Designation: D 6216 – 98

Standard Practice for Opacity Monitor Manufacturers to Certify Conformance with Design and Performance Specifications[1]

This standard is issued under the fixed designation D 6216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the procedure for certifying continuous opacity monitors. It includes design and performance specifications, test procedures, and quality assurance requirements to ensure that continuous opacity monitors meet minimum design and calibration requirements, necessary in part, for accurate opacity monitoring measurements in regulatory environmental opacity monitoring applications subject to 10 % or higher opacity standards.

1.2 This practice applies specifically to the original manufacturer, or to those involved in the repair, remanufacture, or resale of opacity monitors.

1.3 Test procedures that specifically apply to the various equipment configurations of component equipment that comprise either a transmissometer, an opacity monitor, or complete opacity monitoring system are detailed in this practice.

1.4 The specifications and test procedures contained in this practice exceed that of the United States Environmental Protection Agency (USEPA). For each opacity monitor or monitoring system that the manufacturer demonstrates conformance to this practice, the manufacturer may issue a certificate that states that that opacity monitor or monitoring system conforms with all of the applicable design and performance requirements of 40 CFR 60, Appendix B, Performance Specification 1 except those for which tests are required after installation.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres[2]

2.2 *U.S. Environmental Protection Agency Document:*[3]

40 CFR 60 Appendix B, Performance Specification 1

2.3 *Other Documents:*

ISO/DIS 9004 Quality Management and Quality System Elements-Guidelines[4]

ANSI/NCSL Z 540-1-1994 Calibration Laboratories and Measuring Equipment - General Requirements[4]

NIST 260-116 - Filter calibration procedures[5]

3. Terminology

3.1 For terminology relevant to this practice, see Terminology D 1356D 1356.

3.2 *Definitions of Terms Specific to This Standard:*

Analyzer Equipment

3.2.1 *opacity*, *n*—measurement of the degree to which particulate emissions reduce (due to absorption, reflection, and scattering) the intensity of transmitted photopic light and obscure the view of an object through ambient air, an effluent gas stream, or an optical medium, of a given pathlength.

3.2.1.1 *Discussion*—Opacity (Op), expressed as a percent, is related to transmitted light, (T) through the equation:

$$Op = (1 - T)(100). \quad (1)$$

3.2.2 *opacity monitor*, *n*—an instrument that continuously determines the opacity of emissions released to the atmosphere.

3.2.2.1 *Discussion*—An opacity monitor includes a transmissometer that determines the *in-situ* opacity, a means to correct opacity measurements to equivalent single-pass opacity values that would be observed at the pathlength of the emission outlet, and all other interface and peripheral equipment necessary for continuous operation.

3.2.2.2 *Discussion*—An opacity monitor may include the following: (*1*) sample interface equipment such as filters and purge air blowers to protect the instrument and minimize contamination of exposed optical surfaces, (*2*) shutters or other devices to provide protection during power outages or failure of the sample interface, and (*3*) a remote control unit to facilitate monitoring the output of the instrument, initiation of

[1] This practice is under the jurisdiction of ASTM Committee D-22 on Sampling and Analysis of Atmospheres and is the direct responsibility of Subcommittee D22.03 on Ambient Atmospheres and Source Emissions.

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[2] *Annual Book of ASTM Standards*, Vol 11.03.

[3] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

[4] Available from American National Standards Institute, 11 W. 42nd St., 13th floor, New York, NY 10036.

[5] Available from National Institute of Standards and Technology, Gaithersburg, MD 20899.

zero and upscale calibration checks, or control of other capacity monitor functions.

3.2.3 *opacity monitor model*, *n*—a specific transmissometer or opacity monitor configuration identified by the specific measurement system design, including: (*1*) the use of specific light source, detector(s), lenses, mirrors, and other optical components, (*2*) the physical arrangement of optical and other principal components, (*3*) the specific electronics configuration and signal processing approach, (*4*) the specific calibration check mechanisms and drift/dust compensation devices and approaches, and (*5*) the specific software version and data processing algorithms, as implemented in a particular manufacturing process, at a particular facility and subject to an identifiable quality assurance system.

3.2.3.1 *Discussion*—Changing the retro-reflector material or the size of the retro-reflector aperture is not considered to be a model change unless it changes the basic attributes of the optical system.

3.2.4 *opacity monitoring system*, *n*—the entire set of equipment necessary to monitor continuously the in-stack opacity, average the emission measurement data, and permanently record monitoring results.

3.2.4.1 *Discussion*—An opacity monitoring system includes at least one opacity monitor with all of its associated interface and peripheral equipment and the specific data recording system (including software) employed by the end user. An opacity monitoring system may include multiple opacity monitors and a common data acquisition and recording system.

3.2.5 *optical density (OD)*, *n*—a logarithmic measure of the amount of incident light attenuated.

3.2.5.1 *Discussion*—OD is related to transmittance and opacity as follows:

$$OD = \log_{10} (1/T) = -\log_{10} (T) = -\log_{10} (1-Op), \quad (2)$$

where Op is expressed as a fraction.

3.2.6 *transmittance*, *n*—the fraction of incident light within a specified optical region that passes through an optical medium.

3.2.7 *transmissometer*, *n*—an instrument that passes light through a particulate-laden effluent stream and measures *in situ* the optical transmittance of that light within a specified wavelength region.

3.2.7.1 *Discussion*—Single-pass transmissometers consist of a light source and detector components mounted on opposite ends of the measurement path. Double-pass instruments consist of a transceiver (including both light source and detector components) and a reflector mounted on opposite ends of the measurement path.

3.2.7.2 *Discussion*—For the purposes of this practice, the transmissometer includes the following mechanisms (1) means to verify the optical alignment of the components and (2) simulated zero and upscale calibration devices to check calibration drifts when the instrument is installed on a stack or duct.

3.2.7.3 *Discussion*—Transmissometers are sometimes referred to as *opacity analyzers* when they are configured to measure opacity.

Analyzer Zero Adjustments and Devices

3.2.8 *dust compensation*, *n*—a method or procedure for systematically adjusting the output of a transmissometer to account for reduction in transmitted light reaching the detector (apparent increase in opacity) that is specifically due to the accumulation of dust (that is, particulate matter) on the exposed optical surfaces of the transmissometer.

3.2.8.1 *Discussion*—The dust compensation is determined relative to the previous occasion when the exposed optics were cleaned and the dust compensation was reset to zero. The determination of dust accumulation on surfaces exposed to the effluent must be limited to only those surfaces through which the light beam passes under normal opacity measurement and the simulated zero device or equivalent mechanism necessary for the dust compensation measurement.

3.2.8.2 *Discussion*—The dust accumulation for all of the optical surfaces included in the dust compensation method must actually be measured. Unlike zero drift, which may be either positive or negative, dust compensation can only reduce the apparent opacity. A dust compensation procedure can correct for specific bias and provide measurement results equivalent to the *clean window* condition.

