of operational instruments during the annual site servicing visit (refer to Standard Operating Procedure (SOP) 4710, *Transmissometer Field Audit Procedures* and TI 4115-3000, *Annual Site Visit Procedures for Optec LPV-2 Transmissometer Systems (IMPROVE Protocol)*). Audit instrument calibrations are performed prior to and after each use in the field. Calibration of the audit instrument includes:

- Pre-field and post-field receiver detector uniformity checks.
- Pre-field and post-field calibrations of a primary reference lamp, a traveling reference lamp, and four (4) field audit lamps.
- Completing the Optec LPV-2 Transmissometer Calibration Data Form.
- Calculating lamp-specific calibration numbers for use during the field audits.

Window transmittance is an operational factor that is used in determining lamp-specific calibration numbers. Window transmittance measurements include:

- Initial calibration measurements performed prior to using the windows at a site.
- Field verification measurements performed during the annual site visit (refer to TI 4115-3000, *Annual Site Visit Procedures for Optec LPV-2 Transmissometer Systems (IMPROVE Protocol)*).
- Final calibration measurements performed after the windows are removed from a site.

2.0 RESPONSIBILITIES

2.1 PROJECT MANAGER

The project manager shall:

- 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.

2.2 FIELD SPECIALIST

The field specialist shall:

- Perform all required field calibrations.
- Document calibration results on the appropriate calibration form.
- Review all calibration results with the project manager.

- Identify inconsistencies in calibration results and initiate corrective action as required.

- Enter calibration results into the instrument-specific Quality Assurance Database.

- Prepare a site-specific calibration memo for each instrument prior to installing the instrument in the field.

2.3 INSTRUMENT TECHNICIAN

The instrument technician shall:

- Prepare lamps for calibration following lamp burn-in procedures described in TI 4200-2100, *Transmissometer Lamp Preparation (Burn-in) Procedures*.

- Measure pre-calibration lamp voltages following procedures described in TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*.

- Notify the field specialist when laboratory servicing of a transmissometer has been completed and the instrument is ready for calibration.

- Assist the field specialist in analyzing inconsistencies in calibration results.

3.0 REQUIRED EQUIPMENT AND MATERIALS

Calibration of LPV-2 transmissometers is performed at the Fort Collins Transmissometer Test Facility. Specific 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)*

- TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*

Analysis and review of transmissometer calibration data requires the following computer system hardware and software:

- 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

To review descriptions of measurement techniques and system component functions of the LPV-2 transmissometer, refer to SOP 4110, *Transmissometer Maintenance (IMPROVE Protocol)*.

Calibration of the LPV-2 transmissometer determines the irradiance from the transmitter lamp that would be measured by the receiver if the optical sight path between the two units allowed 100% transmission. The LPV-2 transmissometer (all components) must be calibrated as a unit. Each lamp will have its own calibration number for use at a specific site with a specific transmissometer system. Receiver computers are individually calibrated during annual servicing (see TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*) and may be interchanged for emergency maintenance or for use with the audit instrument (see Section 4.3.7). Operation of an instrument with a receiver computer other than the receiver computer used at calibration requires recalculation of calibration numbers, but the instrument does not require recalibration. No other system component, including lamps, may be interchanged with another transmissometer without re-calibration.

All calibrations are performed at the Fort Collins Transmissometer Calibration and Test Facility. This facility, located at Colorado State University's Christman Field, includes sheltering and all support equipment required to conduct operational transmissometer calibrations. On-site instrumentation includes a datalogging system, a tracking transmissometer (to monitor relative changes in visibility along the calibration sight path during calibrations), meteorological instrumentation, electronic test equipment, and other support systems. The calibration path (the distance between transmitter and receiver during calibration) is 0.3 km. At this distance, the atmospheric transmission can be estimated with a high degree of accuracy for use in calculating the calibration number. A precision (2.74% transmission), high-quality, neutral-density filter installed on the transmitter and a 101.51 mm calibration aperture on the receiver telescope reduce the transmitted light intensity to a level well below the receiver detector saturation level. The increased light gathering capability of the receiver telescope operating near-full aperture (110.0 mm) reduces the effects of turbulence on the transmissometer calibration measurements. As a result, transmissometer calibrations can be performed over a wide range of visibility conditions.

Because lamp brightness is dependent on lamp voltage, the lamp voltage is measured in the laboratory prior to calibration, at the test site during calibrations, and in the laboratory following calibration. A shift in lamp voltage may indicate damage to the lamp or a malfunction of the lamp control circuitry. To facilitate lamp voltage measurements, the transmitter control cable for each instrument provides a 4-wire lamp connection at the transmitter lamp housing. Two wires provide power to the lamp directly from the transmitter control box. The other two wires (the

measurement pigtail) provide a non-current carrying connection from the lamp connections to a voltmeter. This arrangement permits lamp voltage to be measured independent of the power cable voltage drop between the control box and the transmitter.

During annual laboratory servicing of the transmissometer, the receiver detector alignment is adjusted for maximum output (refer to TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*). Detector alignment is performed on an optical bench which provides a short (18-20 inches) separation between the light source and the receiver detector. To ensure that the detector alignment is valid over a longer path, a detector uniformity test is performed at the field test site as the first step in performing any calibration.

This section includes four (4) major subsections:

4.1 Pre-Field Calibration
4.2 Post-Field Calibration
4.3 Audit Instrument Calibration
4.4 Window Transmittance Measurements

4.1 PRE-FIELD CALIBRATION

IMPROVE transmissometers are generally serviced and calibrated once per year. Pre-field calibration of a transmissometer is required prior to installing the instrument in the IMPROVE network and includes the following procedures:

- Burn-in of transmissometer lamps
- Measurement of pre-calibration lamp voltages
- Setup of instrumentation at the field calibration facility
- Measurement of receiver detector uniformity
- Calibration of ten (10) transmissometer lamps
- Measurement of pre-field lamp voltages
- Preliminary processing of calibration data
- Quality assurance review of calibration data
- Entry of calibration data into the Transmissometer Calibration Database
- Calculation of site-specific pre-field calibration numbers for each lamp
- Maintenance of pre-calibration documentation

The following subsections provide detailed instructions for performing the pre-field calibration procedures listed above.

4.1.1 Lamp Burn-in

All transmissometer lamps require a 72-hour burn-in cycle prior to being assigned to an operational instrument. The burn-in cycle is performed in the laboratory to stabilize the filament position and reduce the incidence of premature lamp failure in the operational network. Procedures for lamp burn-in are described in TI 4200-2110, *Transmissometer Lamp Preparation (Burn-in) Procedures*.

4.1.2 Pre-Calibration Lamp Voltages

Service procedures for the LPV-2 transmissometer (see TI 4110-3400, *Annual Laboratory Maintenance Procedures for Optec LPV-2 Transmissometer Systems (IMPROVE Protocol)*) include lamp voltage measurements. Following instrument servicing, lamp voltages are measured after the lamp has operated for five minutes. These laboratory measurements are documented on the Transmissometer Lamp Voltage Measurements Log (Figure 4-1).

4.1.3 Calibration Instrumentation Setup

The Calibration Setup Checklist/Documentation Form (Figure 4-2) must be used to document the test site instrumentation configuration for all transmissometer calibrations. This form presents the major setup tasks in the order they are to be performed. All items are to be documented as they are completed. The following task descriptions are presented in the order they appear on the form.

CALIBRATION TYPE — Indicate the type of calibration(s) to be performed with this setup onfiguration.

TRANSMITTER SETUP — The transmitter setup procedures described below apply to both the calibration and tracking transmitters.

- Remove the transmitter shelter windows. All test site calibrations are performed with the windows removed.
- Clean the transmitter projection lens with Kimwipes and isopropyl alcohol. Use canned air to remove any remaining lint or dust particles.
- Remove the 2.74% neutral density filter (NDF) from the air-tight filter storage container. Clean both surfaces of the NDF with Kimwipes and alcohol and use canned air to remove any remaining lint or dust particles. Install the NDF on the transmitter telescope.
- A test lamp for use during calibration transmitter setup is provided in the calibration transmitter shelter. Install this lamp and record the lamp number on the setup form.

  The tracking transmitter lamp is normally left installed in the transmitter between calibrations. If the lamp is not installed, or if it burns out, a replacement lamp (stored in the tracking transmitter lamp case) should be installed. Record the lamp number for the lamp actually used on the setup form.

OPTEC LPV-2 TRANSMISSOMETER
TRANSMITTER LAMP VOLTAGE MEASUREMENTS RECORD

Instrument Number: _____
Date: _____
Technician: _____

LAMP VOLTAGE MEASUREMENTS

Lamp #	Setup Voltage		Pre-Cal Voltage	Install Voltage	Post-Cal Voltage
	Initial	Final			

TRANSMITTER TEST POINT VOLTAGES - LAMP #: _____

	T1	T2	T3	T4
SETUP				
PRE-CAL				
POST-CAL				

Figure 4-1. Transmissometer Lamp Voltage Measurements Log.

Technician: _____ Date: _____
Tracking LPV #: _____ Calibration LPV #: _____

CALIBRATION SETUP CHECKLIST/DOCUMENTATION FORM
OPTEC LPV-2 TRANSMISSOMETER

CALIBRATION TYPE

☐ Detector Uniformity ☐ Pre-Field/Site _____ ☐ Audit Instrument
☐ Post-Field/Site _____ ☐ Window Transmittance

TRANSMITTER SETUP

Calibration Transmitter	Tracking Transmitter
☐ Window Removed	☐ Window Removed
☐ Transmitter Lens Cleaned	☐ Transmitter Lens Cleaned
☐ Neutral Density Filter Cleaned and in Place	☐ Neutral Density Filter Cleaned and in Place
☐ Test Lamp #_____ Installed	☐ Tracking Lamp #_____ Installed
☐ Transmitter On and Aligned	☐ Transmitter On and Aligned

TRANSMITTER CONTROL BOX SWITCH SETTINGS

Switch Settings	Calibration Transmitter	Tracking Transmissometer
Cycle (STD = 1)	_____	_____
Integration (STD = 64)	_____	_____

RECEIVER SETUP

Calibration Receiver
☐ Window Removed
☐ Receiver Lens Cleaned
Aperture (detector uniformity)
☐ Full - STD for all telescopes
☐ Other - _____ mm
Aperture (calibration)
☐ 101.51 mm - STD for large telescopes
☐ Full - STD for small telescopes
☐ Other - _____ mm
☐ Telescope Focused and Aligned

Tracking Receiver
☐ Window Removed
☐ Receiver Lens Cleaned
Aperture:
☐ Standard (101.51 mm)
☐ Other _____mm
☐ Telescope Focused and Aligned

RECEIVER COMPUTER SWITCH SETTINGS

Switch Settings	Calibration Receiver	Tracking Receiver
Gain (STD = 100)	_____	_____
A1 (STD = C)	_____	_____
A2 (STD = CR)	_____	_____
Cycle (STD = Continuous)	_____	_____
Integration (STD = 1 Minute)	_____	_____

DATALOGGER SETUP

☐ Printer On
☐ Datalogger Operation Verified
☐ Storage Module #_____ in Place
☐ Storage Module Cleared
☐ Storage Module Operation Verified

Caldoc.frm (10/96)

Figure 4-2. Calibration Setup Checklist/Documentation Form.

- Turn on the 12 volt DC power supply and the transmitter control box. Verify that the lamp also turns on and that the chopper blade is turning. Align the transmitter telescope on the center of the corresponding receiver window.

TRANSMITTER CONTROL BOX SWITCH SETTINGS

The "CYCLE" and "INTEG" switches must be set for continuous operation prior to initiating a calibration. To access these switches, the cover of the control box must be removed. The locations of the two switches are shown in Figure 4-3, Transmitter Configuration Switch Locations (LPV-2 Transmissometer). The switch position labels on the "CYCLE" switch are in hours (except for the 20-minute position). The "INTEG" switch position labels are in minutes. Both switches are pc-board mounted dip switches and should be adjusted using the small plastic tipped adjustment tool in the transmitter shelter tool kit. The correct switch positions for continuous operation are indicated by the arrows in Figure 4-3. After the switches have been set, reset the transmitter control box by depressing the **RESET** switch.

RECEIVER SETUP

The receiver setup procedures described below apply to both the calibration and tracking receivers:

- Remove both receiver shelter windows.

- Clean the receiver telescope objective lens with Kimwipes and isopropyl alcohol. Use canned air to remove any remaining lint or dust particles.

- Detector uniformity checks are normally performed with the receiver telescope at full aperture. If the raw readings at full aperture are greater than 975, install the 101.51 mm calibration aperture prior to performing the detector uniformity check.

- Prior to initiating an instrument calibration, the 101.51 mm calibration aperture should be installed on the receiver telescope. If the calibration receiver telescope full aperture is less than 105 mm, a calibration aperture is not required.

- When a transmissometer is operating at a network site, the receiver telescope is focused at infinity. During calibration, the calibration receiver telescope focus should be adjusted to 0.3 km, the length of the sight path. To refocus the receiver telescope, loosen the thumbscrew that secures the objective lens and rotate the objective lens clockwise (viewed from the front of the telescope) until the transmitter lamp is sharply focused. The tracking receiver telescope is normally left focused at 0.3 km, but the focus should always be verified during receiver setup. After focusing, the receiver telescope should be aligned to place the transmitter lamp in the center of the alignment reticle.

