



Standard Practice for Opacity Monitor Manufacturers to Certify Conformance with Design and Performance Specifications¹

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1. Scope*

1.1 This practice covers the procedure for certifying continuous opacity monitors. In the main part of this practice, 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. In **Annex A1**, additional or alternative specifications are provided for certifying opacity monitors intended for use in applications where the opacity standard is less than 10 %, or where the user expects the opacity to be less than 10 % and elects to use the more restrictive criteria in **Annex A1**. In both cases, the error budgets for the opacity measurements are given in **X1**.

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 the main part of this practice have been adopted by reference by 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 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.

¹ This practice is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.03 on Ambient Atmospheres and Source Emissions.

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2. Referenced Documents

2.1 ASTM Standards:²

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

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-Guidelines⁴

ANSI/NCSL Z 540-1-1994 Calibration Laboratories and Measuring Equipment - General Requirements⁴

NIST 260-116 - Filter calibration procedures⁵

3. Terminology

3.1 For terminology relevant to this practice, see Terminology **D1356**.

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

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401.

⁴ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

⁵ Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 3460, Gaithersburg, MD 20899-3460.

*A Summary of Changes section appears at the end of this standard

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 zero and upscale calibration checks, or control of other opacity 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.

3.2.3.2 Discussion—Minor changes to software or data outputs may not be considered as a model change provided that the manufacturer documents all such changes and provides a satisfactory explanation in a report.

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—Dust compensation may be included as an optional feature but is not required.

3.2.8.2 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. The determination of dust compensation is not required to include all surfaces exposed to the effluent or dust accumulation.

3.2.8.3 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.

3.2.8.4 Discussion—In those cases where dust compensation is used, 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 path-length 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 in accordance with 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.

3.2.23.3 *Discussion*—**Warning**—In cases where the PLCF value is greater than typical values, (for example, greater than two) the effects of measurement errors will be significantly increased.

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 40 CFR 60, 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

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 22°C (40°F) change over specified operational range
Insensitivity to ambient light	±2.0 % opacity max. change for 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 110 % 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	≤3.0 % 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 ±2.0 % due to misalignment as system is misaligned both linearly and rotationally in horizontal and vertical planes
Calibration device repeatability	≤1.5 % opacity

optional procedure for opacity monitors with external zero devices which regulatory agencies may 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, including corrective actions when non-conformance with specifications is detected.

4.5 **Annex A1** details additional or alternative specifications for certifying opacity monitors for use in applications where the opacity standard is less than 10 % opacity, or where the

user expects the opacity to be less than 10 % and elects to use the more restrictive criteria in **Annex A1**. **Annex A2** provides procedures for calibration of primary neutral density attenuators.

4.6 **X1** provides error budgets and estimates of measurement uncertainty for opacity monitors that conform with requirements of the main part of this practice or conform with the requirements in **Annex A1** for low level opacity measurements. **X2** provides guidelines for ensuring adequate performance of opacity monitors. **X3** presents an example data summary form for reporting results of the manufacturer's certification.

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

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)	3.00 m	NA
Insensitivity to supply voltage variations	monthly, or 1 in 20 units (whichever is more frequent)	3.00 m	1.00
Thermal stability	annually ^B	3.00 m (external jig for tests)	1.00
Insensitivity to ambient light	annually ^B	3.00 m	1.00
External zero device repeatability - optional	annually ^B	3.00 m	1.00
Additional design specifications ^C	as applicable		

^AThe 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.

^BAnnually, and whenever there is a change in the design, manufacturing process, or component that might affect performance.

^CThe 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.

installed systems meet certain design and performance specifications. Performance Specification 1 adopts this ASTM practice by reference so that manufacturers can demonstrate conformance with certain design specifications by selecting and testing representative instruments.

5.4 Experience demonstrated that EPA Performance Specification 1 prior to the August 10, 2000 revisions did 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 were previously 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 of the procedures used.