3.2.8.3 *Discussion*—The opacity monitor must provide a means to display the level of dust compensation. Regulatory requirements may impose a limit on the amount of dust compensation that can be applied and require that an alarm be activated when the limit is reached.

3.2.9 *external zero device*, *n*—an external device for checking the zero alignment of the transmissometer by simulating the zero opacity condition for a specific installed opacity monitor.

3.2.10 *simulated zero device*, *n*—an automated mechanism within the transmissometer that produces a simulated clear path condition or low level opacity condition.

3.2.10.1 *Discussion*—The simulated zero device is used to check zero drift daily or more frequently and whenever necessary (for example, after corrective actions or repairs) to assess opacity monitor performance while the instrument is installed on the stack or duct.

3.2.10.2 *Discussion*—The proper response to the simulated zero device is established under clear path conditions while the transmissometer is optically aligned at the installation pathlength and accurately calibrated. The simulated zero device is then the surrogate, clear path calibration value, while the opacity monitor is in service.

3.2.10.3 *Discussion*—Simulated zero checks do not necessarily assess the optical alignment, the reflector status (for double-pass systems), or the dust contamination level on all optical surfaces. (See also 6.9.1.)

3.2.11 *zero alignment*, *n*—the process of establishing the quantitative relationship between the simulated zero device and the actual clear path opacity responses of a transmissometer.

3.2.12 *zero compensation*, *n*—an automatic adjustment of the transmissometer to achieve the correct response to the simulated zero device.

3.2.12.1 *Discussion*—The zero compensation adjustment is fundamental to the transmissometer design and may be inherent to its operation (for example, continuous adjustment based on comparison to reference values/conditions, use of automatic control mechanisms, rapid comparisons with simulated zero and upscale calibration drift check values, and so forth) or it may occur each time a calibration check cycle (zero and upscale calibration drift check) is performed by applying either analog or digital adjustments within the transmissometer.

3.2.12.2 *Discussion*—For opacity monitors that do not distinguish between zero compensation and dust compensation, the accumulated zero compensation may be designated as the dust compensation. Regulatory requirements may impose a limit on the amount of dust compensation that can be applied and require that an alarm be activated when the limit is reached.

3.2.13 *zero drift*, *n*—the difference between the opacity monitor response to the simulated zero device and its nominal value (reported as percent opacity) after a period of normal continuous operation during which no maintenance, repairs, or external adjustments to the opacity monitor took place.

3.2.13.1 *Discussion*—Zero drift may occur due to changes in the light source, changes in the detector, variations due to internal scattering, changes in electronic components, or varying environmental conditions such as temperature, voltage or other external factors. Depending on the design of the transmissometer, particulate matter (that is, dust) deposited on optical surfaces may contribute to zero drift. Zero drift may be positive or negative.

Calibrations and Adjustments

3.2.14 *attenuator*, *n*—a glass or grid filter that reduces the transmittance of light.

3.2.15 *calibration drift*, *n*—the difference between the opacity monitor response to the upscale calibration device and its nominal value after a period of normal continuous operation during which no maintenance, repairs, or external adjustments to the opacity monitor took place.

3.2.15.1 *Discussion*—Calibration drift may be determined after determining and correcting for zero drift. For opacity monitors that include automatic zero compensation or dust compensation features, calibration drift may be determined after zero drift or dust compensation, or both, are applied.

3.2.16 *calibration error*, *n*—the sum of the absolute value of the mean difference and confidence coefficient for the opacity values indicated by an optically aligned opacity monitor (laboratory test) or opacity monitoring system (field test) as compared to the known values of three calibration attenuators under clear path conditions.

3.2.16.1 *Discussion*—The calibration error indicates the fundamental calibration status of the opacity.

3.2.17 *external adjustment*, *n*—either (*1*) a physical adjustment to a component of the opacity monitoring system that affects its response or its performance, or (*2*) an adjustment applied by the data acquisition system (for example, mathematical adjustment to compensate for drift) which is external to the transmissometer and control unit, if applicable.

3.2.17.1 *Discussion*—External adjustments are made at the election of the end user but may be subject to various regulatory requirements.

3.2.18 *intrinsic adjustment*, *n*—an automatic and essential feature of an opacity monitor that provides for the internal control of specific components or adjustment of the opacity monitor response in a manner consistent with the manufacturer's design of the instrument and its intended operation.

3.2.18.1 *Discussion*—Examples of intrinsic adjustments include automatic gain control used to maintain signal amplitudes constant with respect to some reference value, or the technique of ratioing the measurement and reference beams in dual beam systems. Intrinsic adjustments are either non-elective or are configured according to factory recommended procedures; they are not subject to change from time to time at the discretion of the end user.

3.2.19 *upscale calibration device*, *n*—an automated mechanism (employing a filter or reduced reflectance device) within the transmissometer that produces an upscale opacity value.

3.2.19.1 *Discussion*—The upscale calibration device is used to check the upscale drift of the measurement system. It may be used in conjunction with the simulated zero device (for example, filter superimposed on simulated zero reflector) or a parallel fashion (for example, zero and upscale (reduced reflectance) devices applied to the light beam sequentially). (See also 6.9.2.)

Opacity Monitor Location Characteristics

3.2.20 *installation pathlength*, *n*—the installation flange-to-flange separation distance between the transceiver and reflector for a double-pass transmissometer or between the transmitter and receiver for a single-pass transmissometer.

3.2.21 *monitoring pathlength*, *n*—the effective single pass depth of effluent between the receiver and the transmitter of a single-pass transmissometer, or between the transceiver and reflector of a double-pass transmissometer at the installation location.

3.2.22 *emission outlet pathlength*, *n*—the physical pathlength (single pass depth of effluent) at the location where emissions are released to the atmosphere.

3.2.22.1 *Discussion*—For circular stacks, the emission outlet pathlength is the internal diameter at the stack exit. For non-circular outlets, the emission outlet pathlength is the hydraulic diameter. For rectangular stacks:

$$D = (2LW)/(L + W), \quad (3)$$

where L is the length of the outlet and W is the width of the stack exit.

3.2.23 *pathlength correction factor (PLCF)*, *n*—the ratio of the emission outlet pathlength to the monitoring pathlength.

3.2.23.1 *Discussion*—The PLCF is used to calculate the equivalent single pass opacity that would be observed at the stack exit.

3.2.23.2 *Discussion*—A number of similar terms are found in the literature, manufacturer operating manuals, and in common usage. OPLR (optical pathlength ratio) and STR (stack taper ratio) are common. The OPLR is equal to one half of the pathlength correction. Refer to the instrument manufacturer for the proper factor.

Opacity Monitor Optical Characteristics

3.2.24 *angle of projection (AOP)*, *n*—the total angle that contains all of the visible (photopic) radiation projected from the light source of the transmissometer at a level greater than 2.5 % of its peak illuminance.

3.2.25 *angle of view (AOV)*, *n*—the total angle that contains all of the visible (photopic) radiation detected by the photodetector assembly of the transmissometer at a level greater than 2.5 % of the peak detector response.