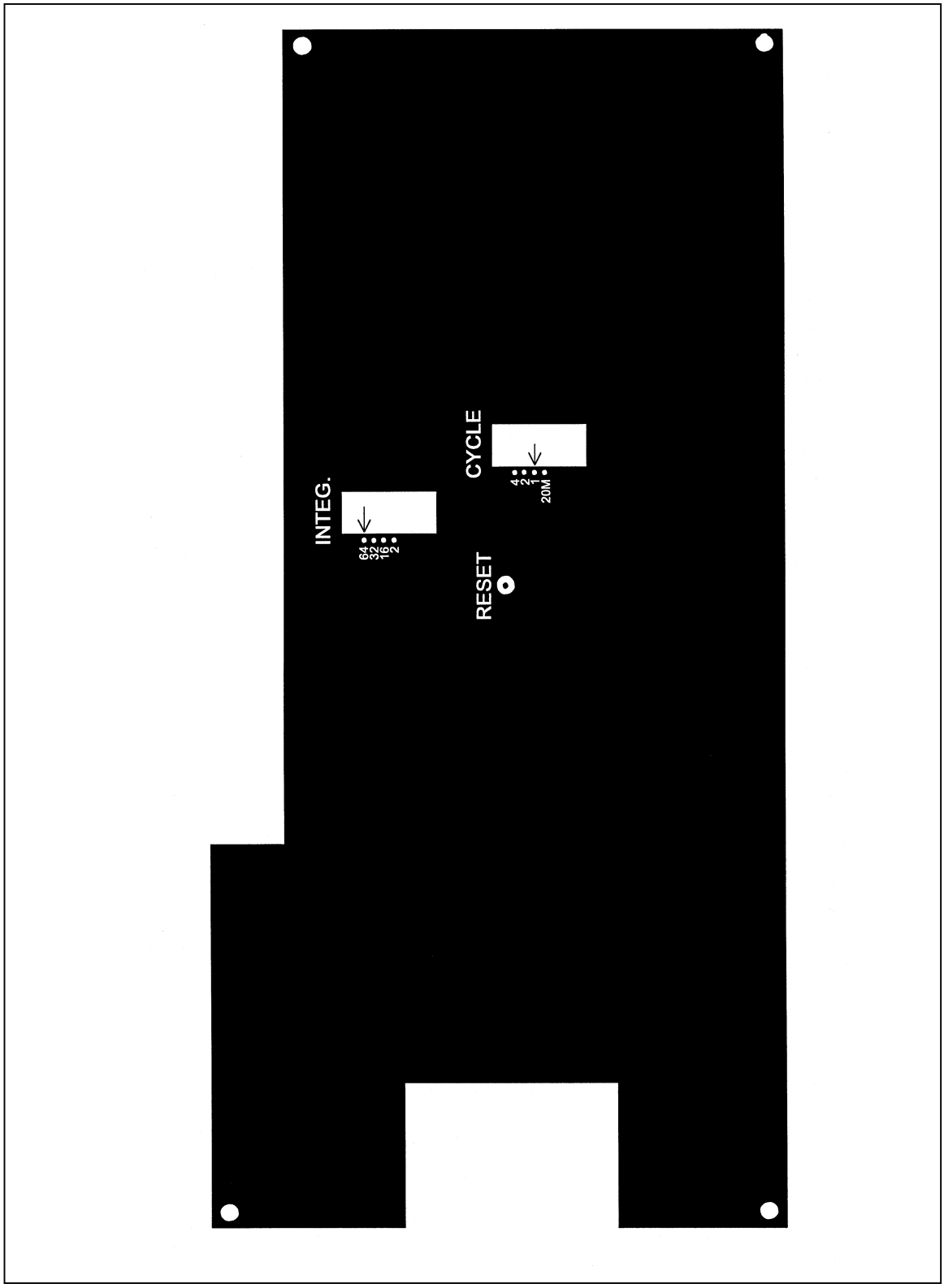


Figure 4-3. Transmitter Configuration Switch Locations (LPV-2 Transmissometer).

RECEIVER COMPUTER SWITCH SETTINGS

There are five front panel switches on the receiver computer that must be set and the settings documented prior to beginning a calibration. All IMPROVE network instruments should be calibrated with the switches set to the standard settings specified on the setup form. When calibrating non-IMPROVE instruments requiring non-standard switch settings, note the switch setting actually used on the setup form. The tracking instrument setup always uses the standard settings.

DATALOGGER SETUP

Calibration data (one-minute averaged raw readings from both the calibration receiver and the tracking receiver) are collected by a Campbell 21X datalogger and SM64 solid state storage module. An on-line printer provides a hard copy output (see Figure 4-4, Example Printout of Calibration Data) of the one-minute averaged data. Figure 4-5, Front Panel - SM64 Storage Module, shows the switch locations, connectors, and the status LED on the SM64 storage module and includes a listing of the switch positions for specific data storage functions. Proper operation of the datalogger components must be verified prior to performing a calibration.

- Turn the printer "ON" and verify that the printer is in the "ON-LINE" mode. Verify that the paper supply is adequate.

- The datalogger will date- and time-stamp each data record written to the storage module and printer. Verify that the time and date shown on the printer output are correct. If incorrect, reset the date and time following the procedures described in TI 4250-2000, *Servicing and Calibration of Campbell 21X Dataloggers*.

- The one-minute raw readings from columns #4 and #6 of the data printout (after dividing by 10 and rounding off to the nearest integer value) should agree (within ± 1 count) with the calibration receiver computer display. The raw readings from columns #5 and #7 should match the tracking receiver computer display in the same manner.

- Connect a storage module to the datalogger and record the storage module serial number on the setup form.

- Set the storage module front panel dip switches for "INITIALIZE" as specified in Figure 4-5. Initialize the storage module by pressing and releasing the **INITIALIZE** switch. About two seconds after the switch is released, the "Status LED" will light for a period of approximately two seconds, indicating that the module has been initialized.

- Reset the front panel dip switches for "DOWNLOAD DATA" as specified in Figure 4-5. At one-minute intervals, the "Status LED" will flash as data are transferred from the datalogger. This flashing action verifies that the datalogger and storage module are operating.

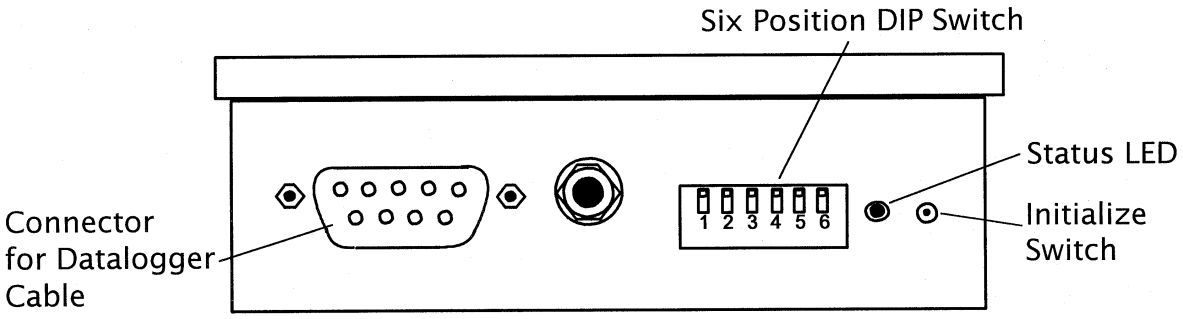
1/1/94
LPV-005 POST-FIELD CALIB.

01+0105.	02+0001.	03+1408.	04+0.0000	05+7795.4	06+0.0000	07+7796.3
01+0105.	02+0001.	03+1409.	04+0.0000	05+7798.2	06+0.0000	07+7799.0
01+0105.	02+0001.	03+1410.	04-2.7446	05+7795.4	06-1.3727	07+7796.9
01+0105.	02+0001.	03+1411.	04+4015.3	05+7800.2	06+4017.6	07+7801.1
01+0105.	02+0001.	03+1412.	04+6573.3	05+7778.3	06+6575.2	07+7779.1
01+0105.	02+0001.	03+1413.	04+6590.4	05+7800.2	06+6592.4	07+7801.8
01+0105.	02+0001.	03+1414.	04+6576.0	05+7800.9	06+6577.3	07+7801.8
01+0105.	02+0001.	03+1415.	04+6558.9	05+7813.2	06+6560.8	07+7814.1
01+0105.	02+0001.	03+1416.	04+6591.1	05+7813.2	06+6592.4	07+7799.7
01+0105.	02+0001.	03+1417.	04+6599.1	05+7798.2	06+6590.3	07+7799.0
01+0105.	02+0001.	03+1418.	04+6613.1	05+7813.2	06+6614.4	07+7813.4
01+0105.	02+0001.	03+1419.	04+6578.8	05+7810.5	06+6580.7	07+7812.0
01+0105.	02+0001.	03+1420.	04+6595.9	05+7805.7	06+6597.9	07+7807.2
01+0105.	02+0001.	03+1421.	04+6598.7	05+7796.1	06+6600.6	07+7796.9
01+0105.	02+0001.	03+1422.	04+6598.7	05+7783.7	06+6578.7	07+7784.6
01+0105.	02+0001.	03+1423.	04+6576.7	05+7816.0	06+6578.7	07+7816.9
01+0105.	02+0001.	03+1424.	04+2938.5	05+7788.5	06+2939.6	07+7790.1
01+0105.	02+0001.	03+1425.	04+7104.3	05+7808.4	06+7106.5	07+7809.3
01+0105.	02+0001.	03+1426.	04+7092.7	05+7776.9	06+7094.1	07+7777.7
01+0105.	02+0001.	03+1427.	04+5611.3	05+7805.7	06+5612.3	07+7807.2
01+0105.	02+0001.	03+1428.	04+3153.5	05+7789.2	06+3155.2	07+7790.1
01+0105.	02+0001.	03+1429.	04+7094.1	05+7815.3	06+7096.3	07+7816.2
01+0105.	02+0001.	03+1430.	04+7084.5	05+7800.9	06+7086.7	07+7801.8
01+0105.	02+0001.	03+1431.	04+7105.9	05+7790.6	06+7109.2	07+7792.8
01+0105.	02+0001.	03+1432.	04+7109.8	05+7793.4	06+7110.7	07+7794.2
01+0105.	02+0001.	03+1433.	04+7086.7	05+7818.7	06+7089.4	07+7818.9
01+0105.	02+0001.	03+1434.	04+7099.0	05+7805.7	06+7101.8	07+7806.6
01+0105.	02+0001.	03+1435.	04+7116.2	05+7803.7	06+7118.9	07+7804.5
01+0105.	02+0001.	03+1436.	04+7121.0	05+7802.3	06+7123.7	07+7803.8
01+0105.	02+0001.	03+1437.	04+7116.2	05+7817.4	06+7118.3	07+7818.9
01+0105.	02+0001.	03+1438.	04+7105.9	05+7795.4	06+7108.0	07+7796.3
01+0105.	02+0001.	03+1439.	04+7103.8	05+7812.6	06+7106.6	07+7813.5

#667
REF. LAMP
5.865V
$\beta_5 = 0.035$

#668
6.036V
$\beta_5 = 0.039$

Figure 4-4. Example Calibration Data Printout.



SWITCH SETTINGS						
Initialize Module	D	D	D	U	U	U
Collect Data	D	D	D	U	D	D
Download Data	U	D	U	U	D	D

Figure 4-5. Front Panel - SM64 Storage Module.

4.1.4 Receiver Detector Uniformity

Prior to performing a detector uniformity field check, the Calibration Setup Checklist/Documentation Form must have been completed in accordance with the procedures described in Section 4.1.3, Calibration Instrumentation Setup.

The detector uniformity check is performed by comparing: 1) lamp irradiance measurements obtained with the receiver telescope misaligned so that the transmitter lamp image appears at four specified locations near the outer edge of the receiver telescope alignment reticle, with 2) lamp irradiance measurements obtained with the receiver telescope properly aligned. The Detector Uniformity Field Check Form (Figure 4-6) includes a diagram indicating five alignment points. A measurement sequence consists of one-minute averaged raw readings from each position, beginning with position 1. This sequence of five 1-minute readings is repeated five times. The Campbell 21X datalogger is used as a voltmeter, providing increased resolution and accuracy over the receiver computer display. All data are recorded on the field check form. Specific procedures for performing the detector uniformity field check are as follows:

- Document the test configuration on the Detector Uniformity Field Check Form.
- Set the datalogger to monitor channel 5.
- Align the receiver telescope at position 1.
- Turn the receiver computer "ON" (initiating a one-minute measurement).
- After one minute, record on the field check form: 1) the one-minute averaged raw reading (as shown on the datalogger display) as the position 1 reading, and 2) the time (hours:minutes) the reading was taken.
- Turn the receiver computer "OFF," realign the receiver telescope at each successive position (2-5) and repeat the previous two steps.
- Perform the previous four steps (which comprise one complete measurement sequence) four additional times (providing five measurement sequences at each of the five telescope alignment positions).

Detector uniformity is determined by calculating the mean and standard deviation of the five 1-minute readings obtained at each alignment position and comparing the mean values for positions 2 through 5 to the mean value for position 1. The standard deviation values provide a measure of the stability of the visibility conditions during this test. Detector uniformity is considered acceptable when the mean values for positions 2 through 5 are equal to the position 1 mean value with a tolerance of +0.25% / -1.0%. These calculations are initially performed at the test site using a scientific calculator. The calculated means, standard deviations, and percent deviation of the mean values are recorded on the field check form. After returning to the office, the measurement data are entered into the a detector uniformity worksheet (included with the ARS calibration software) and the means and standard deviations described above are recalculated as a check on the manually calculated values.

Technician:________________

Date:____________
LPV#:____________

DETECTOR UNIFORMITY FIELD CHECK
OPTEC LPV-2 TRANSMISSOMETER

TEST CONFIGURATION

Lamp #: ________ Aperture: ________ Gain Setting: __________

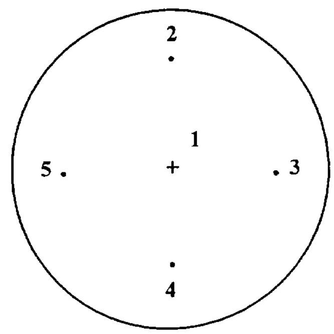
Position	Reading	Time
1		:
2		:
3		:
4		:
5		:

Position	Reading	Time
1		:
2		:
3		:
4		:
5		:

Position	Reading	Time
1		:
2		:
3		:
4		:
5		:

Position	Reading	Time
1		:
2		:
3		:
4		:
5		:

Position	Reading	Time
1		:
2		:
3		:
4		:
5		:



Position	Mean	Standard Deviation
1		
2		
3		
4		
5		

Position	Deviation from Position 1 Mean
2	
3	
4	
5	

COMMENTS:____

(4.37 1/94)

Figure 4-6. Detector Uniformity Field Check Form.