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 applicable requirements of EPA Performance Specification 1 for which the manufacturer can certify conformance. 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 40 CFR 60, 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, or exceed, or both, 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 in accordance with 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 in accordance with 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 NO₂, 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 in accordance with 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 those 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 (see 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 transmission filter that (1) has monotonically decreasing transmission between 500 and 600 nanometres, (2) has transmission greater than 80 % at 500 nm, (3) has its 50 % transmission point between 550 and 575 nm, (4) has less than 20 % transmission at 600 nm and, (5) has less than 5 % transmission at all wavelengths greater than 625 nm. Such filters are widely available. Calibrate and verify the transmittance of the 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 transmission filter into the clear-stack path of the transmissometer by (1) performing a point-wise multiplication of the square of the transmission curve with the normalized transmissometer response curve, (2) summing the products, (3) dividing by the sum of the 10 nm responses to form the double-pass transmission, (4) calculating the single-pass transmission as the square root of the double pass transmission and, (5) 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 3.00 m.

6.3.6 *Test Fixture*— Set up the AOV test fixture that incorporates (1) a movable light source along arcs of radius equivalent to 3.00 m flange-to-flange installation separation distance, 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 radius equivalent to 3.00 m flange-to-flange separation distance 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 equivalent to a 3.00 m flange-to-flange separation distance 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 equivalent to a 3.00 m flange-to-flange separation distance 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 does not 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 $\pm 10\%$.

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 with 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 $\leq 0.5^\circ$ 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 3.00 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 $\pm 0.3^\circ$, 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 $\pm 10\%$ 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 $\pm 1.0\%$ single pass opacity for variations in the supply voltage over $\pm 10\%$ 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 $\pm 0.5\%$. Measure the supply voltage over $\pm 10\%$ 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 flange-to-flange separation pathlength of 3.00 m. Use a pathlength correction factor of 1.00. 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 from nominal voltage to minimum voltage in at least five evenly spaced increments and record the stable measurement response to the attenuator at each voltage. 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. Increase the supply voltage from nominal voltage to maximum voltage in at least five evenly spaced increments and record the stable measurement response to the attenuator at each voltage. 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

$\pm 2.0\%$ single pass opacity for every 22°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 flange-to-flange separation distance of 3.00 m. Use a pathlength correction factor of 1.00. 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, $20 \pm 3^\circ\text{C}$ ($68 \pm 5^\circ\text{F}$). 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°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°C (20°F) per hour until the maximum temperature is reached. Allow the opacity monitor to remain at

the maximum temperature for at least 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 critical component that could affect the opacity monitor sensitivity to ambient light.

6.6.2 *Specification*—The opacity monitor output (including zero and upscale reference calibration check values, and normal measurements of an upscale filter value) must not deviate more than $\pm 2.0\%$ single pass opacity when exposed to an artificial light source described herein as compared to the effect of normal room lighting. This artificial light source is deemed to be sufficiently equivalent to solar radiation to be used for the purpose of demonstrating insensitivity to ambient outdoor light.

6.6.3 *Design Specification Verification Procedure:*

6.6.3.1 Perform this test for a specific opacity monitor that has previously successfully completed the spectral response, thermal stability tests, and other design specification verification procedures.

6.6.3.2 Set-up the opacity monitor with the monitor's light path in a horizontal plane. Use mounting tubes and mounting flanges of normal length and diameter per standard manufacturer's instructions, and attach the flanges to mounting plates that extend at least 0.30 m (12 in.) above, below, and to both sides of the mounting flanges. These plates simulate the inside surfaces of the stack or duct of a typical installation configuration. Paint the interior surfaces of the mounting tubes, 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 flange-to-flange pathlength of 3.00 m. Use a pathlength correction factor of 1.00. Calibrate the instrument using external attenuators appropriate for a 20 % opacity limit 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. These measurements, taken using normal room lighting constitute the reference readings against which subsequent readings will be compared. In all cases, document whether readings are taken with or without zero compensation.

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 $\pm 5\%$ against industry standards, (3) has a sensitivity of at least 75 $\mu\text{A}/100\text{ W}/\text{m}^2$, and (4) has a linearity with a maximum deviation of less than 1 % up to 3000 W/m^2 . Mount the solar radiation monitor on the white surface simulating the inside of the stack on the transceiver side (for double-pass opacity

monitors) or detector side mounting plate (for single-pass opacity monitors) such that the radiation monitor is aligned parallel to the measurement beam of the opacity monitor as close to the optical axis as is practical without obstructing the measurement beam, aligned parallel to the optical axis of the opacity monitor.