3.2.26 *instrument response time*, *n*—the time required for the electrical output of an opacity monitor to achieve 95 % of a step change in the path opacity.

3.2.27 *mean spectral response*, *n*—the mean response wavelength of the wavelength distribution for the effective spectral response curve of the transmissometer.

3.2.28 *optical alignment indicator*, *n*—a device or means to determine objectively the optical alignment status of opacity monitor components.

3.2.29 *peak spectral response*, *n*—the wavelength of maximum sensitivity of the transmissometer.

3.2.30 *photopic*, *n*—a region of the electromagnetic spectrum defined by the response of the light-adapted human eye as characterized in the "Source C, Human Eye Response" contained in 40CFR60, Appendix B, Performance Specification 1.

4. Summary of Practice

4.1 A comprehensive series of specifications and test procedures that opacity monitor manufacturers must use to certify opacity monitoring equipment (that is, that the equipment meets minimum design and performance requirements) prior to shipment to the end user is provided. The design and performance specifications are summarized in Table 1.

4.2 Design specifications and test procedures for (*1*) peak and mean spectral responses, (*2*) angle of view and angle of projection, (*3*) insensitivity to supply voltage variations, (*4*) thermal stability, (*5*) insensitivity to ambient light, and (*6*) an optional procedure for opacity monitors with external zero devices that states or other regulatory agencies might require are included. The manufacturer periodically selects and tests for conformance with these design specifications an instrument that is representative of a group of instruments) produced during a specified period or lot. Non-conformance with the design specifications requires corrective action and retesting. Each remanufactured opacity monitor must be tested to demonstrate conformance with the design specifications. The test frequency, transmissometer installation pathlength (that is, set-up distance) and pathlength correction factor for each design specification test are summarized in Table 2.

4.3 This practice includes manufacturer's performance specifications and test procedures for (*1*) instrument response time, (*2*) calibration error, (*3*) optical alignment sight performance - homogeneity of light beam and detector. It also includes a performance check of the spectral response of the instrument. Conformance with these performance specifications is determined by testing each opacity monitor prior to shipment to the end user. (The validity of the results of the calibration error test depends upon the accuracy of the installation pathlength measurements, which is provided by the end user.) The test frequency, transmissometer installation pathlength (that is, set-up distance) and pathlength correction factor for each performance specification test are summarized in Table 3.

4.4 This practice establishes appropriate guidelines for QA programs for manufacturers of continuous opacity monitors,

TABLE 1 Summary of Manufacturer's Specifications and Requirements

Specification	Requirement
Spectral response	peak and mean spectral response between 500 and 600 nm: less than 10% of peak response below 400 nm and above 700 nm
Angle of view, angle of projection	≤4° for all radiation above 2.5 % of peak
Insensitivity to supply voltage variations	±1.0 % opacity max. change over specified range of supply voltage variation, or ±10 % variation from the nominal supply voltage
Thermal stability	±2.0 % opacity change per 40°F change over specified operational range
Insensitivity to ambient light	±2.0 % opacity max. change from sunrise to sunset with at least one 1-h average solar radiation level of ≥ 900 W/m^2
External audit filter access	required
External zero device repeatability - Optional	±1.0 % opacity
Automated calibration checks	check of all active analyzer internal optics with power or curvature, all active electronic circuitry including the light source and photodetector assembly, and electric or electro-mechanical systems used during normal measurement operation
Simulated zero check device	simulated condition during which the energy reaching the detector is between 90 and 190 % of the energy reaching the detector under actual clear path conditions
Upscale calibration check device	check of the measurement system where the energy level reaching the detector is between the energy levels corresponding to 10 % opacity and the highest level filter used to determine calibration error
Status indicators	manufacturer to identify and specify
Pathlength correction factor security	manufacturer to specify one of three options
Measurement output resolution	0.5 % opacity over measurement range from -5 % to 50 % opacity, or higher value
Measurement and recording frequency	sampling and analyzing at least every 10 s: calculate averages from at least 6 measurements per minute
Instrument response time	≤10 s to 95 % of final value
Calibration error	≤3 % opacity for the sum of the absolute value of mean difference and 95 % confidence coefficient for each of three test filters
Optical alignment indicator - (uniformity of light beam and detector)	clear indication of misalignment at or before the point where opacity changes ±2 % due to misalignment as system is misaligned both linearly and rotationally in horizontal and vertical planes
Calibration device repeatability	≤1.5 % opacity

TABLE 2 Manufacturer's Design Specifications – Test Frequency, Set-Up Distance, and Pathlength Correction Factor

Manufacturer's Design Specification	Test Frequency	Set-Up Distance	Pathlength Correction Factor
Spectral Response	annually, and following failure of spectral response performance check[A]	1 to 3 m when measured (not applicable when spectral response is calculated)	NA
Angle of view, angle of projection	monthly, or 1 in 20 units (whichever is more frequent)	3 m	NA
Insensitivity to supply voltage variations	monthly, or 1 in 20 units (whichever is more frequent)	3 m	1.0
Thermal stability	annually[B]	3 m (external jig for tests)	1.0
Insensitivity to ambient light	annually[B]	3 m	1.0
External zero device repeatability - optional	annually[B]	3 m	1.0
Additional design specifications[C]	as applicable		

[A]The spectral response is determined annually for each model and whenever there is a change in the design, manufacturing process, or component that might affect performance. Reevaluation of the spectral response is necessary when an instrument fails to meet the spectral response performance check.

[B]Annually, and whenever there is a change in the design, manufacturing process, or component that might affect performance.

[C]The manufacturer shall certify that the opacity monitor design meets the applicable requirements for (*a*) external audit filter access, (*b*) external zero device (if applicable), (*c*) simulated zero and upscale calibration devices, (*d*) status indicators, (*e*) pathlength correction factor security, (*f*) measurement output resolution, and (*g*) measurement recording frequency.

TABLE 3 Manufacturer's Performance Specification – Test Applicability, Set-Up Distance and Pathlength Correction Factor

Manufacturer's Performance Specification	Test Applicability	Set-Up Distance	Pathlength Correction Factor
Instrument response time	each instrument	per actual installation	per actual installation
Calibration error	each instrument	per actual installation[A]	per actual installation[A]
Acceptable tolerance comparing test to actual conditions		±10 % reset clear path zero values for subsequent monitoring[B]	±10 %, use actual value for all subsequent monitoring[B]
Optical alignment indicator - (uniformity of light beam and detector)	each instrument	per actual installation	per actual installation
Spectral response performance check	each instrument	per actual installation	per actual installation
Calibration device repeatability	each instrument	per actual installation	per actual installation

[A] Default test values are provided for use where the installation pathlength and pathlength correction factor can not be determined.

[B]When actual measurements are within ±10 % tolerance, a field performance audit can be performed rather than a field calibration error test at the time of installation.

including corrective actions when non-conformance with specifications is detected.