4.1.5 Lamp Calibration

Ten (10) uncalibrated transmissometer lamps (1 primary reference lamp, 1 on-site reference lamp, 6 operational lamps, and 2 spare lamps) are assigned to each transmissometer during annual laboratory servicing (see TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*). During calibration, the primary reference lamp is calibrated three times (at the beginning, in the middle, and at the end of the calibration). All other lamps are calibrated once.

Procedures for performing and documenting lamp calibrations are as follows:

COMPLETE SETUP FORM	Complete the Calibration Setup Checklist/Documentation Form as described in Section 4.1.3, Calibration Instrumentation Setup.
COMPLETE CALIBRATION DATA FORM	Use the Optec LPV-2 Transmissometer Calibration Data Form, Figure 4-7, to document test site weather and visibility conditions, preliminary support equipment measurements, calibration type, and lamp-specific calibration parameters.
PHOTOGRAPH SITE	Photographic documentation is required at the start and finish of a calibration. Three views are photographed from the northwest corner of the transmitter compound. Each view, the approximate bearing from the transmitter compound, and the lens used for photographing the view are presented in Figure 4-8, Test Site Photographic Documentation.
MEASURE TRANSMITTER VOLTAGES	Transmitter test point voltages are measured on the printed circuit board inside the calibration transmitter control box and documented on the lamp calibration data form. Connect the negative (ground) lead of the voltmeter to the negative (black) terminal of the external T5 jack located on the side of the transmitter control box (see Figure 4-9, Transmitter Control Circuit Component Layout). Note that the calibration instrument test point voltages are measured only during the first (reference lamp) calibration segment. The tracking instrument lamp voltage is measured during the first and last calibration segments.
RECORD PARAMETERS	Meteorological parameters are logged by the datalogger at the transmitter compound and should be recorded at the start, middle, and end of the calibration.
DOCUMENT LAMP HOURS	The tracking instrument lamp hours and lamp voltage should be documented at the start (during the first calibration segment) and finish (during the final calibration segment) of the calibration. Lamp hours are logged on a DC timer located in the tracking instrument transmitter shelter and connected to the transmitter control box. If a new lamp is installed in the tracking transmitter, the DC timer should be reset to zero.

Technician: _____ Date: _____

Tracking LPV#:_____ Calibration LPV #: _____

CALIBRATION DATA

OPTEC LPV-2 TRANSMISSOMETER

TEST SITE CONDITIONS

Weather _____

Visibility _____ Estimated b_{ext} _____

☐ Initial Photo Documentation Completed Time_____:_____ ☐ Final Photo Documentation Completed Time_____:_____

METEOROLOGICAL PARAMETERS

	Air Temperature	Relative Humidity	Wind Speed	Wind Direction	Solar Radiation
START OF CALIBRATION					
MIDDLE OF CALIBRATION					
END OF CALIBRATION					

CALIBRATION INSTRUMENT - Transmitter Test Point Measurements

Reference Lamp # _____ TI _____ T2 _____ T3 _____ T4 _____ T5 _____

TRACKING INSTRUMENT - Transmitter Measurements

Tracking Lamp #_____ Lamp Hours: ON _____ OFF _____

Lamp Voltage: Start _____ Finish _____

CALIBRATION TYPE: ☐ Pre-Field ☐ Audit Instrument ☐ Post-Field ☐ Test Instrument

CALIBRATION TEST SEGMENTS LOG

☐ Lamp voltage datalogger connected to transmitter measurement pigtail

☐ Datalogger ground connected to negative T5 terminal on control box

Lamp #	Alignment	Start Time	End Time	Lamp Voltage	b_{scat}	Comments
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			

caldata.frm (2/95)

Figure 4-7. Optec LPV-2 Transmissometer Calibration Data Form.

Description: Toward Engineering Research Center centered on upper south end of Soldier Canyon Dam

Bearing 250°

Lens Size: 135 mm

Description: Toward north centered on horizon halfway between the Ideal Cement Plant and Rawhide Power Plant.

Bearing 10°

Lens Size: 50 mm

Description: Toward north centered on Rawhide Power Plant.

Bearing 15°

Lens Size: 135 mm

Figure 4-8. Test Site Photographic Documentation.

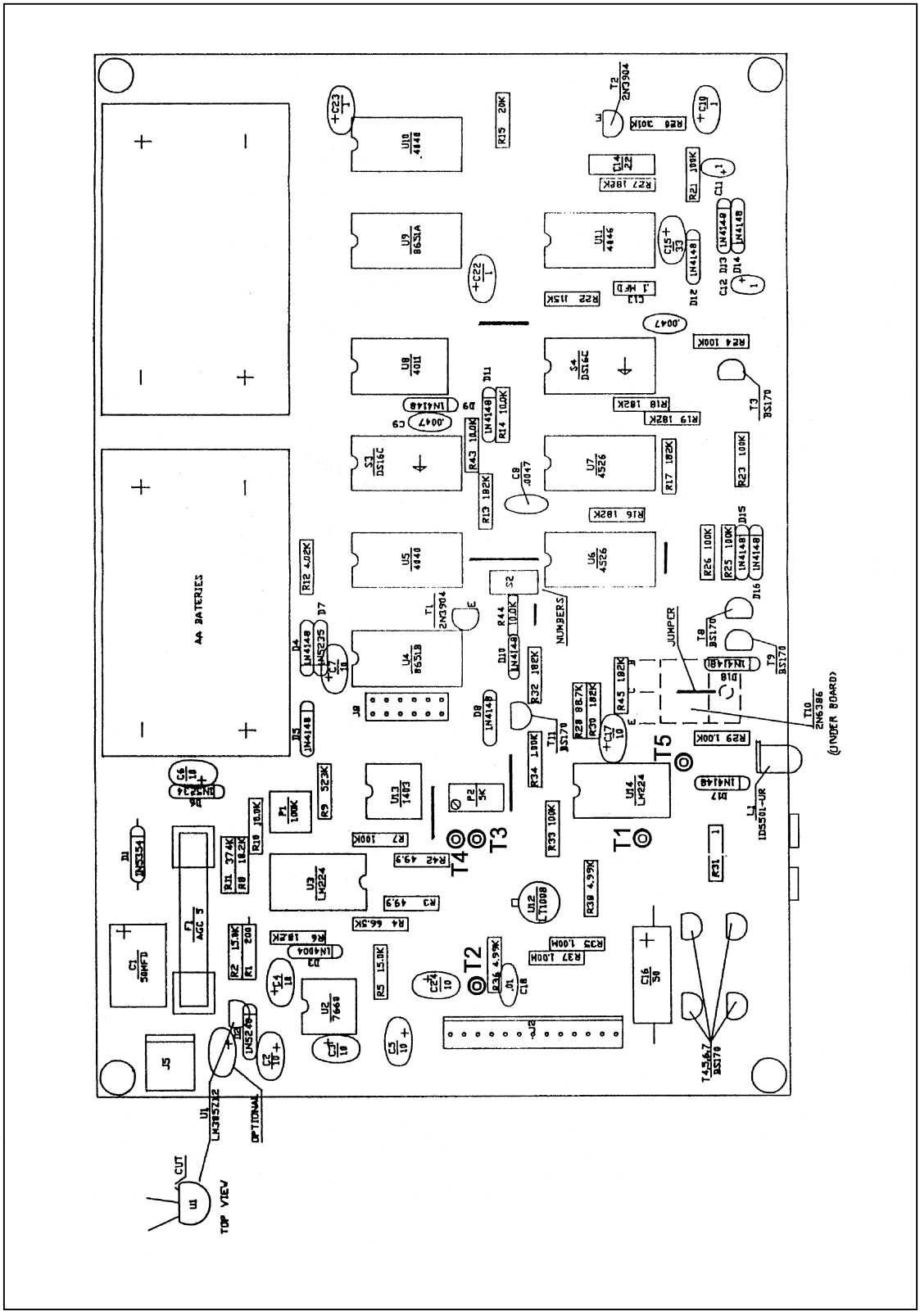


Figure 4-9. Transmitter Control Circuit Component Layout.

- Lamps are calibrated by serial number (ascending order). The lamp with the lowest serial number is always designated as the reference lamp and is used for repeat calibrations as defined by the type of calibration.

- Turn the transmitter power switch "OFF" prior to installing or removing a lamp.

MEASURE AND RECORD LAMP VOLTAGES

At the end of each calibration segment, measure and record the lamp voltage. Prior to initiating the first calibration segment, connect the lamp voltage datalogger to the transmitter cable measurement pigtail (located at the control box end of the transmitter cable). Connect the datalogger ground connection to the negative (black terminal of the external T5 jack located on the side of the transmitter control box). (See Figure 4-9, Transmitter Control Circuit Component Layout). Press ***6A** to display the lamp voltage on the datalogger. All lamp voltages are obtained using this measurement configuration and recorded on the calibration data form (Figure 4-7).

To initiate a calibration, remove the test lamp from the calibration transmitter (after turning the transmitter "OFF") and install the reference lamp for use. The reference lamp should be cleaned with the microfiber cleaning cloth located in the transmitter shelter. Measure and record the lamp voltage after the lamp has been operating for about five minutes. For each calibration segment (10-12 uninterrupted one-minute readings from a single lamp), perform and document the following procedures:

INSTALL LAMP

Visually inspect and clean each lamp before installing the lamp in the transmitter. Clean the lamp with the microfiber cleaning cloth located in the transmitter shelter. Inspect the lamp to make sure there are no spots on the bulb or damage to the filament. Be sure the lamp is fully inserted into the lamp socket. Check the telescope alignment and correct if necessary.

CAUTION! Transmissometer lamps are fragile and should be handled with great care. Dropping the lamp case or the lamp can result in a broken or damaged filament, even though the bulb does not appear broken.

TURN TRANSMITTER ON

Turn the transmitter power switch "ON" and document the calibration start time. Watch the lamp voltage as the lamp comes up to full power. Verify that the lamp voltage begins to stabilize near the standard operating voltage (approximately 5.5 volts). Each lamp should operate for approximately 15 minutes.

DOCUMENT LAMP VOLTAGE

The lamp voltage should be documented at the end of each calibration segment. Compare this lamp voltage with previously measured values as shown on the Transmitter Lamp Voltage Measurements Log included in the Instrument History Notebook. If the values differ by more than 30 mV, the lamp should be removed, reinserted, and the calibration segment restarted.

OBTAIN b_{SCAT}	Obtain the current test site b_{scat} reading from the datalogger at the NGN-2 nephelometer test area.
TURN TRANSMITTER OFF	After the lamp has operated long enough for the receiver to collect 10-12 uninterrupted one-minute readings, turn the transmitter power "OFF," document the end time, and check the telescope alignment. If the alignment is correct, remove the lamp from the transmitter. Let the lamp cool before reinserting the lamp into the lamp storage case. If the alignment is not correct, realign and retest the lamp.
DOCUMENT OBSERVATIONS	Document any unusual observations, changes in conditions, or other factors that might influence the calibration results.
REPEAT	Repeat these procedures for all lamps.
VERIFY OPERATION	At 45-minute intervals, verify receiver, datalogger, and printer operation.

4.1.6 Measurement of Pre-Field Lamp Voltages

When the calibrated instrument is returned to the laboratory, pre-field lamp voltages are measured for all lamps and recorded on the Lamp Voltage Measurement Record as described in Section 4.1.2, Pre-Calibration Lamp Voltages and TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*).

4.1.7 Preliminary Processing of Calibration Data

Prior to final review of the calibration data, the raw data must be transferred from the datalogger storage module to a computer data file and processed to present the data in a summarized format. Procedures for performing these tasks are as follows:

DOWNLOAD CALIBRATION DATA	Use the Campbell datalogger support software and the Campbell storage module interface to download calibration data from the Campbell SM64 storage module to a calibration data file. Prior to downloading from the storage module, the front panel switches must be configured for "DOWNLOAD" (refer to Figure 4-5, Front Panel - SM64 Storage Module). The naming convention for downloaded data files is "MMDDYYX.DAT" where MM denotes the month, DD the day, YY the year, and X, a letter indicating that this is the first (A), second (B), third (C), etc., calibration performed that day.
GENERATE CALIBRATION REPORT	Use the ARS calibration support software for preliminary processing of downloaded data files. This software reads each valid record from the data file and calculates the mean value, the 95% confidence interval (CI), and the ratio of the CI to the mean for raw readings measured by both the calibration and tracking instruments during each individual lamp calibration segment. A preliminary calibration report (see Figure 4-10, Example Test Site Calibration Report) is generated and includes:

TEST SITE CALIBRATION

Calibration Date: 12/14/93A — Instrument: 014
Operator: M. MILLS — Gain: 100
Data File: 121493A.DAT — Aperture: 101.51
Cal type: PRE — Path: 0.3
Bext: 0.020

Tracking Instrument Lamp No. 997 On 277.0 Off 280.0

Comments: 50F; WIND FROM SW @ 10-15 MPH

CALIBRATION RESULTS

Lamp No.	Volt.	Mean	CI/ mean	Ctrl Mean	Ctrl CI/Mn	T.Mn/ C.Mn	Comment
671	5.565	555.0	0.13	778.5	0.12	0.7130	REF LAMP, .025 BSCAT
954	5.851	552.9	0.09	778.9	0.07	0.7099	
955	5.533	552.8	0.15	777.2	0.21	0.7112	
963	5.808	550.1	0.13	779.2	0.14	0.7060	
970	5.806	540.5	0.08	778.7	0.08	0.6940	
671	5.570	558.4	0.10	776.8	0.12	0.7189	REF REPEAT, .028
972	5.869	552.0	0.15	776.8	0.16	0.7106	
973	5.637	533.8	0.21	773.6	0.22	0.6900	
974	5.738	545.0	0.13	770.4	0.10	0.7074	
975	5.795	556.7	0.19	770.9	0.16	0.7222	
976	5.730	539.8	0.21	773.0	0.26	0.6984	
671	5.566	555.9	0.17	771.9	0.24	0.7202	REF REPEAT, .031

Figure 4-10. Example Test Site Calibration Report.