6.6.3.4 Using a halogen lamp spotlight with nominal color temperature of 2950 Kelvin, illuminate the transceiver (for double-path models) or the detector (for single-path models) such that the radiation monitor indicates a light intensity of at least 900 watts/m^2 for light that has passed through a Schott K4 filter (or equivalent with transmission within 20 % of the transmission of the Schott filter for all wavelengths between 400 nm and 1100 nm). A suitable spotlight for this purpose is a halogen 1000-watt bulb on a flagpole fixture. The opacity manufacturer may, at its discretion, place the filter over the lamp, such that all the emitted light is filtered (which subjects the opacity monitor to light with a color temperature reasonably equivalent to mid-morning or mid-afternoon solar radiation) or only over the radiation detector (which subjects the opacity monitor to more total radiation, but permits use of a smaller, less expensive filter). The spotlight must be directed from a location in the vertical plane above the measurement beam of the opacity monitor: Within this vertical plane, the opacity manufacturer may direct the spotlight at the front of the transceiver (or detector) at any angle or from any distance, provided that the illuminated area is at least 0.35 m in diameter and is centered on the optical axis of the opacity monitor.

6.6.3.5 Record the opacity monitor response, in the presence of the added radiation to the attenuator. Remove the attenuator and initiate a calibration check cycle, recording the upscale and zero response in the presence of the added radiation. Switch the spotlight off and record the response to the attenuator.

6.6.3.6 Repeat steps 6.6.3.3 through 6.6.3.5 with the solar radiation monitor similarly mounted on the other mounting plate and the spotlight illuminating the retro-reflector (for double-pass monitors) or the source (for single pass instruments).

6.6.3.7 Determine conformance with the specifications 6.6.2 by calculating the change in the reading of the upscale fixture due to the effect of the spotlight, from the normal measurements recorded in 6.6.3.2. Separately record the effect with the spotlight illuminating each of the sides of the opacity monitor set-up. Neither of the sets of tests may result in more than a 2 % change in the reading.

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 $\pm 1.0\%$ 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 flange-to-flange separation distance of 3.00 m. 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 $0.0 \pm 0.5\%$ 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 6.8.2.

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 110 % 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, all active electronic circuitry including the light source and photodetector assembly, and electric or electro-mechanical systems, and hardware, or software, or both, 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, excessive zero or dust compensation, and so forth.

6.10.1 Specify the conditions under which the alarms or fault condition warnings are activated.

6.10.2 Verify the conditions of activations in 6.10.1 on an annual basis.

6.10.3 Certify that the system's visual indications, or audible alarms, as well as electrical outputs can be recorded as part of the opacity data record and automatically indicate when either of the following conditions are detected:

6.10.3.1 A failure of a sub-system or component which can be reasonably expected to invalidate the opacity measurement, or

6.10.3.2 A degradation of a subsystem or component which requires maintenance to preclude resulting failure.

6.11 *Pathlength Correction Factor (PLCF) Security:*

6.11.1 Certify that the opacity monitor has been designed and constructed so that the value of the pathlength correction factor

6.11.1.1 Cannot be changed by the end user without assistance from the manufacturer, or

6.11.1.2 Is available to be recorded during each calibration check cycle, or

6.11.1.3 The opacity monitor provides an alarm when the value is changed from the certified value.

6.11.2 Document the option(s) that are selected and write corresponding instructions. Provide them to the end user to minimize the likelihood that the PLCF will be changed inadvertently.

6.12 *Measurement Output Resolution:*

6.12.1 Certify that the opacity monitor output, including visual measurement displays, analog outputs, or digital outputs, or combinations thereof, have a resolution $\leq 0.5\%$ opacity over the measurement range from -4.0% opacity to 50% opacity or higher value.

NOTE 22—The 0.5% opacity resolution is required for determining calibration error or achieving conformance with applicable regulatory requirements.