5. Significance and Use

5.1 Continuous opacity monitors are required to be installed at many stationary sources of air pollution by federal, state, and local air pollution control agency regulations. EPA regulations regarding the design and performance of opacity monitoring systems for sources subject to "Standards of Performance for New Stationary Sources" are found in 40 CFR 60, Subpart A General Provisions, §60.13 Monitoring Provisions, Appendix B, Performance Specification 1, and in applicable source-specific subparts. Many states have adopted these or very similar requirements for opacity monitoring systems.

5.2 Regulated industrial facilities are required to report continuous opacity monitoring data to control agencies on a periodic basis. The control agencies use the data as an indirect measure of particulate emission levels and as an indicator of the adequacy of process and control equipment operation and maintenance practices.

5.3 EPA Performance Specification 1 provides minimum specifications for opacity monitors and requires source owners or operators of regulated facilities to demonstrate that their installed systems meet certain design and performance specifications. Performance Specification 1 allows, as an alternative to testing each instrument, manufacturers to demonstrate conformance with certain design specifications by selecting and testing representative instruments.

5.4 Previous experience has demonstrated that EPA Performance Specification 1 does not address all of the important design and performance parameters for opacity monitoring systems. The additional design and performance specifications included in this practice are needed to eliminate many of the performance problems that have been encountered. This practice also provides purchasers and vendors flexibility, by designing the test procedures for basic transmissometer components or opacity monitors, or in certain cases, complete opacity monitoring systems. However, the specifications and test procedures are also sufficiently detailed to support the manufacturer's certification and to facilitate independent third party evaluations (if desired) of the procedures.

5.5 Purchasers of opacity monitoring equipment meeting all of the requirements of this practice are assured that the opacity monitoring equipment meets all of the design requirements of EPA Performance Specification 1, and additional design specifications that eliminate many of the operational problems that have been encountered in the field. Purchasers can rely on the manufacturer's published operating range specifications for ambient temperature and supply voltage. These purchasers are also assured that the specific instrument has been tested at the point of manufacture and demonstrated to meet the manufacturer's performance specifications for instrument response time, calibration error (based on pathlength measurements provided by the end user), optical alignment, and the spectral response performance check requirement. Conformance with the requirements of this practice ensures conformance with all of the requirements of 40CFR60, Appendix B, Performance Specification 1 except those requirements for which tests are required after installation.

5.6 The original manufacturer, or those involved in the repair, remanufacture, or resale of opacity monitors can use this practice to demonstrate that the equipment components or opacity monitoring systems provided meet appropriate design and performance specifications.

5.7 The applicable test procedures and specifications of this practice are selected to address the equipment and activities that are within the control of the manufacturer; they do not mandate testing of the opacity system data recording equipment or reporting.

5.8 This practice also may serve as the basis for third party independent audits of the certification procedures used by manufacturers of opacity monitoring equipment.

6. Procedure—Design Specification Verification

6.1 *Test Opacity Monitor Selection, Test Frequency, and Summary of Tests*:

6.1.1 Perform the design specification verification procedures in this section for each representative model or configuration involving substantially different optics, electronics, or software before being shipped to the end user.

6.1.2 At a minimum, select one opacity monitor from each month's production, or one opacity monitor from each group of twenty opacity monitors, whichever is more frequent. Test this opacity monitor for (*1*) angle of view, (*2*) angle of projection, and (*3*) insensitivity to supply voltage variations. If any design specification is unacceptable, institute corrective action according to the established quality assurance program and remedy the cause of unacceptability for all opacity monitors produced during the month or group of twenty. In addition, test all of the opacity monitors in the group and verify conformance with the design specifications before shipment to the end users.

NOTE 1—The selected opacity monitor may be the first opacity monitor produced each month, or the first opacity monitor in each group of twenty, provided that it is representative of the entire group.

6.1.3 At a minimum, test one opacity monitor each year for (*1*) spectral response, (*2*) thermal stability, and (*3*) insensitivity to ambient light. If any design specification is unacceptable, institute corrective action according to the established quality assurance program and remedy the cause of unacceptability for all affected opacity monitors. In addition, retest another representative opacity monitor after corrective action has been implemented to verify that the problem has been resolved.

6.1.4 Certify that the opacity monitor design meets the applicable requirements (see 6.7-6.13) for (*1*) external audit filter access, (*2*) external zero device (if applicable), (*3*) simulated zero and upscale calibration devices, (*4*) status indicators, (*5*) pathlength correction factor security, (*6*) measurement output resolution, and (*7*) measurement recording frequency. Maintain documentation of tests and data necessary to support certification.

6.2 *Spectral Response*:

NOTE 2—The purpose of the spectral response specifications is to ensure that the transmissometer measures the transmittance of light within the photopic range. The spectral response requirements ensure some level of consistency among opacity monitors because the determination of transmittance for effluent streams depends on the particle size, wavelength, and other parameters. The spectral response requirements also eliminate potential interfering effects due to absorption by various gaseous constituents except NO_2 which can be an interferent if present in abnormally high concentrations or over long pathlengths, or both. The spectral response requirements apply to the entire transmissometer. Any combination of components may be used in the transmissometer so long as the response of the entire transmissometer satisfies the applicable requirements.

6.2.1 *Test Frequency*— See 6.1.3. In addition, conduct this test (*1*) anytime a change in the manufacturing process occurs or a change in a component that may affect the spectral response of the transmissometer occurs or (*2*) on each opacity monitor that fails the spectral response performance check in 7.10.

6.2.2 *Specification*— The peak and mean spectral responses must occur between 500 nm and 600 nm. The response at any wavelength below 400 nm and above 700 nm must be less than 10 % of the peak spectral response. Calculate the mean spectral response as the arithmetic mean value of the wavelength distribution for the effective spectral response curve of the transmissometer.

6.2.3 *Spectral Response Design Specification Verification Procedure*—Determine the spectral response of the transmissometer by either of the procedures in 6.2.4 (Option 1) or 6.2.5 (Option 2), then calculate the mean response wavelength from the normalized spectral response curve according to 6.2.6. Option 1 is to measure the spectral response using a variable slit monochromator. Option 2 is to determine the spectral response from manufacturer-supplied data for the active optical components of the measurement system.

6.2.4 *Option 1, Monochromator*—Use the following procedure:

6.2.4.1 Verify the performance of the monochromator using a NIST traceable photopic band pass filter or light source, or both.

6.2.4.2 Set-up, optically align, and calibrate the transmissometer for operation on a pathlength of 1 to 3 m.

6.2.4.3 Connect an appropriate data recorder to the transmissometer and adjust the gain to an acceptable measurement level.

6.2.4.4 Place the monochromator in the optical path with the slit edge at an appropriate distance from the permanently mounted focusing lenses.

6.2.4.5 Use the monochromator with a range from 350 nm to 750 nm or greater resolution. Record the response of the transmissometer at each wavelength in units of optical density or voltage.