- Calibration parameters
- Estimated b_{ext}
- Comments describing weather and visibility
- Calibration lamp voltages
- Calibration instrument - calculated mean raw readings and CI/mean for each calibration lamp
- Tracking instrument - calculated mean raw readings and CI/mean for tracking lamp during each calibration segment
- Ratio of the tracking instrument mean to the calibration instrument mean for each calibration segment

4.1.8 Quality Assurance Review of Calibration Data

After all calibration data have been collected and the Test Site Calibration Report generated, the field specialist and the project manager review the data to verify that all procedures have been followed, that specific measurement relationships are satisfied, and that the data appear reasonable. Specific procedures for performing this review are as follows:

REVIEW SETUP FORM	Review the Calibration Setup Checklist/Documentation Form. Verify that all required information has been properly documented.
REVIEW LAMP VOLTAGE LOG	Review the Transmissometer Lamp Voltage Measurements Log. Verify that lamp voltages recorded to date do not vary by more than 30 mV.
REVIEW DETECTOR UNIFORMITY CHECK	Review the detector uniformity check. Verify that the maximum deviation of peripheral alignment measurements from centered alignment measurements is +0.25% / -1.0%.
REVIEW CALIBRATION REPORT	Review the Test Site Calibration Report for the ten (10) lamp final calibration. The CI/mean is a measure of the stability of the visibility conditions over the time period during which each lamp was calibrated and should be less than 0.5% for both the calibration instrument and the tracking instrument. If the CI/mean is 0.5% or greater, the data are reviewed to determine if the high CI/mean is due to a single bad measurement. If the CI/mean exceeds 0.5% for several lamps, the calibration must be repeated. The ratio of the tracking mean to the calibration mean should not change by more than 1% for repeat calibrations of a specific lamp. This ratio is used to compare repeat calibrations performed over a wide range of visibility conditions.

4.1.9 Entry of Calibration Data Into the Calibration Database

When the quality assurance review of the calibration data is complete, the data from the ten (10) lamp final calibration are normalized and entered into the Transmissometer Calibration Database. ARS calibration support software is used in performing both of these functions.

The calibration data are normalized to account for small changes in test site visibility conditions through the calibration. The normalization process includes the following steps:

- The tracking instrument mean raw readings for each lamp calibration segment are averaged to provide one tracking instrument raw reading value, RAW_{cal}, to apply to the entire calibration.

- The ratio of the individual lamp tracking instrument mean raw readings to the calibration instrument raw readings is defined as K_{lamp}, the lamp calibration factor.

- The normalized mean raw reading, CR, is then:

$$CR = K_{lamp} * RAW_{cal}$$

Figure 4-11 is an example of a Normalized Calibration Raw Readings Report (Normalized Data Report).

Calibration data are entered into the calibration database via the entry screen for pre-field calibration data, shown as Figure 4-12. Each record includes all calibration-related information for a specific lamp. Lamp-specific calibration data to be entered into the database via this screen include:

- CALDATE - Enter the calibration date from the Normalized Data Report.

- EST b_{EXT} - Enter the estimated b_{ext} from the Normalized Data Report.

- LPV# - Enter the calibration transmissometer serial number from the Normalized Data Report.

- LAMP# - Enter the lamp number from the Normalized Data Report.

- LAMPVOLT - Enter the lamp voltage (measured during calibration) from the Normalized Data Report.

- CALRAW - Enter the normalized raw reading, CR, from the Normalized Data Report.

- CALPATH - Auto-entry (0.3000 km), calibration path length in kilometers.

- CALGAIN - Auto-entry (100), receiver computer gain switch position during calibration.

- CALAP - Auto-entry (101.51 mm), calibration aperture diameter in millimeters.

- NDF-T - Auto-entry (0.0274), transmittance value for the neutral density calibration filter.

NORMALIZED CALIBRATION RAW READINGS REPORT

LPV-005 (08/14/92) **PRE-CAL** **Bext =.030**

LAMP #	T5 VOLTS	RAWcal	RAWtrk	CAL/TRK	NORMcal(CR)
667	5.892	693.9	793.0	0.8750	697.6
668	5.885	715.6	796.0	0.8990	716.7
709	5.863	714.4	797.9	0.8954	713.8
710	5.856	704.5	798.9	0.8818	703.0
667	5.900	701.1	798.6	0.8779	699.9
711	5.876	715.8	797.3	0.8978	715.7
712	5.718	712.0	796.6	0.8938	712.5
713	5.851	702.4	795.1	0.8834	704.2
714	5.764	692.3	800.1	0.8653	689.8
667	5.889	695.0	798.3	0.8706	694.0
			797.2		

LPV-005 (01/01/94) **POST-CAL** **Bext =.040**

LAMP #	T5 VOLTS	RAWcal	RAWtrk	CAL/TRK	NORMcal(CR)
667	5.865	658.7	780.2	0.8443	658.7
668	6.036	710.4	780.5	0.9102	710.1
709	6.033	717.9	780.3	0.9200	717.8
710	5.993	705.7	780.1	0.9046	705.8
713	5.991	711.1	779.2	0.9126	712.0
714	5.815	669.7	780.1	0.8585	669.8
667	5.877	662.9	781.1	0.8487	662.1
			780.2		

Normalization of calibration raw readings based on tracking instrument mean raw readings.

Figure 4-11. Example Normalized Calibration Raw Readings Report.

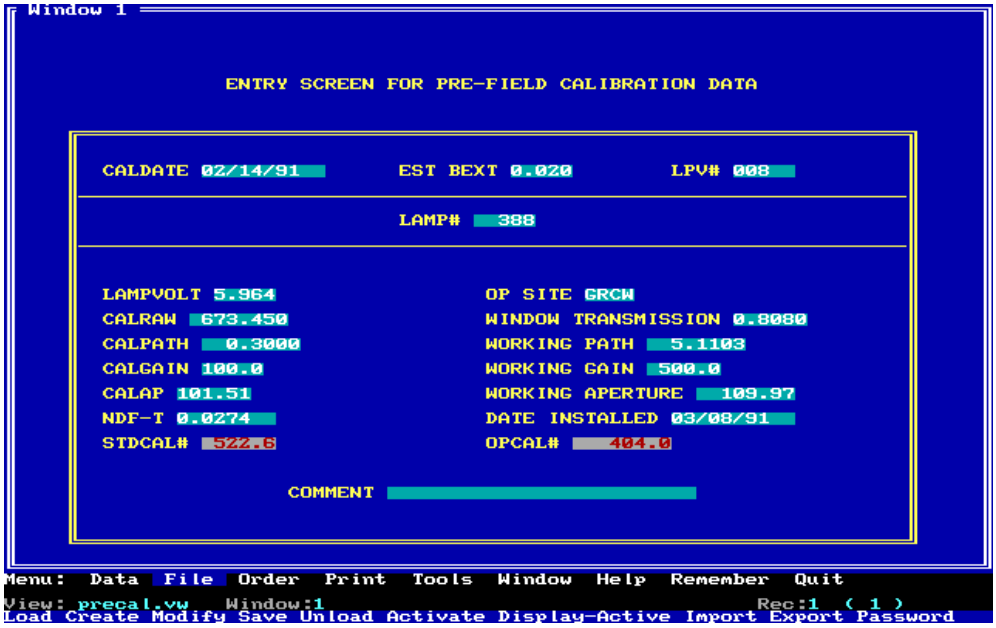


Figure 4-12. Entry Screen for Pre-Field Calibration Data.

- STDCAL# - The default values shown in parentheses are automatically entered into auto-entry fields when the cursor is moved into that field. When the cursor is moved to the "STDCAL#" field, the software will calculate a "standardized" calibration number for the lamp associated with this calibration record. The standardized calibration number assumes a working path length of 5.000 km, a working gain of 500, a working aperture of 110.00 mm, and a window transmittance of 1.0000 (no windows). The standardized calibration number is calculated using the following equation:

  $$\text{Calibration \#} = (CP/WP)^2 * (WG/CG) * (WA/CA)^2 * (1/FT) * WT * (1/T) * CR$$

  where

  CP = calibration path length, 0.300 km
  WP = working path length, 0.500 to 10.000 km (5.000 km for standardized calibration number)

  WG = working gain, nominal values are 100, 300, 500, 700, or 900 (500 for standardized calibration number)
  CG = calibration gain, nominal values are 100, 300, 500, 700, or 900

  WA = working aperture, approximately 110.00 mm (110.00 for standardized calibration number)
  CA = calibration aperture, 101.51 mm

  FT = calibration filter (NDF) transmittance, 2.74% or 0.0274
  WT = total window transmittance for the operational system (typically 80% or 0.800) (1.000 for standardized calibration number)

  T = estimated atmospheric transmittance for the calibration path ($T=e^{-bext*CP}$)
  CR = normalized average of 10-12 readings over the calibration path

  The standardized calibration number is used in calculating lamp brightening and varies from instrument to instrument, but typically is in the range 400-475 for pre-field calibrations.

Fields shown on the data entry screen but not described above are site-related operational parameters that are entered when the instrument is assigned to a specific site in the IMPROVE network. The fields are discussed in the following section.

4.1.10 Calculation of Site-Specific Pre-Field Calibration Numbers

When a transmissometer is selected for installation at a specific IMPROVE network site, ARS calibration support software is used to enter site-specific operating parameters into lamp-specific data records for the instrument. Site-specific calibration numbers are calculated for each lamp and a calibration memo detailing the calibration parameters, site parameters, and calibration results is generated. Operational parameters are entered into the database via the Entry Screen for Pre-Field Calibration Data (see Figure 4-12). Specific information added to the database includes:

- OP SITE - Enter the four (4) letter abbreviation for the operational site.

- WINDOW TRANSMISSION - Measured window transmittance (both windows combined) is typically around 80% (0.800) with resolution of 0.1% (0.001). If new windows are being installed, enter the WT value measured at the test site (refer to Section 4.4, Window Transmittance Measurements). If the windows currently in use at the network site are to be used, use the WT value currently in use for these windows. Window transmittance measurements are performed on-site during each annual site visit as described in SOP 4710, *Transmissometer Field Audit Procedures*. The WT value in the database should be updated and the calibration numbers recalculated using the on-site WT measurement.

- WORKING PATH - Enter the site path length in kilometers, with a resolution of 0.1 meters (e.g., 5.4339 km). The site path length is precisely measured and documented as described in TI 4070-3010, *Installation and Site Documentation for Optec LPV-2 Transmissometer Systems (IMPROVE Protocol)*.

- WORKING GAIN - Enter the receiver computer working gain (resolution to one (1) decimal place, e.g., 501.3) required to achieve calibration numbers greater than 600. The actual value of the receiver computer gain at each gain switch setting is measured during annual servicing of the transmissometer. Refer to TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*).

- WORKING APERTURE - If the receiver telescope is being operated at full aperture, enter the aperture as documented during annual servicing (refer to TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*). If a reduced aperture is required at a specific site, enter the aperture diameter as marked on the aperture ring.

- DATE INSTALLED - The installation date should be entered <u>after</u> the instrument is installed and operational parameters such as window transmission, working gain, and working aperture have been updated to reflect changes occurring at installation.

- OPCAL# - The computer software will calculate this number.

- COMMENT - Enter any comment appropriate to the calibration, if needed.

An example calibration memo is shown as Figure 4-13. The calibration numbers are calculated using the calibration equation described in Section 4.1.9.

4.1.11 <u>Maintenance of Calibration Documentation</u>

All calibration documentation is maintained in the ARS Data Collection Center. Following completion of all pre-field calibration procedures, the following documentation is transferred to the Data Collection Center:

- Transmissometer Lamp Voltage Measurements Log

- Calibration Setup Checklist/Documentation Form

- Detector Uniformity Field Check Form

TRANSMISSOMETER CALIBRATION MEMO

PATH SETTING: 5.79
GAIN SWITCH SETTING: 900

SITE: GRCA
LPV#: 016
DATE INSTALLED: 11/09/93

CALIBRATION SETUP VALUES

CAL DATE - 11/02/93

CP: 0.3000 km
CA: 101.51 mm
Bext: 0.035
FT: 0.0274

SITE CALIBRATION PARAMETERS

WP: 5.7904 km
WA: 110.00 mm
WG: 906.4
WT: 0.7992

LAMP#	LAMP VOLTAGE	RAW READING	COMPUTER CAL #	SITE CAL #	COMMENT
904	5.765	566.9	477.4	477	REFERENCE LAMP - RUN #1
904	5.772	571.0	480.9	481	REFERENCE LAMP - RUN #2
904	5.771	567.4	477.8	478	REFERENCE LAMP - RUN #3
905	5.772	573.7	483.1	483	OPERATIONAL LAMP #1
906	5.870	570.8	480.7	481	OPERATIONAL LAMP #2
907	5.692	576.8	485.7	486	OPERATIONAL LAMP #3
908	5.719	569.6	479.7	480	OPERATIONAL LAMP #4
909	5.876	576.5	485.5	485	OPERATIONAL LAMP #5
910	5.640	577.6	486.4	486	OPERATIONAL LAMP #6
911	5.768	576.3	485.3	485	SPARE LAMP #1
912	5.686	573.4	482.9	483	SPARE LAMP #2
913	5.630	573.8	483.2	483	ON-SITE REFERENCE LAMP

REPORT PRINTED 01/31/94 AT 15:57:24

Figure 4-13. Example Transmissometer Calibration Memo.