6.13 *Measurement and Recording Frequency:*

6.13.1 Certify that each opacity monitor is designed and constructed to do the following:

6.13.1.1 To complete a minimum of one cycle of sampling and analyzing for each successive 10-second period.

6.13.1.2 To calculate average opacity values from six or more data points equally spaced over each 1-minute period included in the average (for example, 6 measurements per 1-minute average or 36 measurements per 6-minute average),

6.13.1.3 To record values for each averaging period.

NOTE 23—Most regulations require recording of 6-minute average opacity values, however, some regulatory agencies require calculation of 1-minute or other less than 6-minute average values.

7. Procedure—Manufacturer's Performance Specifications

7.1 *Required Performance Tests*—Test each instrument prior to shipment to ensure that the opacity monitor meets manufacturer's performance specifications for instrument response time, calibration error, and optical alignment sight performance. Conduct a performance check of the spectral response for each instrument.

NOTE 24—These tests are performed for the specific transmissometer components (transceiver and reflector for double-pass opacity monitors or transmitter and receiver for single-pass opacity monitors), the specific control unit (if included in the installation), and any other measurement system components that are supplied by the manufacturer. The data recording system that will be employed by the end user is not required to be evaluated by these tests. Additional field tests are necessary to evaluate the complete opacity monitoring system after it is installed at the end user's facility. The field test procedures may be simplified when certain conditions are met in the conduct of the manufacturer's performance specification tests.

7.2 *Representative Test Conditions:*

7.2.1 Conduct the manufacturer's performance specification tests under conditions that are representative of the specific intended installation, whenever possible. Obtain from the end user accurate information about the installation pathlength (that is, flange-to-flange separation distance), monitoring pathlength, emission outlet pathlength, and the applicable opacity standard. Use the applicable opacity standard, monitoring pathlength, and emission outlet pathlength to select appropriate attenuators for the calibration error test and to establish the pathlength correction factor for the opacity monitor being tested. Set-up and test the transmissometer components at the same installation pathlength and the same pathlength correction factor as that of the field installation.

NOTE 25—When these conditions are met, the equivalent *clear path* setting for an external zero device can be established in conjunction with the manufacturer's calibration error test. This device can then be used in subsequent field calibration error tests to verify performance of the opacity monitor. If both the actual installation pathlength and the pathlength correction factors are within $\pm 10\%$ of the values used for the manufacturer's calibration error test, the manufacturer's calibration error test results are valid and representative for the installation.

7.2.2 If actual pathlength values differ by $>2\%$, but $\leq 10\%$ relative to that used for the manufacturer's calibration error test, repeat the zero alignment (for installation pathlength errors) or reset the pathlength correction factor (for pathlength correction errors) prior to subsequent opacity monitoring.

NOTE 26—A field performance audit may be substituted for the field calibration error test when the above criteria are satisfied.

7.2.3 If the actual installation pathlength, or pathlength correction factors, or both, exceed $\pm 10\%$ of the values used for the manufacturer's calibration error test, repeat the calibration error test.

7.3 *Default Test Conditions*—If the installation pathlength, monitoring pathlength, and emission outlet pathlength cannot be determined by the manufacturer (for example, opacity monitor is intended for future resale, opacity monitor will serve as backup for multiple installations, construction of facility is not complete and so forth), test the opacity monitor at a flange-to-flange installation pathlength of 3.00 m and use a pathlength correction factor of 1.00. If the applicable opacity standard cannot be determined, assume a standard of 20% opacity for the selection of attenuators used for the calibration error test.

7.4 *Test Set-Up*—Conduct the performance tests of the opacity monitor in a clean environment in an area protected from manufacturing or other activities that create dust, mist, fumes, smoke, or any other ambient condition that will interfere with establishing a clear path opacity condition.

7.4.1 Set-up the transmissometer components on test stands that will facilitate adjustments to, and maintenance of, the optical alignment throughout the test procedure.