6.2.4.6 Cover the reflector for double-pass transmissometers, or turn off the light source for single-pass transmissometers, and repeat the test to compensate measurement values for dark current at each wavelength.

6.2.4.7 Determine the spectral response from the opacity monitor double pass response and the monochromator calibration.

6.2.4.8 Graph the raw spectral response of the transmissometer over the test range.

6.2.4.9 Normalize the raw response curve to unity by dividing the response at 10 nm intervals by the peak response.

6.2.5 *Option 2, Calculation from Manufacturer Supplied Data*—Obtain data from component suppliers that describes the spectral characteristics of the light source, detector, filters, and all other optical components that are part of the instrument design and affect the spectral response of the transmissometer. Ensure that such information is accurately determined using reliable means and that the information is representative of the specific components used in current production of the transmissometer under evaluation. Update the information at least every year or when new components are used, or both. Keep the information and records necessary to demonstrate its applicability to the current spectral response determination on file. Using the component manufacturer-supplied data, calculate the effective spectral response for the transmissometer as follows:

6.2.5.1 Obtain the spectral emission curve for the source. The data must be applicable for the same voltages or currents, or both, as that used to power the source in the instrument.

6.2.5.2 Obtain the spectral sensitivity curve for the detector that is being used in the system.

6.2.5.3 Obtain spectral transmittance curves for all filters and other active optical components that affect the spectral response.

6.2.5.4 Perform a point-wise multiplication of the data obtained in 6.2.5.1-6.2.5.3, at 10 nm intervals, over the range 350 to 750 nm, to yield the raw response curve for the system.

6.2.5.5 Normalize the raw response curve to unity by dividing the response at 10 nm intervals by the peak response.

6.2.6 Using the results from Option 1 or 2, as applicable, determine conformance to the specifications in 6.2.2. Then calculate the mean response wavelength (response-weighted average wavelength) by (*1*) multiplying the response at 10 nm intervals by the wavelength, (*2*) summing all the products, and (*3*) dividing by the sum of all 10 nm interval responses. Verify that this result is greater than 500 nm but less than 600 nm.

6.2.7 *Monitor-Specific Performance Check Limits*—Establish the monitor-specific performance check limits for use in conducting the Spectral Response Performance Check (7.10) as follows:

NOTE 3—The equivalent single-pass opacity from 6.2.7.2 and the single-pass opacity results corresponding to the applicable shifts from 6.2.7.3 bound the acceptable limits for the spectral response performance check.

6.2.7.1 Obtain a photopic transmission filter that has (*1*) a peak transmission ≥70 %, (*2*) maximum transmission between 550 nm and 560 nm, (*3*) half-maximum transmission between 500 nm and 520 nm, (*4*) half-maximum transmission between 600 nm and 620 nm, (*5*) transmission <10 % at any wavelength less than 450 nm or greater than 650 nm, and (*6*) a traceable calibration. Calibrate and verify the transmittance of the photopic filter as a function of wavelength initially and at least annually.

6.2.7.2 Calculate the expected single-pass opacity (assuming PLCF=1) that would result from inserting the photopic transmission filter into the clear-stack path of the transmissometer by (*1*) performing a point-wise multiplication of the photopic transmission filter curve with the normalized transmissometer response curve (obtained from 6.2.4.9 or 6.2.5.5), (*2*) summing the products, (*3*) dividing by the sum of the 10 nm responses to form the single-pass transmission, and (*4*) calculating the equivalent single-pass opacity.

6.2.7.3 Repeat the calculations in 6.2.7.2, except use (*1*) the normalized transmissometer curve shifted by +20 nm or the amount which would cause the peak or mean spectral response to shift to the limiting value of 600 nm, whichever shift is less, and (*2*) the normalized transmissometer curve shifted by –20 nm or the amount which would cause the peak or mean spectral response to shift to the limiting value of 500 nm, whichever shift is less.

6.2.7.4 Repeat the calculations with any design changes involving the source, detector(s), or light transmitting optics. Although failure of the spectral response performance check in 7.10 does not necessarily mean that the transmissometer response is no longer within the photopic range, it is a sufficient basis to warrant additional investigation, including reevaluation of the spectral response and performance check limits, explanation, and documentation of the problem.

6.3 *Angle of View and Angle of Projection*:

NOTE 4—The purpose of the angle of view (AOV) and angle of projection (AOP) design specifications is to minimize the effects of light scattering in the measurement path when determining transmittance or opacity.

6.3.1 *Test Frequency*— See 6.1.2. Manufacturers that demonstrate and document using good engineering practice that a specific design results in an AOP of less than 0.5° are not required to perform the following AOP or AOV tests.

6.3.2 *Specification*— The total AOP and the total AOV must each be no greater than 4°. Transmissometers with an AOP of less than 0.5° are exempt from the AOV or AOP specification.

6.3.3 *AOV and AOP Design Specification Verification Procedure*—Conduct the AOV and AOP tests using the procedures given in 6.3.4-6.3.13.

6.3.4 *Transmissometer Configuration*—Conduct the AOV and AOP tests with the complete transmissometer assembly, including all parts of the measurement system that may impact the results. Provide a justification of (*1*) exactly what is included and excluded from the AOV and AOP tests and (*2*) any test procedure modifications necessary to accommodate particular designs, such as those that may be required for dual beam designs that are chopped and synchronously detected. Include the justifications with documentation of the results.

6.3.5 *Set-Up*—Focus and configure the transmissometer for a flange-to-flange installation separation distance of 3 m.

6.3.6 *Test Fixture*— Set up the AOV test fixture that incorporates (*1*) a movable light source along arcs of 3 m radius relative to the first optical surface encountered by the light beam entering the detector housing assembly, in both the horizontal and vertical directions relative to the normal installation orientation, and (*2*) recording measurements at 2.5 cm increments along the arc. Similarly, set up the AOP test fixture that incorporates (*1*) a movable photodetector along an arc of 3 m radius relative to the final optical surface encountered by the light beam exiting the transmitter housing assembly, in both the horizontal and vertical directions relative to the normal installation orientation, and (*2*) recording measurements at 2.5 cm increments along the arc.

NOTE 5—It is helpful to mount on test stands the detector and transmitter housings for single-pass transmissometers, or the transceiver for double-pass transmissometers.

6.3.7 *Alternative Test Fixture*—For the AOV test, at a distance of 3 m from a stationary light source, mount the detector housing on a turntable that can be rotated (both horizontally and vertically) in increments of 0.5° [28.6 min], corresponding to measurements displaced 2.5 cm along the arc, to a maximum angle of 5° (corresponding to a distance of 26 cm along the arc) on either side of the alignment centerline. Similarly, for the AOP test, mount transmitter housing on the turntable at a distance of 3 m relative to a stationary photodetector.

NOTE 6—If the turntable is capable of rotating only in either the horizontal or vertical direction, the detector or transmitter housing may be mounted on its side or bottom (as appropriate) to simulate the other direction.