- Optec LPV-2 Transmissometer Calibration Data Form
- Test Site Calibration Data Report
- Normalized Calibration Raw Readings Report
- Transmissometer Calibration Memo
- Test site photographic documentation

Data Collection Center staff distribute calibration documentation as required.

4.2 POST-FIELD CALIBRATION

Post-field calibration of a transmissometer is required after the instrument is removed from the IMPROVE network and includes the following procedures:

- Setup of instrumentation at the field calibration facility
- Measurement of receiver detector uniformity
- Calibration of ten (10) transmissometer lamps
- Measurement of post-calibration lamp voltages
- Preliminary processing of calibration data
- Quality assurance review of calibration data
- Entry of calibration data into the Transmissometer Calibration Database
- Calculation of site-specific post-field calibration numbers for each lamp
- Calculation of lamp brightening factor for each post-field calibrated lamp
- Maintenance of post-calibration documentation

The following subsections provide detailed instructions for performing the post-field calibration procedures listed above. Many of the procedures required for performing post-field calibrations parallel pre-field calibration procedures described in Section 4.1.

4.2.1 Calibration Instrumentation Setup

Setup and documentation for all post-field calibrations are performed using the Calibration Setup Checklist/Documentation Form and follow the detailed procedures described in Section 4.1.3.

4.2.2 Receiver Detector Uniformity

Detector uniformity checks are an integral part of all post-field calibrations and are performed according to the detailed procedures described in Section 4.1.4.

4.2.3 Lamp Calibration

Post-field calibration of LPV-2 transmissometers is performed according to the detailed procedures for pre-field calibrations described in Section 4.1.5. Exceptions to these procedures are: 1) the number of lamps post-field calibrated, and 2) additional procedures for quantifying the affects of optical interference related to the transmissometer telescopes (receiver and/or transmitter). These exceptions are described below:

- Of the nine (9) transmissometer lamps initially sent to a field site, lamp breakage and failure often will reduce the number of lamps returned for post-calibration. All lamps returned with an operational instrument and the primary reference lamp must be post-field calibrated so that the lamp brightening characteristics can be measured and added to the lamp brightening database.

- If the initial inspection of the transmissometer (refer to TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Monitoring Systems (IMPROVE Protocol)*) identifies smudges, cobwebs, or other optical interference that might introduce errors into the transmissometer measurements, the instrument is calibrated "as is" with the primary reference lamp, the on-site reference lamp, and one operational lamp. The interference is then removed and a full post-field calibration is performed. The effect of the optical interference can then be quantified and the operational data adjusted accordingly.

4.2.4 Measurement of Post-Calibration Lamp Voltages

When the post-field calibration is complete and the instrument is returned to the laboratory, post-field lamp voltages are measured for all lamps and recorded on the Transmissometer Lamp Voltage Measurements Log as described in TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*).

4.2.5 Preliminary Processing of Calibration Data

Prior to final review of the calibration data, the raw calibration data must be transferred from the datalogger storage module to a computer data file and processed to present the data in a summarized format. Procedures for performing these tasks are described in Section 4.1.7.

4.2.6 Quality Assurance Review of Calibration Data

After all calibration data have been collected, the field specialist and project manager review the data to verify that all procedures have been followed, that specific measurement relationships are satisfied, and that the data appear reasonable. Specific procedures for performing this review are as follows:

REVIEW SETUP FORM	Review the Calibration Setup Checklist/Documentation Form. Verify that all required information has been properly documented.
REVIEW LAMP VOLTAGE LOGS	Review Transmissometer Lamp Voltage Measurements Logs. Verify that lamp voltages for the primary and on-site reference lamps have not varied by more than 30 mV between calibrations.

REVIEW DETECTOR UNIFORMITY CHECK	Review the detector uniformity check. Verify that the maximum deviation of peripheral alignment measurements from centered alignment measurements is +0.25% / -1.0%.
REVIEW CALIBRATION REPORT	Review the Test Site Calibration Report. The CI/mean is a measure of the stability of the visibility conditions over the time period during which each lamp was calibrated and should be less than 0.5% for both the calibration instrument and the tracking instrument. If the CI/mean is 0.5% or greater, the data are reviewed to determine if the high CI/mean is due to a single bad measurement. If the CI/mean exceeds 0.5% for several lamps, the calibration must be repeated. The ratio of the tracking mean to the calibration mean should not change by more than 1% for repeat calibrations of a specific lamp. This ratio is used to compare repeat calibrations performed over a wide range of visibility conditions.

4.2.7 Entry of Calibration Data Into the Calibration Database

After the quality assurance review of the calibration data is complete, the data from the post-field calibration are normalized and entered into the Transmissometer Calibration Database. ARS calibration support software is used in performing both of these functions following the procedures described in Section 4.1.9. The normalized data are added to the database using the Entry Screen for Post-Field Calibration Data (see Figure 4-14). This data entry screen includes the same input fields as the entry screen described in Section 4.1.9.

4.2.8 Calculation of Site-Specific Post-Field Calibration Numbers

Post-field calibration numbers are calculated by ARS calibration support software after entering the site-specific operating parameters as described in Section 4.1.10. Post-field calibration numbers for the primary and on-site reference lamps and any unused lamps are expected to agree with the pre-field calibration numbers within 0.5%. Changes in the calibration number for lamps used operationally are dependent upon hours of operation and lamp-specific brightening. Procedures for determining the lamp brightening factor are described in Section 4.2.9.

4.2.9 Calculation of Lamp Brightening Factors

The transmitted light intensity of transmissometer lamps increases (brightens) with increased hours of lamp use. On a lamp-by-lamp basis, this brightening factor is calculated by comparing the pre-field and post-field calibration numbers and applying this change over the total number of lamp hours accumulated during field operation. Calculating a lamp brightening factor in this manner assumes a linear increase in lamp brightness. ARS has developed a lamp brightening database which includes the shift in lamp brightness (based on a comparison of pre-field and post-field calibration numbers) as a function of lamp-use hours. All post-calibrated lamp data are added to this database. Lamp brightening statistics can then be analyzed (using a set of lamps with specific lamp factors such as operating voltage or lamp manufacturer). A lamp brightening curve can then be defined for these lamps and a lamp drift correction factor applied to the operational transmissometer data. Refer to TI 4400-5000, *Transmissometer Data Reduction and Validation (IMPROVE Protocol)* for detailed procedures for applying the lamp brightening factor.

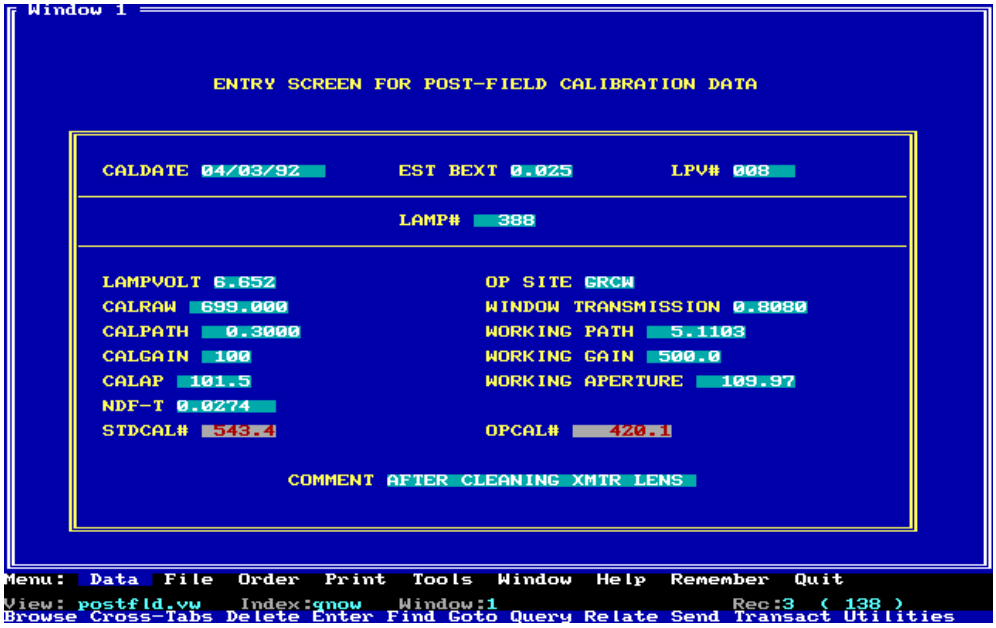


Figure 4-14. Entry Screen for Post-Field Calibration Data.

ARS calibration support software is used to access the calibration database and determine the lamp brightness increase. Standardized calibration numbers (see Section 4.1.9) from the pre-field and post-field calibration are used, along with the operational period for each lamp, to calculate the percent shift in lamp brightness and the lamp brightening factor (percent per 500 hours). A lamp brightening analysis report is generated for each post-calibrated instrument. Procedures for performing these functions are:

QUERY DATABASE	Using the Lamp Brightening Data Entry Screen (see Figure 4-15), query the database to select pre-field and post-field calibration records for a specific instrument post-field calibrated on a specific date.
ENTER DATE AND TIME	Enter the date and time for "LAMP ON" and "LAMP OFF." This information is available from the Data Collection Center - See TI 4300-4023, *Transmissometer Daily Compilation and Review of DCP Collected Data (IMPROVE Protocol)*. "TOTAL HOURS" and "LAMP BRIGHTENING FACTOR" are calculated automatically.
RETRIEVE VALUES	All precal and postcal values are automatically retrieved from the database. Precal to postcal changes in the calibration number and lamp voltage are calculated automatically.
	An example Lamp Brightening Analysis Report is shown as Figure 4-16.

4.2.10 Maintenance of Calibration Documentation

All calibration documentation is maintained in the ARS Data Collection Center. Following completion of all post-field calibration procedures, the following documentation is transferred to the Data Collection Center:

- Transmissometer Lamp Voltage Measurements Log
- Calibration Setup Checklist/Documentation Form
- Detector Uniformity Field Check Form
- Optec LPV-2 Transmissometer Calibration Data Form
- Test Site Calibration Data Report
- Normalized Calibration Raw Readings Report
- Lamp Brightening Analysis Report

Data Collection Center staff distribute calibration documentation as required.

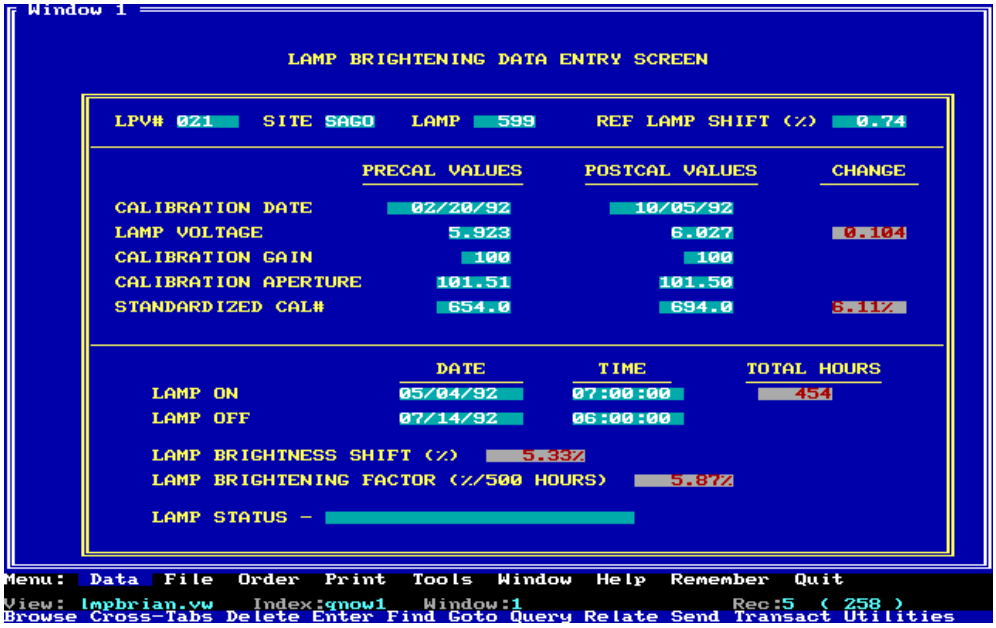


Figure 4-15. Lamp Brightening Data Entry Screen.

SITE ABBREVIATION: GRBA
INSTRUMENT SERIAL NUMBER: LPV# 005
PRE-FIELD CALIBRATION DATE: 08/14/92
POST-FIELD CALIBRATION DATE: 01/01/94

LAMP BRIGHTENING ANALYSIS REPORT
01/29/94

LAMP	PRECAL T5 VOLTS	CHNG (mv)	STD PRECAL#	STD POSTCAL#	CAL# CHANGE	LAMP SHIFT	DATE ON	DATE OFF	LAMP HOURS	LBF %/500 hrs	LAMP STATUS
667	5.892	5.865	540.1	514.4	-4.77%	0.00%				0.00%	PRIMARY REFERENCE LAMP
667	5.892	5.877	540.1	517.0	-4.28%	0.00%				0.00%	REF LAMP REPEAT
668	5.885	6.036	557.9	554.5	-0.60%	3.84%	08/20/92	11/13/92	544	3.53%	
709	5.863	6.033	555.6	560.5	0.88%	5.39%	01/20/93	04/26/93	615	4.38%	
710	5.856	5.993	547.2	551.1	0.72%	5.22%	11/13/92	01/20/93	434	6.01%	
713	5.851	5.991	548.1	556.0	1.43%	5.97%	04/26/93	07/19/93	537	5.55%	
714	5.764	5.815	536.9	523.0	-2.59%	1.77%	10/25/93	11/18/93	154	5.75%	ON-SITE REFERENCE LAMP

VIEW: LMPBRIAN.VW
REPORT DEFINITION: LPA_RPT1.DFR
REPORT PRINTED 01/29/94 AT 14:35:35

Figure 4-16. Example Lamp Brightening Analysis Report.