7.4.2 Use the appropriate installation pathlength as determined from 7.2, if possible, or 7.3, if necessary.

7.4.3 Adjust the focus of the transmissometer for the installation pathlength, if applicable.

7.4.4 Optically align the transmissometer components in accordance with the written procedures of the manufacturer.

7.4.5 Verify that the alignment sight indicates proper alignment.

7.4.6 Enter the proper pathlength correction factor (if applicable) for the opacity monitor.

7.4.7 Establish proper calibration of the measurement system in accordance with the manufacturer's written procedures.

7.4.8 Connect the opacity monitor to an appropriate data recorder for documenting the performance test results. At a minimum, use a data recorder that

7.4.8.1 Is capable of resolving 0.25 % opacity,

7.4.8.2 Has been accurately calibrated and verified in accordance with the manufacturer's QA procedures, and

7.4.8.3 Has a sufficiently fast response to measure the instrument response time.

7.5 *Selection of Calibration Attenuators*—Using the applicable pathlength correction factor and opacity standard values from 7.2 (if possible) or 7.3 (if necessary), select calibration attenuators that will provide an opacity monitor response corrected to single-pass opacity values for the emission outlet pathlength in accordance with the following:

Applicable Standard	10 to 19 % opacity	≥20 % opacity
Low level:	5 to 10 % opacity	10 to 20 % opacity
Mid level:	10 to 20 % opacity	20 to 30 % opacity
High level:	20 to 40 % opacity	30 to 60 % opacity

NOTE 27—The manufacturer may elect to use additional calibration attenuators in the calibration error test. The use of additional calibration attenuators may be advantageous in demonstrating the linear range of the measurement system. Alternate calibration attenuator values may be used where required by applicable regulatory requirements (for example, state or local regulations, permit requirements, and so forth).

7.6 *Attenuator Calibrations*—Calibrate the attenuators using the procedures in Annex A2. After initial calibration, recalibrate the attenuators every six months, or more frequently.

7.7 Instrument Response Time:

NOTE 28—The purpose of the instrument response time test is to demonstrate that the instantaneous output of the opacity monitor is capable of tracking rapid changes in effluent opacity, when the instantaneous output is used to generate averages. It includes the transmissometer components and the control unit if one is included for the particular installation. The instrument response time test does not include the opacity monitoring system permanent data recorder. (A separate field test should be conducted to verify the ability of the system to properly average or integrate and record 6-min opacity values.)

7.7.1 *Specification*—The instrument response time must be less than or equal to 10 s.

7.7.2 *Instrument Response Time Test Procedure*—The test shall be performed with all opacity monitor internal settings, adjustments or software values, or both which affect the opacity monitor time constant, response time, or data averaging set at the same positions or values as to be used for effluent monitoring. The internal settings, or software values, or both, used for the response time test shall be recorded and reported with the response time test results. Using a high-level calibration attenuator, alternately insert the filter five times and remove it from the transmissometer light path.

7.7.2.1 For each filter insertion and removal, determine the amount of time required for the opacity monitor to display 95 % of the step change in opacity on the data recorder used for

the test. For upscale response time, determine the time it takes to reach 95 % of the final, steady upscale reading. For downscale response time, determine the time it takes for the display reading to fall to 5 % of the initial upscale opacity reading.

7.7.2.2 Calculate the mean of the five upscale response time measurements and the mean of the five downscale response time measurements. Report each of the upscale and downscale response time determinations and the mean upscale and downscale response times.

7.7.3 Determine conformance with the specification in 7.7.1. If the response time is not acceptable, take corrective action and repeat the test.

7.8 Calibration Error:

NOTE 29—The calibration error test is performed to demonstrate that the opacity monitor is properly calibrated and can provide accurate and precise measurements.

7.8.1 *Specification*—The calibration error must be ≤3.0 % opacity as calculated as the sum of the absolute value of the mean difference and confidence coefficient for each of three test attenuators.

7.8.2 Calibration Error Test Procedure:

7.8.2.1 Zero the instrument. Insert the calibration attenuators (low-, mid- and high-level) into the light path between the transceiver and reflector (or transmitter and receiver).

7.8.2.2 While inserting the attenuator, ensure that the entire beam received by the detector passes through the attenuator and insert the attenuator in a manner that minimizes interference from the reflected light.

NOTE 30—See also Note 15. The placement and removal of the attenuator must be such that measurement of opacity is performed over a sufficient period to obtain a stable response from the opacity monitor.

7.8.2.3 Make a total of five non-consecutive readings for each filter. Record the opacity monitoring system output readings in single-pass percent opacity.