6.3.8 *Light Source*— For the AOV test, use a small non-directional light source (less than 3 cm wide relative to the direction of movement) that (*1*) includes the visible wavelengths emitted by the light source installed in the transmissometer, (*2*) provides sufficient illuminance to conduct the test but doe snot saturate the detector, (*3*) does not include lenses or focusing devices, and (*4*) does not include non-directional characteristics, that is, the intensity in the 20° sector facing the detector assembly varies by less than ±10 %.

NOTE 7—A light source that does not meet the non-directional criteria may still be used for the AOV test, if a specific procedure is followed. This procedure is given in 6.3.9.

6.3.9 *Alternative Light Source*—For the AOV test, if the light source does not meet the non-directional criteria, rotate the light source in the vertical and horizontal planes about its normal optical axis as it is pointed at the entrance aperture of the instrument under test in order to obtain the maximum response from the instrument under test at each position in the test procedure.

6.3.10 *AOV Test Procedure*—Test the entire detector assembly (that is, transceiver for double-pass transmissometers or receiver/detector for a single-pass transmissometer). If applicable, include the mounting flanges normally supplied with the opacity monitor. Use an appropriate data recorder to record continuously the detector response during the test.

NOTE 8—Alternative AOV test procedures are necessary for certain designs. For example, a transmissometer with an optical chopper/modulator responds only to light modulated at a certain frequency. An external chopper/modulator used in conjunction with the test light source must match both the phase and duty cycle for accurate results. If this cannot be done, the manufacturer may either (*1*) provide additional electronics to drive another similar external source in parallel wit the internal source or (*2*) modify the detector electronics so that its response may be used to accurately evaluate the AOV of the test transmissometer. The manufacturer must take appropriate measures to ensure (*1*) that the background, or ambient light, and detector offsets do not significantly reduce the accuracy of the AOV measurements, (*2*) that the field of view restricting hardware normally included with the instrument are not modified in any way, and (*3*) that good engineering practice is followed in the design of the test configuration to ensure an accurate measurement of AOV.

6.3.10.1 Align the test light source at the center position and observe the detector assembly response. Optimize the test light source and optical chopper/modulator (if applicable) to maximize the detector assembly response. If the detector response is not within the normal operating range (that is, 25 to 200 % of the energy value equivalent to a clear path transmittance measurement for the transmissometer), adjust the test apparatus (for example, light source power supply) to achieve a detector response in the acceptable range.

6.3.10.2 Position the test light source on the horizontal arc 26 cm from the detector centerline (5°) and record the detector response. Move the light source along the arc at intervals not larger than 2.5 cm (or rotate the turntable in increments not larger than 0.5°) and record the detector response for each measurement location. Continue to make measurements through the aligned position and on until a position 26 cm (5°) on the opposite side of the arc from the starting position is reached. Record the response for each measurement location and over the full test range; continue recording data for all positions up to 26 cm (5°) even if no response is observed at an angle of ≤26 cm (5°) from the centerline.

6.3.10.3 Repeat the AOV test on an arc in the vertical direction relative to the normal orientation of the detector housing.

6.3.10.4 For both the horizontal and vertical directions, calculate the relative response of the detector as a function of viewing angle (response at each measurement location as a percentage of the peak response). Determine the maximum viewing angle for the horizontal and vertical directions yielding a response greater than 2.5 % of the peak response. Determine conformance to the specification in 6.3.2. Report these angles as the angle of view. Report the relative angle of view curves in both the horizontal and vertical directions. Document and explain any modifications to the test procedures as described in 6.3.11.

6.3.11 *AOP Test Procedure*—Perform this test for the entire light source assembly (that is, transceiver for double-pass transmissometers or transmitter for single-pass transmissometers). The test may also include the mounting flanges normally supplied with the opacity monitor. Conduct the AOP test using the procedures in either 6.3.12 or 6.3.13.

6.3.12 *Option 1*—Use a photodetector (*1*) that is less than 3 cm wide relative to the direction of movement, (*2*) that is preferably of the same type and has the same spectral response as the photodetector in the transmissometer, (*3*) that is capable of detecting 1 % of the peak response, and (*4*) that does not saturate at the peak illuminance (that is, when aligned at the center position of the light beam. Use an appropriate data recorder to record continuously the photodetector response during the test.

6.3.12.1 Perform this test in a dark room. If the external photodetector output is measured in a dc-coupled circuit, measure the ambient light level in the room (must be <0.5 % of the peak light intensity to accurately define the point at which 2.5 % peak intensity occurs). If the external photodetector is measured in an ac-coupled configuration, demonstrate that (*1*) ambient light level in the room, when added to the test light beam, does not cause the detector to saturate, and (*2*) turning on and off the ambient lights does not change the detected signal output. Include documentation for these demonstrations in the report.

6.3.12.2 Position the photodetector on the horizontal arc 26 cm from the projected beam centerline (5°) and record the response. Move the photodetector along the arc at ≤2.5-cm intervals (or rotate the turntable in ≤0.5° increments) until a position 26 cm (5°) on the opposite side of the arc is reached. Record the response for each measurement location and over the full test range; continue recording data for all positions up to 26 cm (5°) even if no response is observed at an angle of ≤26 cm (5°) from the centerline.

6.3.12.3 Repeat the AOP test on an arc in the vertical direction relative to the normal orientation of the detector housing.

6.3.12.4 For both the horizontal and vertical directions, calculate the relative response of the photodetector as a function of projection angle (response at each measurement location as a percentage of the peak response). Determine the maximum projection angle for the horizontal and vertical directions yielding a response greater than 2.5 % of the peak response. Determine conformance to the specification in 6.3.2. Report these angles as the angle of projection. Report the relative angle of projection curves in both the horizontal and vertical directions.

6.3.13 *Option 2*—Use this test procedure for only transmissometer designs that have previously met the AOP specification using Option 1 procedure during the preceding 12 months. Ensure that the light beam is focused at the actual flange-to-flange separation distance of the transmissometer.

6.3.13.1 Perform this test in a darkened room. Project the light beam onto a target located at a distance of 3 m from the transceiver/transmitter. Focus the light beam on the target.

6.3.13.2 Measure the beam dimensions (for example, diameter) on the target in both the horizontal and vertical directions. Calculate the maximum total angle of projection (that is, total subtended angle) based on the separation distance and beam dimensions. Compare this result to the previously measured AOP result obtained using Option 1. If the AOP results obtained by Option 1 and Option 2 do not agree within ±0.3°, repeat the test using Option 1.

6.3.13.3 Report the greater AOV result of Option 1 or Option 2 as the AOV for the test instrument.

6.4 *Insensitivity to Supply Voltage Variations*:

NOTE 9—The purpose of this design specification is to ensure that the accuracy of opacity monitoring data is not affected by supply voltage variations over ±10 % from nominal or the range specified by the manufacturer, whichever is greater. This specification does not address rapid voltage fluctuations (that is, peaks, glitches, or other transient conditions), emf susceptibility or frequency variations in the power supply.

6.4.1 *Test Frequency*— See 6.1.2.