4.3 AUDIT INSTRUMENT CALIBRATION

Calibration of the audit transmissometer is required prior to and following its use in performing a field audit, and includes the following procedures:

- Setup of instrumentation at field calibration facility
- Measurement of receiver detector uniformity
- Calibration of six (6) transmissometer lamps
- Preliminary processing of calibration data
- Quality assurance review of calibration data
- Entry of calibration data into the Transmissometer Calibration Database
- Calculation of site-specific audit calibration numbers for each lamp
- Maintenance of audit instrument calibration documentation

4.3.1 Calibration Instrumentation Setup

Setup and documentation for all audit instrument calibrations are performed using the Calibration Setup Checklist/Documentation Form and follow the detailed procedures described in Section 4.1.3.

4.3.2 Receiver Detector Uniformity

Detector uniformity checks are an integral part of all audit instrument calibrations and are performed according to the detailed procedures described in Section 4.1.4.

4.3.3 Lamp Calibration

Calibration of the LPV-2 audit transmissometer is performed according to the detailed procedures for pre-field calibrations described in Section 4.1.5. The only exception to these procedures is that six (6) lamps are calibrated for use with the audit instrument (a primary reference lamp, a traveling reference lamp, and four (4) audit lamps). The audit instrument is recalibrated following any field audit requiring shipment (air freight, UPS, Fed Ex, etc.) of the instrument.

4.3.4 Preliminary Processing of Calibration Data

Prior to final review of the calibration data, the raw calibration data must be transferred from the datalogger storage module to a computer data file and processed to present the data in a summarized format. Procedures for performing these tasks are described in Section 4.1.7.

4.3.5 Quality Assurance Review of Calibration Data

After all calibration data have been collected, the field specialist and project manager review data to verify that all procedures have been followed, that specific measurement relationships are satisfied, and that the data appear reasonable. Specific procedures for performing this review are as follows:

REVIEW SETUP FORM	Review the Calibration Setup Checklist/Documentation Form. Verify that all required information has been properly documented.
REVIEW LAMP VOLTAGE LOGS	Review Transmissometer Lamp Voltage Measurements Logs. Verify that lamp voltages for the primary and on-site reference lamps have not varied by more than 30 mV between calibrations.
REVIEW DETECTOR UNIFORMITY CHECK	Review the detector uniformity check. Verify that the maximum deviation of peripheral alignment measurements from centered alignment measurements is +0.25% / -1.0%.
REVIEW CALIBRATION REPORT	Review the Test Site Calibration Report. The CI/mean is a measure of the stability of the visibility conditions over the time period during which each lamp was calibrated and should be less than 0.5% for both the calibration instrument and the tracking instrument. If the CI/mean is 0.5% or greater, the data are reviewed to determine if the high CI/mean is due to a single bad measurement. If the CI/mean exceeds 0.5% for several lamps, the calibration must be repeated. The ratio of the tracking mean to the calibration mean should not change by more than 1% for repeat calibrations of a specific lamp. This ratio is used to compare repeat calibrations performed over a wide range of visibility conditions.
COMPARE READINGS	Compare lamp-specific raw readings obtained during this calibration with readings obtained with the same lamps in recent audit instrument calibrations.

4.3.6 Entry of Calibration Data Into the Calibration Database

After the quality assurance review of the calibration data is complete, data from the post-field calibration are normalized and entered into the Transmissometer Calibration Database. ARS calibration support software is used in performing both of these functions following the procedures described in Section 4.1.9. The normalized data are added to the database using the Entry Screen for Audit Instrument Calibration Data (see Figure 4-17). This screen includes the same calibration data input fields as the entry screen described in Section 4.1.9.

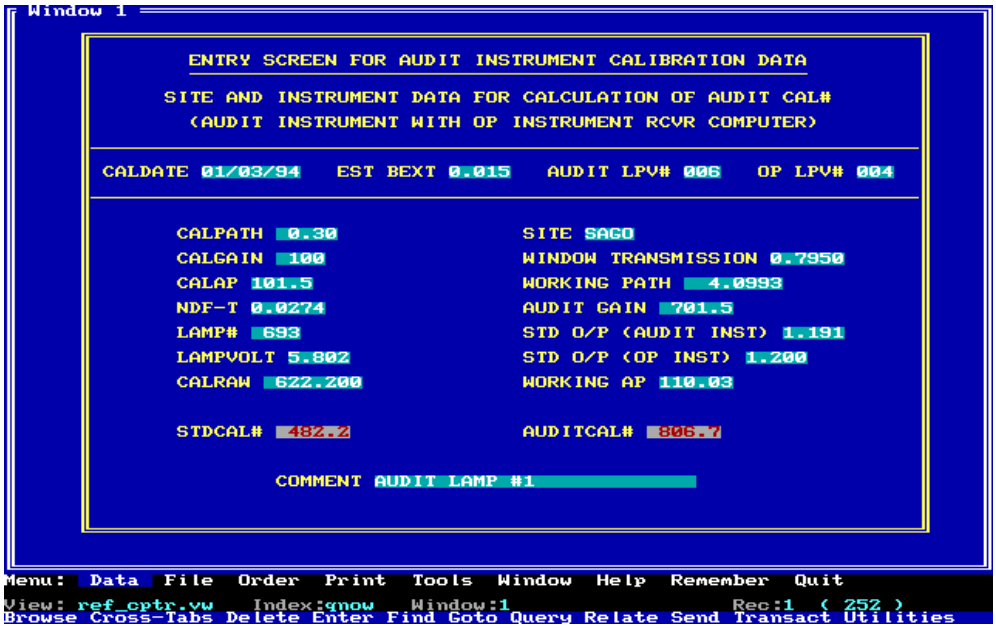


Figure 4-17. Entry Screen for Audit Instrument Calibration Data.

4.3.7 Calculation of Site-Specific Audit Instrument Calibration Numbers

Audit calibration numbers are calculated using ARS calibration support software. The Entry Screen for Audit Instrument Calibration Data (see Figure 4-17) is used to access the calibration database and display the calibration data entered in Section 4.3.6. Operational parameters are entered into the database via this screen. Specific information added includes:

- OP SITE - Enter the four (4) letter abbreviation for the operational site.

- WINDOW TRANSMISSION - Refer to procedures described in Section 4.1.10.

- WORKING PATH - Enter the sight path length in km, with a resolution of 0.1 meters (e.g., 5.4339 km). The sight path length is precisely measured and documented as described in TI 4070-3010, *Installation and Site Documentation for Optec LPV-2 Transmissometer Systems*. If a reduced aperture is required for operation of the audit instrument, enter the aperture diameter marked on the aperture ring.

- AUDIT GAIN - Enter the working gain for the instrument to be installed as the operational instrument. The gain value should be selected to ensure calibration numbers greater than 600. The gain value entered into this field should include one (1) decimal place (e.g., 501.3). The actual value of the receiver computer gain at each gain switch setting is measured during annual servicing of the transmissometer. Refer to TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*.

- STD O/P (AUD INST) and STD O/P (OP INST) - The field audit procedures (refer to SOP 4710, *Transmissometer Field Audit Procedures*) specify that the audit transmissometer use the replacement instrument receiver computer during all phases of the audit. To account for differences in receiver computer measurement parameters, calculation of audit calibration numbers includes a relative gain correction factor based on receiver computer output measurements (Gain Switch set at 100) for a standard input signal (see TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*). These standardized receiver computer output values are documented in the instrument servicing records and typically range from 1.180 to 1.250.

- WORKING APERTURE - If the receiver telescope is being operated at full aperture, enter the aperture as documented during annual servicing (refer to the Transmissometer Servicing Checklist, TI 4110-3400, *Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)*).

An Audit Calibration Numbers Report is generated for both the instrument to be removed and the instrument to be installed. An example Audit Instrument Calibration Numbers Report is shown as Figure 4-18. The calibration numbers are calculated using the calibration equation described in Section 4.1.9 and a multiplication factor based on the standardized receiver computer output measurements. The multiplier, K_{gain} is calculated using the following equation:

$$K_{gain} = STD_{opr} / STD_{aud}$$

where

STD_{opr} = Standardized receiver computer output - operational instrument
STD_{aud} = Standardized receiver computer output - audit instrument

AUDIT INSTRUMENT
CALIBRATION NUMBERS REPORT

Site: SAGO

AUDIT INSTRUMENT INFO

LPV#: 006
Cal Date: 01/03/94
Working AP: 110.03
EST Bext: 0.015
Std Output: 1.191

REPLACEMENT INSTRUMENT INFO

LPV#: 004
Working Path: 4.0993
Audit Gain: 701.5
Windows (WT): 0.7950
Std Output: 1.200

LAMP#	LAMP VOLTS	CALRAW	STD CAL#	AUDIT CAL#	LAMP STATUS / COMMENT
692	5.798	621.700	481.8	806.1	REFERENCE LAMP
692	5.799	621.100	481.4	805.3	REFERENCE LAMP
692	5.801	622.600	482.5	807.2	REFERENCE LAMP
693	5.802	622.200	482.2	806.7	AUDIT LAMP #1
722	5.810	633.100	490.7	820.8	AUDIT LAMP #2
768	5.912	635.300	492.4	823.7	AUDIT SPARE #1
838	5.912	641.400	497.1	831.6	AUDIT SPARE #2
839	6.063	648.400	502.5	840.7	TRAVELING REFERENCE LAMP

View: REF_CPTR
Report Definition: REF_AUD#
Report Printed 01/31/94 at 15:52:49

Figure 4-18. Example Audit Instrument Calibration Numbers Report.

4.3.8 Maintenance of Calibration Documentation

All calibration documentation is maintained in the ARS Data Collection Center. Following completion of all post-field calibration procedures, the following audit instrument documentation is transferred to the Data Collection Center:

- Transmissometer Lamp Voltage Measurements Log
- Calibration Setup Checklist/Documentation Form
- Detector Uniformity Field Check Form
- Optec LPV-2 Transmissometer Calibration Data Form
- Test Site Calibration Data Report
- Normalized Calibration Raw Readings Report
- Lamp Brightening Analysis Report
- Audit Calibration Numbers Report

Data Collection Center staff distribute calibration documentation as required.

4.4 WINDOW TRANSMITTANCE MEASUREMENTS

Calibration of a window for use in the IMPROVE transmissometer network requires measurement of light loss as transmitted light passes through the window. Initial measurements of window transmittance are performed at the test site and follow the basic measurement procedures described for other calibrations. Individual and combined transmittance is measured for the transmitter and receiver windows. The transmittance is determined by measuring the light received at the receiver with the window(s) in place and the window(s) removed. The ratio of the average readings with the windows in to the average readings with the windows out, is the window transmittance. Procedures for performing test site window transmittance measurements are as follows:

- Setup of instrumentation at field calibration facility
- Measurement of window transmittances
- Preliminary processing of calibration data
- Quality assurance review of calibration data
- Calculation of window transmittances

Window transmittance measurements are also performed during the annual site visit (refer to TI 4115-3000, *Annual Site Visit Procedures for Optec LPV-2 Transmissometer Systems (IMPROVE Protocol)*).

4.4.1 Calibration Instrumentation Setup

Setup and documentation for window transmittance measurements are performed using the Calibration Setup Checklist/Documentation Form and follow the detailed procedures described in Section 4.1.3.

4.4.2 Window Transmittance Measurements

All windows in the IMPROVE network are calibrated in pairs, one (1) transmitter window and one (1) receiver window. The procedures for performing and documenting window transmittance measurements are as follows:

DOCUMENT INFORMATION — Use the Window Transmittance Data Form (Figure 4-19) to document test site weather and visibility conditions, preliminary support equipment measurements, window serial numbers, and measurement data.

MEASURE WINDOW TRANSMITTANCES — Use the calibration transmitter with a test lamp to measure window transmittances.

- Do not initiate transmittance measurements until the lamp voltage has stabilized around 5.6 volts.
- Five measurement segments of 10-12 one-minute readings per segment are required for calibrating a pair of windows:

  Segment #1 Both windows out
  Segment #2 Transmitter window in
  Segment #3 Both windows in
  Segment #4 Receiver window in
  Segment #5 Both windows out

OBTAIN b_{SCAT} — Obtain the current test site b_{scat} reading from the datalogger located at the NGN-2 test area.

4.4.3 Preliminary Processing of Calibration Data

Prior to final review of the calibration data, the raw calibration data must be transferred from the datalogger storage module to a computer data file and processed to present the data in a summarized format. Procedures for performing these tasks are described in Section 4.1.7.

4.4.4 Quality Assurance Review of Calibration Data

After all calibration data have been collected, the field specialist and the project manager review data to verify that all procedures have been followed, that specific measurement relationships are satisfied, and that the data appear reasonable. Specific procedures for performing this review are as follows:

REVIEW SETUP FORM — Review Calibration Setup Checklist/Documentation Form. Verify that all required information has been properly documented.

Technician: _____ **Date:** _____
Tracking LPV#: _____ **Transmitter Window #:** _____
Calibration LPV#: _____ **Receiver Window #:** _____

WINDOW TRANSMITTANCE DATA

TEST SITE CONDITIONS

Weather: _____
Visibility: _____

CALIBRATION INSTRUMENT - Transmitter Test Point Measurements

Test Lamp #: _____ **T1** _____ **T2** _____ **T3** _____ **T4** _____ **T5**

TRACKING INSTRUMENT - Transmitter Measurements

Tracking Lamp #: _____ **Lamp Hours:** **ON** _____ : **OFF** _____ :
Lamp Voltage: **Start** _____ **Finish** _____

WINDOW TRANSMITTANCE TEST SEGMENTS LOG

	Alignment	Start Time	End Time	Lamp Voltage	b_{scat}	Comments
No Windows		:	:			
Transmitter Window		:	:			
Both Windows		:	:			
Receiver Window		:	:			
No Windows		:	:			
		:	:			
		:	:			

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Figure 4-19. Window Transmittance Data Form.