7.8.2.4 Subtract the single-pass calibration attenuator values corrected to the stack exit conditions from the opacity monitor responses. Calculate the arithmetic mean difference, standard deviation, and confidence coefficient of the five measurements value. Calculate the calibration error as the sum of the absolute value of the mean difference and the 95 % confidence coefficient for each of the three test attenuators. Report the calibration error test results for each of the three attenuators.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i \quad (4)$$

where:

$\bar{x}$ = arithmetic mean,
 x_i = individual measurements, and
 n = number of data points.

$$S_d = \sqrt{\frac{\sum_{i=1}^n x_i^2 - \frac{\left(\sum_{i=1}^n x_i\right)^2}{n}}{n-1}} \quad (5)$$

where:

S_d = standard deviation.

$$CC = t_{0.975} \frac{S_d}{\sqrt{n}} \quad (6)$$

where:

$t_{0.975}$ = t-value ($t_{0.975} = 2.776$ for $n = 5$), and

CC = confidence coefficient

7.8.2.5 Determine conformance with the specification in 7.8.1. If the calibration error test results are not acceptable, take corrective action, recalibrate the opacity monitor in accordance with the manufacturer's written instructions, and repeat the calibration error test.

7.9 Optical Alignment Indicator – (Uniformity of Light Beam and Detector):

NOTE 31—Each transmissometer must provide a means for visually determining that the instrument is optically aligned. The purpose of this specification is to ensure that the alignment device is capable of clearly indicating when the transmissometer components are misaligned. The performance test procedure will also detect opacity monitors where the accuracy of opacity measurements is adversely affected by the use of the light beams having non-uniform intensity, or the use of non-uniform detectors, or inefficient or poor quality retro-reflector material.

7.9.1 *Specification*—The alignment sight must clearly indicate that the unit is misaligned when an error of $\pm 2.0\%$ single-pass opacity occurs due to shifts in the optical alignment of the transmissometer components. For opacity monitor designs that include automatic beam steering (that is beam position sensing and an active means for adjusting alignment so that centered alignment is maintained even with slowly changing misalignment conditions), an alarm must be activated when the alignment is varied beyond the manufacturer's specified range of angular tolerance is unable to maintain alignment.

NOTE 32—Modifications of the alignment indicator test procedures for systems with beam steering are included in 7.9.8.

7.9.2 *Alignment Indicator Performance Test Procedure*—Conduct the alignment indicator test in accordance with the procedures in 7.9.3-7.9.7.

NOTE 33—The test procedure can be modified to accommodate moving of either component of the transmissometer to achieve equivalent geometric misalignment as described in 7.9.3-7.9.6. Alignments tests may be performed in the horizontal or vertical planes of the instrument and the instrument components may be turned on their side to accommodate the tests.

7.9.3 Set-up:

7.9.3.1 Set up the transmissometer on test stands that allow adjustments for the rotational and translational misalignment tests.

7.9.3.2 Optically align the transceiver and reflector (double-pass opacity monitor) or transmitter and receiver (single-pass opacity monitor) in accordance with the manufacturer's written instructions. Verify that all alignment indicator devices show proper alignment.

7.9.3.3 Conduct the alignment indicator performance test with a clear path condition. Alternatively, insert an external attenuator that produces a response $\leq 10\%$ single-pass opacity into the measurement path turn it approximately 3° from normal to the light path to eliminate surface reflection, and record the indicated opacity.

7.9.4 Case 1, Single and Double Pass Opacity Monitors:

7.9.4.1 Slowly tilt the transceiver (double-pass opacity monitor) or transmitter (single-pass opacity monitor) upward in the vertical plane (for example, adjust the appropriate alignment bolts or mounting mechanism) relative to the reflector (double-pass opacity monitor) or receiver (single-pass opacity monitor) until an error of $\pm 2.0\%$ opacity is first indicated on the data recorder. Verify that the alignment indicator shows misalignment.

7.9.4.2 Illustrate and record the alignment indicator and the degree of misalignment shown.

7.9.4.3 Return the system to its aligned condition.

7.9.4.4 Repeat the entire procedure by tilting the transceiver in the opposite (downward) direction.

7.9.4.5 Repeat the rotational misalignment check of the transceiver or transmitter in the horizontal plane (both to the left and right) and again illustrate and record the visual depiction of the alignment for each step of the procedure.