6.4.2 *Specification*— The opacity monitor output (measurement and calibration check responses, both with and without compensation, if applicable) must not deviate more than ±1.0 % single pass opacity for variations in the supply voltage over ±10 % from nominal or the range specified by the manufacturer, whichever is greater.

6.4.3 *Design Specification Verification Procedure*:

6.4.3.1 Determine the acceptable supply voltage range from the manufacturer's published specifications for the model of opacity monitor to be tested. Use a variable voltage regulator and a digital voltmeter to monitor the rms supply voltage to within ±0.5 %. Measure the supply voltage over ±10 % from nominal, or the range specified by the manufacturer, whichever is greater.

6.4.3.2 Set-up and align the opacity monitor (transceiver and reflector for double-pass opacity monitors, or transmitter and receiver for single-pass opacity monitors) at a measurement pathlength of 3 m. Use a pathlength correction factor of 1.0. Calibrate the instrument using external attenuators at the nominal operating voltage. Insert an external attenuator with a nominal value between 10 and 20 % single-pass opacity into the measurement path and record the response. Initiate a calibration check cycle and record the low level and upscale responses.

6.4.3.3 Do not initiate any calibration check cycle during this test procedure except as specifically required. Decrease the supply voltage in increments of 2 % of the nominal value and record the one-minute or more frequent measurement response to the attenuator at each voltage (after the instrument response has stabilized) until the minimum value is reached. Initiate a calibration check cycle at the minimum supply voltage and record the low level and upscale responses. Reset the supply voltage to the nominal value and then increase the supply voltage in increments of 2 % of the nominal value and record the measurement response to the attenuator at each voltage (after the instrument response has stabilized) until the maximum value is reached. Initiate a calibration check cycle at the maximum supply voltage and record the low level and upscale responses, both with and without compensation, if applicable.

6.4.3.4 Determine conformance to specifications in 6.4.2.

6.5 *Thermal Stability*:

NOTE 10—The purpose of this design specification is to ensure that the accuracy of opacity monitoring data is not affected by ambient temperature variations over the range specified by the manufacturer.

6.5.1 *Test Frequency*— See 6.1.3. Repeat this test anytime there is a major change in the manufacturing process or change in a major component that could affect thermal stability.

6.5.2 *Specification*— The opacity monitor output (measurement and calibration check responses, both with and without compensation, if applicable) must not deviate more than ±2.0 % single pass opacity for every 22.2°C (40°F) change in ambient temperature over the range specified by the manufacturer.

6.5.3 *Design Specification Verification Procedure*:

6.5.3.1 Determine the acceptable ambient temperature range from the manufacturer's published specifications for the model of opacity monitor to be tested. Use a climate chamber capable of operation over the specified range. If the climate chamber cannot achieve the full range (for example, cannot reach minimum temperatures), clearly state the temperature range over which the opacity monitor was tested and provide additional documentation of performance beyond this range to justify operating at lower temperatures.

6.5.3.2 Set-up and align the opacity monitor (transceiver and reflector for double-pass opacity monitors, or transmitter and receiver for single-pass opacity monitors) at a measurement pathlength of 3 m. Use a pathlength correction factor of 1.0. If the opacity monitor design introduces purge air through the housing that contains optical components of the transceiver, transmitter, or detector, operate the purge air system during this test. If the purge air does not contact internal optics and electronics, the air purge system need not be operative during the test.

NOTE 11—For double-pass systems with reflectors that can be shown to be insensitive to temperature, this test may be performed using a zero reference similar to an external zero jig, but one that is designed specifically to evaluate the temperature stability of the instrument for this test. This device must be designed to be temperature invariant so that the test evaluates the stability of the instrument, not the stability of the zero reference. Another acceptable approach is to construct a test chamber where the reflector is mounted outside the chamber at a constant temperature. The control unit, if applicable, need not be installed in the climate chamber if it is to be installed in a controlled environment by the end user.

6.5.3.3 Establish proper calibration of the instrument using external attenuators at a moderate temperature that is, 21.1 ± 2.8°C (70 ± 5°F). Insert an external attenuator with a single-pass value between 10 and 20 % opacity into the measurement path and record the response. Initiate a calibration check cycle and record the low level and upscale responses.

NOTE 12—Grid filters are recommended for these tests to eliminate temperature dependency of the attenuator value.

6.5.3.4 Do not initiate any calibration check cycle during this test procedure except as specifically stated. Continuously record the temperature and measurement response to the attenuator during this entire test. Decrease the temperature in the climate chamber at a rate not to exceed 11.1°C (20°F) per hour until the minimum temperature is reached. Note data recorded during brief periods when condensation occurs on optical surfaces due to temperature changes. Allow the opacity monitor to remain at the minimum temperature for at least one hour and then initiate a calibration check cycle and record the low level and upscale responses with and without compensation, if applicable. Return the opacity monitor to the initial temperature and allow sufficient time for it to equilibrate and for any condensed moisture on exposed optical surfaces to evaporate. Increase the temperature in the climate chamber at a rate not to exceed 11.1°C (20°F) per hour until the maximum temperature is reached. Allow the opacity monitor to remain at the maximum temperature for at lest one hour and then initiate a calibration check cycle and record the low level and upscale responses.

NOTE 13—The notations when condensation occurs are for explanatory purposes only.

6.5.3.5 Determine conformance to specifications in 6.5.2.

6.6 *Insensitivity to Ambient Light*:

NOTE 14—The purpose of this design specification is to ensure that opacity monitoring data are not affected by ambient light.

6.6.1 *Test Frequency*— See 6.1.3. Repeat this test anytime there is a major change in the manufacturing process or change in a major component that could affect the opacity monitor sensitivity to ambient light.

6.6.2 *Specification*— The opacity monitor output (measurement and calibration check responses, both with and without compensation, if applicable) must not deviate more than ±2.0 % single pass opacity when exposed to ambient sunlight over the course of a day.

6.6.3 *Design Specification Verification Procedure*:

6.6.3.1 Perform this test (*1*) at a time of maximum insolation, on a clear day where light scattering from atmospheric haze, clouds, or particulate matter are at a minimum, (*2*) when at least one 1-h solar radiation average is ≥900 W/m ^{2}, and (*3*) for a specific opacity monitor that has successfully completed the spectral response, thermal stability tests, and other design specification verification procedures.

6.6.3.2 Set-up the opacity monitor outside, with the light path in a horizontal position, and where it will be directly exposed to sunlight for the entire day. Use mounting flanges of normal length, and attach the flanges to mounting plates that extend at least 0.305 m (12 in.) above, below, and to both sides of the mounting flanges. Paint the interior surfaces of the mounting flanges and the facing surfaces of the mounting plates white. Optically align the opacity monitor (transceiver and reflector for double-pass opacity monitors, or transmitter and receiver for single-pass opacity monitors) at a measurement pathlength of 3 m on an approximate east-west axis aligned with the transit of the sun. Use a pathlength correction factor of 1.0. Calibrate the instrument using external attenuators prior to the test. Insert an external attenuator with a single-pass value between 10 and 20 % opacity into the measurement path and record the response. Initiate a calibration check cycle and record the low level and upscale responses.