REVIEW CALIBRATION REPORT	Review the Test Site Calibration Report. The CI/mean is a measure of the stability of the visibility conditions over the time period corresponding to each measurement segment and should be less than 0.5% for both the calibration instrument and the tracking instrument. If the CI/mean is 0.5% or greater, the data should be reviewed to determine if the high CI/mean is due to a single bad measurement. If the CI/mean exceeds 0.5% for any segment, the calibration must be repeated. Look for obvious inconsistencies. The raw readings should be approximately the same for segments #2 and #4 and segments #1 and #5. Raw readings for segments #2 and #4 should be about half-way between the segment #3 reading and the segment #1 or #5 reading.

4.4.5 Calculation of Window Transmittances

Data from the Test Site Calibration Report are used to calculate individual and combined window transmittances. A Window Transmittance Measurement Report is generated by the ARS calibration support software.

Raw readings and tracking mean to calibration mean ratios (see Section 4.1.7) for each measurement segment are entered into the calibration database using the Window Transmittance Measurements Data Entry Screen shown as Figure 4-20. Window transmittances are then calculated from raw readings and mean ratios. An example Window Transmittance Measurement Report is presented as Figure 4-21.

4.4.6 Maintenance of Window Transmittance Documentation

All window transmittance documentation is maintained in the ARS Data Collection Center. Following completion of window transmittance tests, the following documentation is transferred to the Data Collection Center:

- Window Transmittance Data Form
- Window Transmittance Measurements Report

Data Collection Center staff distribute window transmittance documentation as required.

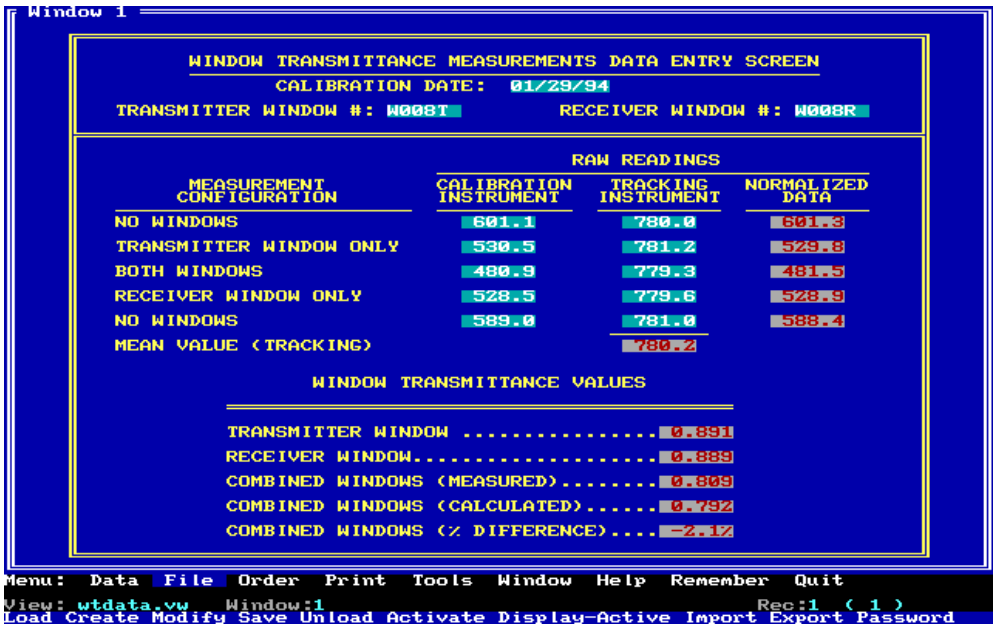

Figure 4-20. Window Transmittance Measurements Data Entry Screen.

WINDOW TRANSMITTANCE MEASUREMENTS DATA ENTRY SCREEN

CALIBRATION DATE: 01/29/94

TRANSMITTER WINDOW #: W008T **RECEIVER WINDOW #: W008R**

MEASUREMENT CONFIGURATION	RAW READINGS		
	CALIBRATION INSTRUMENT	TRACKING INSTRUMENT	NORMALIZED DATA
NO WINDOWS	601.1	780.0	601.3
TRANSMITTER WINDOW ONLY	530.5	781.2	529.8
BOTH WINDOWS	480.9	779.3	481.5
RECEIVER WINDOW ONLY	528.5	779.6	528.9
NO WINDOWS	559.0	781.0	558.4
MEAN VALUE (TRACKING)		780.2	

WINDOW TRANSMITTANCE VALUES

TRANSMITTER WINDOW 0.914

RECEIVER WINDOW 0.912

COMBINED WINDOWS (MEASURED) 0.830

COMBINED WINDOWS (CALCULATED) 0.833

COMBINED WINDOWS (% DIFFERENCE) 0.4%

Figure 4-21. Window Transmittance Measurements Report.

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QUALITY ASSURANCE/QUALITY CONTROL DOCUMENTATION SERIES	
TITLE	**TRANSMISSOMETER LAMP PREPARATION (BURN-IN) PROCEDURES**
TYPE	**TECHNICAL INSTRUCTION**
NUMBER	**4200-2110**
DATE	**FEBRUARY 1994**

AUTHORIZATIONS		
TITLE	NAME	SIGNATURE
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REVISION HISTORY			
REVISION NO.	CHANGE DESCRIPTION	DATE	AUTHORIZATIONS
0.1	Change burn-in hours/update format	October 1996	

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1.0 PURPOSE AND APPLICABILITY

The purpose of this technical instruction (TI) is to describe the procedures for preparing a transmissometer lamp for calibration and operational use in the IMPROVE transmissometer network. The primary purpose of lamp preparation is to assure quality data capture through a transmissometer lamp burn-in procedure that will:

- Stabilize the operational characteristics of the lamps prior to performing pre-field lamp calibrations.
- Reduce infant mortality in operational lamps.

This TI describes all procedures required to perform and document transmissometer lamp preparation and burn-in and is referenced from Standard Operating Procedure (SOP) 4200, *Calibration of Optical Monitoring Systems*, and the following technical instructions:

- TI 4200-2100 *Calibration of Optec LPV-2 Transmissometers (IMPROVE Protocol)*
- TI 4110-3400 *Annual Laboratory Maintenance Procedures for Optec LPV-2 Transmissometer Systems (IMPROVE Protocol)*

2.0 RESPONSIBILITIES

2.1 PROJECT MANAGER

The project manager shall:

- Review lamp inventory and status records to ensure that a sufficient number of burned-in lamps are available to support transmissometer field operations.
- Approve purchase orders for new lamps.

2.2 INSTRUMENT TECHNICIAN

The instrument technician shall:

- Prepare purchase orders for new transmissometer lamps.
- Inspect all new transmissometer lamps when received at ARS.
- Prepare lamp ID labels for all new lamps received and maintain the Transmissometer Lamp Log.
- Perform the lamp burn-in procedures described in this TI.
- Maintain the lamp inventory and status records.
- Ensure that all burned-in lamps are identified properly and stored in a manner that will protect them from damage.

- Coordinate with Optec, Inc. for replacement of lamps that are received damaged or that fail during burn-in.

3.0 REQUIRED EQUIPMENT AND MATERIALS

Specific equipment and materials required for transmissometer lamp burn-in include:

- Supply of lamps
- Lamp ID labels
- Lamp burn-in fixture
- Power Supply (13.8 VDC @ 25 amps)
- Lamp Burn-in Documentation Form
- Lamp inventory and status records
- KimWipe tissues

4.0 METHODS

Transmissometer lamps are purchased from Optec, Inc., Lowell, Michigan. When a lamp order is received, all lamps are visually inspected and lamp ID labels placed on the base of each lamp. Lamps are then installed in the transmissometer lamp burn-in fixture (see Figure 4-1) for a burn-in cycle of 72 hours. The lamp burn-in fixture provides two (2) separate burn-in banks. Each burn-in bank permits up to six (6) lamps to be burned-in during a burn-in cycle. The burn-in control circuit switches power between the two banks at 15 minute intervals. With six lamps installed in each burn-in bank, each lamp is cycled through a 15 minute "on" period followed by a 15 minute "off" period twice an hour. This cycled burn-in technique closely replicates lamp operation in the field. The 72 hour burn-in cycle provides 144 lamp "on" cycles which is equivalent to 144 hours (6 days) of field operation. Once a lamp has been burned-in, the ID label is marked to indicate that the lamp is ready to be assigned to an operational instrument.

This section includes (2) major subsections:

4.1 Lamp Receiving and Preparation
4.2 Lamp Burn-in

4.1 LAMP RECEIVING AND PREPARATION

Specific procedures for receiving and preparing lamps for burn-in are described in the following subsections.

4.1.1 Documentation for Lamps Received

Optec inscribes a lamp serial number on each lamps' plastic base. Lamps are then individually packed in small boxes labelled with the lamp serial number. The individual boxes are packed into a larger box for shipment. Receiving procedures include:

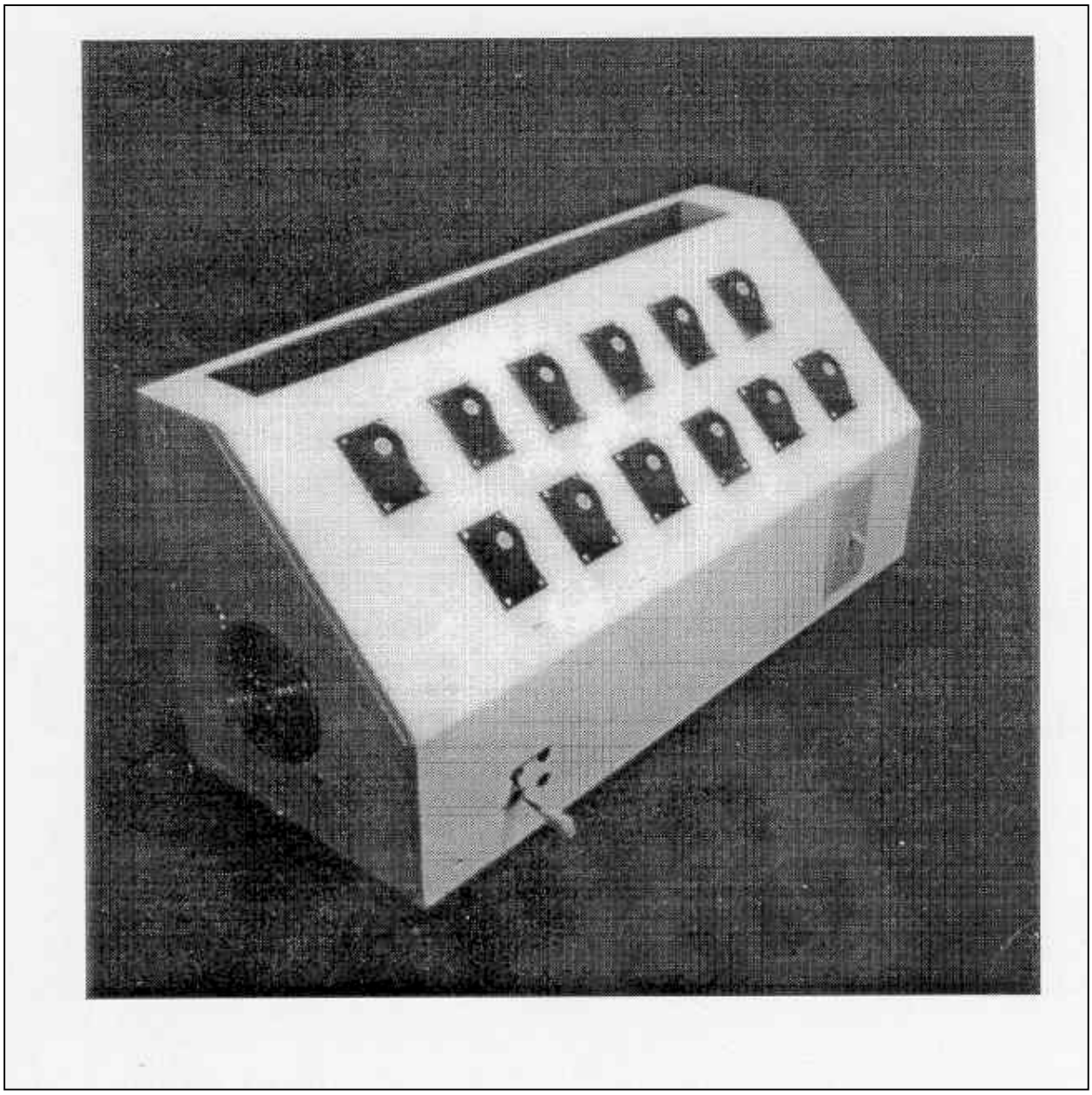

Figure 4-1. Transmissometer Lamp Burn-in Fixture.

CONFIRM NUMBER OF LAMPS	Confirm that the number of lamps received matches the number of lamps shipped (as documented on the packing list).
RECORD SERIAL NUMBERS	Using the Lamp Receiving Log (Figure 4-2), record the serial numbers (from the label on the lamp boxes) of all lamps received.

4.1.2 Visual Inspection of Lamps

Lamp inspection procedures include:

PREPARE LABEL	The lamp serial number inscribed on the lamp base is difficult to see when the lamp is installed in a field instrument. Using the Lamp Receiving Log, prepare an ID label (1/2" diameter adhesive backed) with the lamp serial number for each lamp received.
VERIFY SERIAL NUMBER	Remove each lamp from its shipping box and verify that the serial number inscribed on the base matches the serial number on the box. Apply the ID label to the base as shown in Figure 4-3.
INSPECT LAMP	As each lamp is removed, the lamp should be visually inspected. Lamp condition should also be documented on the Lamp Receiving Log. Typical flaws or lamp damage (examples shown in Figure 4-4) include the following: • Cracked or broken filament • Abnormalities in the shape, texture, clarity, or thickness of the glass bulb • Missing or damaged gold sleeves on lamp power pins • Bent, broken, or missing power pins
PLACE LAMP IN STORAGE	After a lamp has been visually inspected and the inspection results documented on the Lamp Receiving Log, place the lamp in the lamp storage drawer, ensuring that the plastic lamp holder is lined with a KimWipe tissue to prevent damage to the lamp bulb.

4.2 LAMP BURN-IN

Specific procedures for burning in lamps include:

CLEAN LAMPS	Select 12 lamps for burn-in. Clean each lamp with a microfiber optical cleaning cloth and insert into the 12 lamp sockets built into the Lamp Burn-in Fixture.
RECORD SERIAL NUMBERS	Record the lamp serial numbers on the Lamp Burn-in Log Form (Figure 4-5).

TRANSMISSOMETER LAMP RECEIVING LOG

Reference Purchase Order Number: _____ Quantity Received (Packing List): _____
Date Received: _____ Quantity Received (ARS Count): _____

Lamp #	Condition	Lamp #	Condition

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Figure 4-2. Transmissometer Lamp Receiving Log.

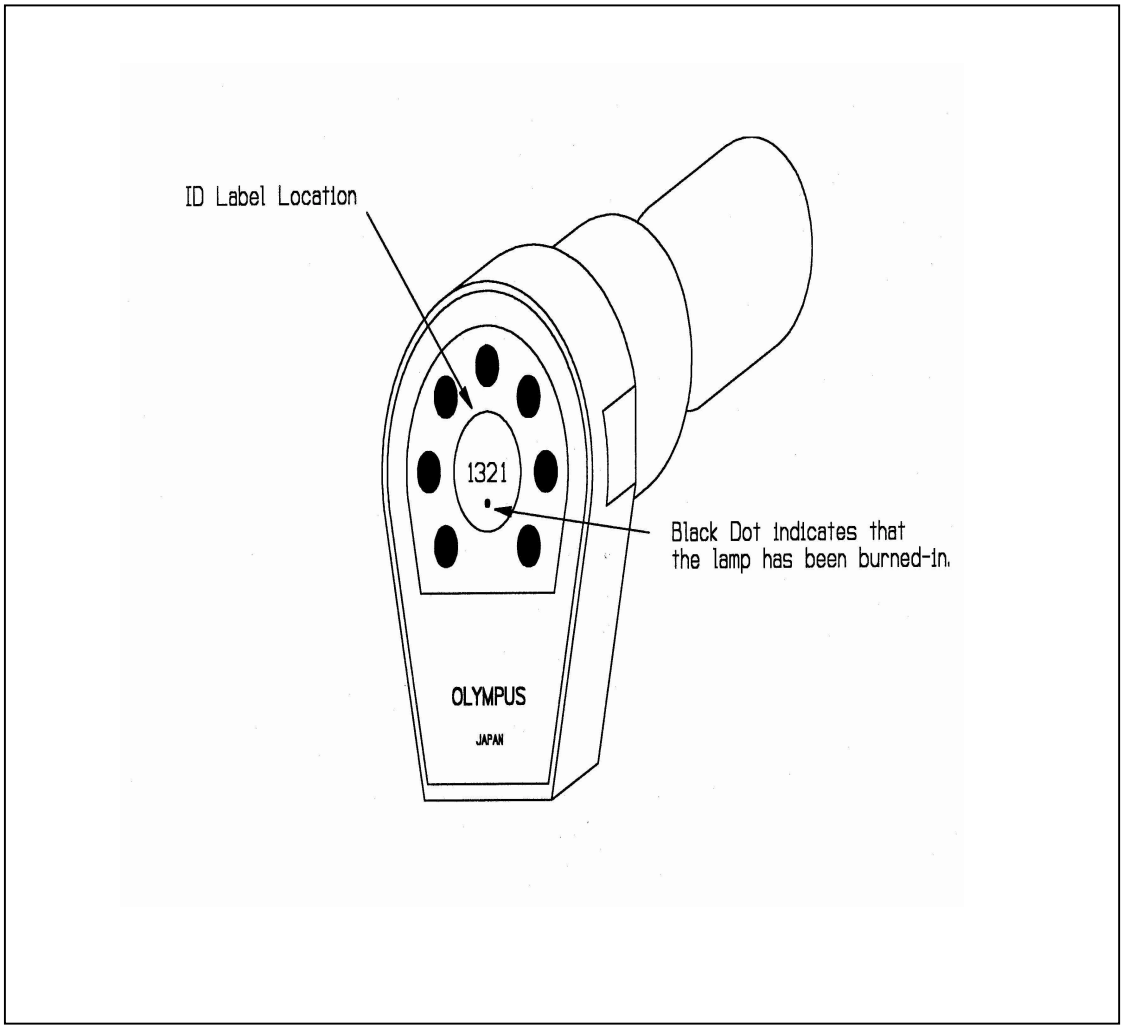

Figure 4-3. Placement of Lamp ID Label on Lamp Base.

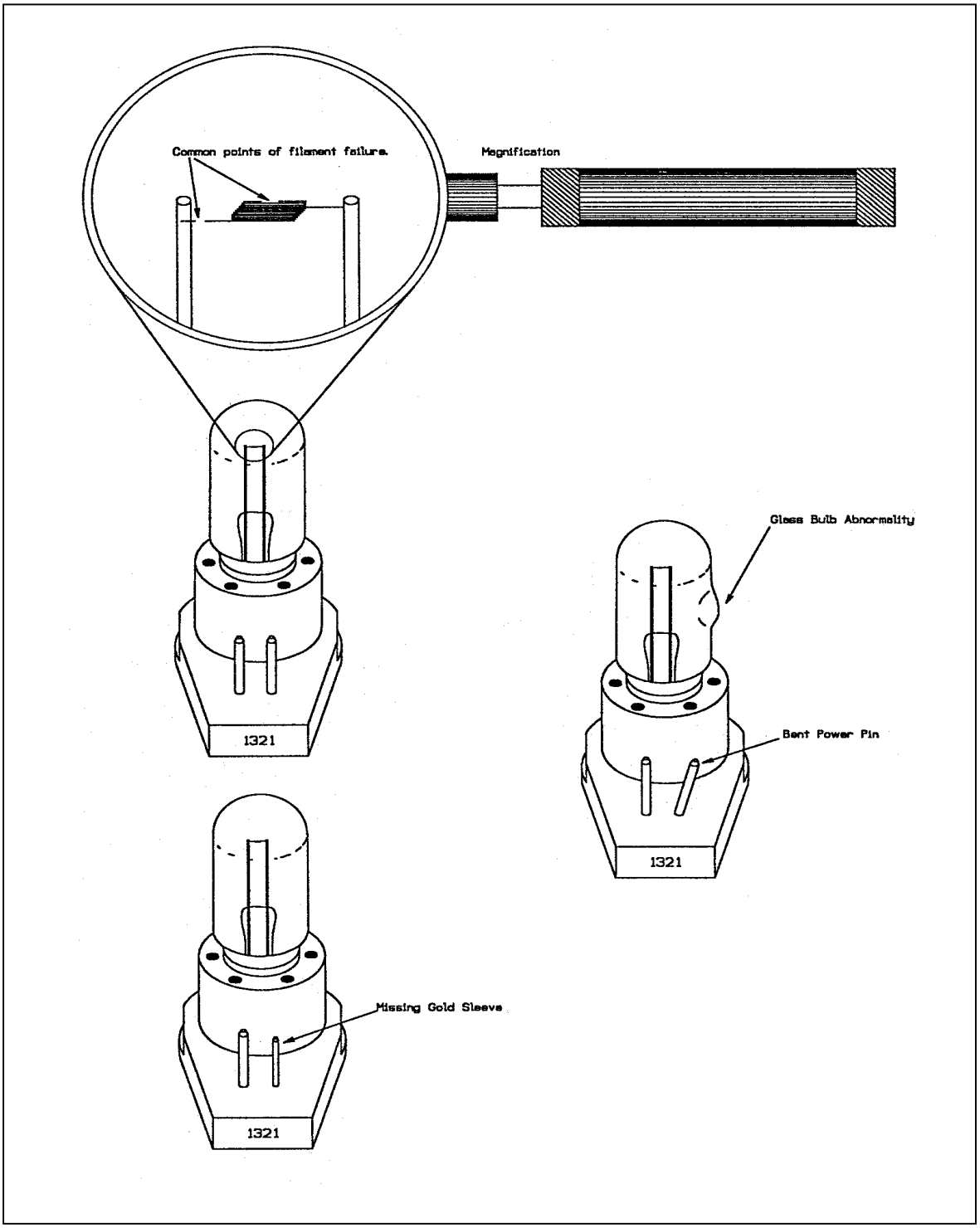

Figure 4-4. Lamp Flaws to Look For During Lamp Inspection.

LAMP BURN-IN LOG SHEET

START BURN-IN: DATE: _____ TIME: _____
BURN-IN COMPLETE: DATE: _____ TIME: _____

BURN-IN COMPLETED					
SOCKET #	LAMP #	YES	NO	ID LABEL MARKED	COMMENTS
1		☐	☐	☐	
2		☐	☐	☐	
3		☐	☐	☐	
4		☐	☐	☐	
5		☐	☐	☐	
6		☐	☐	☐	
7		☐	☐	☐	
8		☐	☐	☐	
9		☐	☐	☐	
10		☐	☐	☐	
11		☐	☐	☐	
12		☐	☐	☐	

OPERATION VERIFIED		
DATE	TIME	TIMER HOURS

FAILED LAMPS		
LAMP #	RETURNED TO OPTEC	REPLACEMENT RECEIVED

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Figure 4-5. Lamp Burn-in Log Form.

CONNECT POWER SUPPLY	Connect the 13.8 VDC power supply to the burn-in fixture.
TURN ON	Turn the power supply on and document the burn-in start time on the Lamp Burn-in Log Form. Reset the burn-in cycle timer to zero.
DOCUMENT HOURS	Periodically, verify that all lamps in both banks are cycling properly. Use the Lamp Burn-in Log Form to document the accumulated hours reading (from the burn-in cycle timer) at the time operation is verified.
TURN POWER OFF	When the burn-in timer indicates 72 accumulated hours of operational time, turn the power supply off and record the burn-in finish time on the Lamp Burn-in Log Form.
COOL LAMPS	Let the lamps cool in the burn-in fixture for 20 minutes.
MARK LABELS	Use a black felt tip pen to mark the ID labels with a dot to indicate that the lamp has been burned-in.
INSPECT LAMP	Remove each lamp from the burn-in fixture, inspecting the lamp for: • Cracked or broken filament. • White film (milky appearance) on the inside surface of the bulb (indicates an air leak in the bulb - see the photograph of Figure 4-6).
STORE LAMP	Return the lamps to the storage drawer.

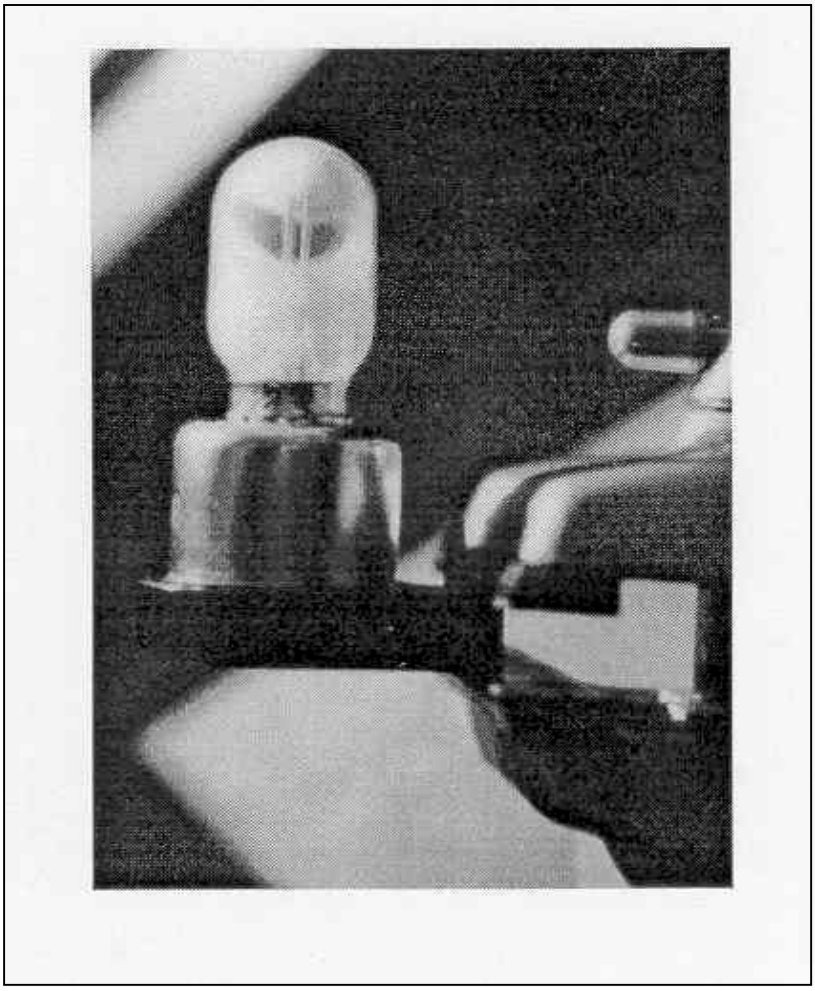

Figure 4-6. Transmissometer Lamp With Air Leak.