6.6.3.3 Use a cosine corrected total solar radiation monitor that (*1*) is capable of detecting light from 400 to 1100 nm, (*2*) has been calibrated under natural daylight conditions to within ±5 % against industry standards, (*3*) has a sensitivity of at least 90 µA/100 W/m ^{2}, and (*4*) has a linearity with a maximum deviation of less than 1 % up to 3000 W/m^2. Place the solar radiation monitor on top of the transceiver for double-pass opacity monitors, or detector for single-pass opacity monitors. If weather covers are supplied with all opacity monitors, install the solar radiation monitor on top of the weather cover. Measure the total solar radiation according to the manufacturer's instructions.

6.6.3.4 Continuously record the opacity monitor response to the attenuator and the output of the solar radiation monitor for a period from two hours before sunrise to two hours after sunset. Record the ambient temperature during this period. Do not conduct calibration check cycles during this test more frequently than once per 24-h period or the longest interval recommended in the manufacturer's published specifications. Document and report the frequency of conducting calibration check cycles during the insensitivity to ambient light test.

6.6.3.5 If necessary, correct the measurement data for changes in instrument response due to ambient temperature variation by running a separate test with the same instrument shielded from the sunlight. Determine the maximum percent deviation in the measurement response for any six minute period during the test.

6.6.3.6 Determine conformance with the specifications 6.6.2.

6.7 *External Audit Filter Access*:

NOTE 15—The opacity monitor design must accommodate independent assessments of the measurement system response to commercially available external (that is, not intrinsic to the instrument) audit filters. These calibration attenuators may be placed within the mounting flange, air purge plenum, or other location after the projected light beam passes through the last optical surface of the transceiver or transmitter. They may also be placed in a similar location at the other end of the measurement path prior to the light beam reaching the first optical surface of the reflector or receiver. The external audit filter access design must ensure (*a*) the filters are used in conjunction with a zero condition based on the same energy level, or within 5 % of the energy reaching the detector under actual clear path conditions, (*b*) the entire beam received by the detector will pass through the attenuator, and (*c*) the attenuator is inserted in a manner that minimizes interference from the reflected light.

6.7.1 Insert the external audit filter into the system.

6.7.2 Determine whether the entire beam received by the detector passes through the attenuator and that interference from reflected light is minimal.

6.7.3 Determine whether the zero condition corresponds to the same energy level reaching the detector as when actual clear path conditions exist

6.8 *External Zero Device—Optional*:

NOTE 16—The opacity monitor design may include an external, removable device for checking the zero alignment of the transmissometer. Such a device may provide an independent means of simulating the zero opacity condition for a specific installed opacity monitor over an extended period of time and can be used by the operator to periodically verify the accuracy of the internal simulated zero device. The external zero device must be designed: (*1*) to simulate the zero opacity condition based on the same energy level reaching the detector as when actual clear path conditions exist; (*2*) to produce the same response each time it is installed on the transmissometer; and (*3*) to minimize the chance that inadvertent adjustments will affect the zero level response produced by the device. The opacity monitor operator is responsible for the proper storage and are of the external zero device and for reverifying the proper calibration of the device during all clear path zero alignment tests.

NOTE 17—The purpose of this design specification is to ensure that the external zero device design and mounting procedure will produce the same response each time that the device is installed on the transmissometer.

6.8.1 *Test Frequency*— If the optional external zero device is supplied with any opacity monitors of the subject model, select and perform this test for one representative external zero device manufactured each year for the opacity monitor model certified by this practice.

6.8.2 *Specification*— The opacity monitor output must not deviate more than ±1.0 % single pass opacity for repeated installations of the external zero device on a transmissometer.

6.8.3 *Design Specification Verification Procedure*—Perform this test using an opacity monitor that has successfully completed the tests to demonstrate insensitivity to ambient light (6.6) and which is set up and properly calibrated for a measurement pathlength of 3 meters. Install the external zero device and make any necessary adjustment to it so that it produces the proper zero opacity response from the test transmissometer. Remove the external zero device and return the test transmissometer to operation and verify that the opacity monitor output indicates 0.0 ± 0.5 % opacity. Without making any adjustments to the external zero device or the test opacity monitor, install and remove the external zero device five times. Record the zero response of the test opacity monitor to the external zero device and to the clear path condition after it is returned to operation after each installation.

6.8.4 Determine conformance with the design specification in 6.8.3.

6.9 *Calibration Check Devices*:

NOTE 18—Opacity monitors covered by this practice must include automated mechanisms to provide calibration checks of the installed opacity monitor.

6.9.1 *Simulated Zero Device*—Establish the proper response to the simulated zero device under clear path conditions while the transmissometer is optically aligned at the installation pathlength and accurately calibrated. Certify that the simulated zero device conforms to the following:

6.9.1.1 The simulated zero device produces a simulated clear path condition or low level opacity condition, where the energy reaching the detector is between 90 and 190 % of the energy reaching the detector under actual clear path conditions. Corrections for energy levels other than 100 % are permitted provided that they do not interfere with the instrument's ability to measure opacity accurately.

6.9.1.2 The simulated zero device provides a check of all active analyzer internal optics with power or curvature, all active electronic circuitry including the light source and photodetector assembly, and electric or electro-mechanical systems, and hardware and/or software used during normal measurement operation.

NOTE 19—The simulated zero device allows the zero drift to be determined while the instrument is installed on the stack or duct. Simulated zero checks, however, do not necessarily assess the optical alignment, status of the reflector (for double-pass systems), or the level of dust contamination of all optical surfaces.

6.9.2 *Upscale Calibration Device*—Certify that the device conforms to the following:

6.9.2.1 The upscale calibration device measures the upscale calibration drift under the same optical, electronic, software, and mechanical components as are included in the simulated zero check.

6.9.2.2 The upscale calibration device checks the pathlength corrected measurement system response where the energy level reaching the detector is between the energy levels corresponding to 10 % opacity and the highest level filter used to determine calibration error.

6.9.2.3 The upscale calibration check response is not altered by electronic hardware or software modification during the calibration cycle and is representative of the gains and offsets applied to normal effluent opacity measurements.

NOTE 20—The upscale calibration device may employ a neutral density filter or reduced reflectance device to produce an upscale drift check of the measurement system. The upscale calibration device may be used in conjunction with the simulated zero device (for example, neutral density filter superimposed on simulated zero reflector) or in a parallel fashion (for example, zero and upscale [reduced reflectance] devices applied to the light beam sequentially).

6.10 *Status Indicators*:

NOTE 21—Opacity monitors must include alarms or fault condition warnings to facilitate proper operation and maintenance of the opacity monitor. Such alarms or fault condition warnings may include lamp/source failure, purge air blower failure, excessive zero or calibration drift,