7.9.5 Case 2, Single-Pass Opacity Monitors Only

7.9.5.1 Slowly tilt the receiver in the vertical plane (for example, adjust the appropriate alignment bolts or mounting mechanism) until an error of $\pm 2.0\%$ opacity is first indicated on the data recorder. Verify that the alignment indicator shows misalignment.

7.9.5.2 Illustrate and record the alignment indicator and the degree of misalignment shown.

7.9.5.3 Return the system to its aligned condition and again draw the alignment indicator.

7.9.5.4 Repeat the entire procedure by tilting the receiver in the opposite direction.

7.9.5.5 Repeat the rotational misalignment check of the receiver in the horizontal plane (both to the left and right) and again illustrate and record the visual depiction of the alignment for each step of the procedure.

7.9.6 Case 3, Single and Double Pass Opacity Monitors:

7.9.6.1 Achieve lateral misalignment of the transceiver or transmitter relative to the reflector or receiver by slowly moving either assembly linearly to the left until a positive or negative error of $\pm 2.0\%$ opacity is first indicated on the data recorder. Verify that the alignment indicator shows lateral misalignment of the transceiver or transmitter relative to reflector or receiver.

7.9.6.2 Illustrate and record the alignment indicator and the degree of misalignment shown.

7.9.6.3 Return the system to its aligned condition and again draw the alignment indicator.

7.9.6.4 Repeat the entire procedure by moving the same component to the right.

7.9.6.5 Repeat the test in the vertical plane (both above and below the aligned position) and again illustrate and record the visual depiction of the alignment for each step of the procedure.

7.9.7 *Assessment*—Determine conformance with the specification in 7.9.1.

NOTE 34—The performance of the alignment indicator is acceptable if: (1) for each case of rotational or translational misalignment, misalignment is clearly shown when an error of $\pm 2.0\%$ single-pass opacity first occurs in each direction, and (2) proper alignment status is consistently indicated when the opacity monitor is optically aligned. A clear indication of

misalignment is one that is objectively apparent relative to reference marks or conditions; an alignment device that requires a subjective judgement of the degree of misalignment is not acceptable.

7.9.8 *Automatic Beam Steering:*

7.9.8.1 If the design includes automatic beam steering, investigate each case of rotational and translational misalignment. Vary the alignment over the manufacturer's specified range of angular tolerance for which the alignment is maintained and for which the opacity is maintained within ± 2.0 % single pass opacity.

7.9.8.2 During each misalignment test, record the angular misalignment where the alarm is activated.

7.9.8.3 Determine conformance with the specification in 7.9.1.

NOTE 35—Acceptable performance is indicated if (1) the alarm is activated or misalignment is clearly shown at, or before, the angular tolerance specified by the manufacturer is reached, and (2) for translational misalignment, an alarm is activated or misalignment is clearly shown at, or before, an error of ± 2.0 % single-pass opacity first occurs in each direction.

7.10 *Spectral Response Performance Check:*

NOTE 36—This performance check provides a simple method to ensure that the spectral response of each instrument satisfies the spectral response design specifications of 6.2. The performance check uses a transmission filter placed in the measurement beam and comparison with a range of expected responses determined from Monitor-Specific Performance Check Limits (6.2.7).

7.10.1 *Specification*—The transmissometer response to the transmission filter used to establish performance check limits, after correction of the response to account for the applicable pathlength correction factor, must be within ± 2.0 % opacity of the range defined by the maximum and minimum responses (determined in 6.2.7 in units of percent opacity).

7.10.2 *Spectral Response Performance Check Procedure:*

7.10.2.1 Insert the transmission filter used to establish the performance check limits into the opacity monitor measurement beam after the calibration error test has been completed. Record the opacity monitor response to the transmission filter in units of percent opacity.

7.10.2.2 Correct the opacity monitor response to the equivalent value corresponding to a pathlength correction factor of 1.00.

7.10.2.3 Compare the corrected response to the acceptable limits and determine conformance with the specification in 7.10.1.

7.10.2.4 If an unacceptable result is obtained, do not assume that the spectral response design requirements are met. Investigate the causes for an unacceptable result. Unless a clear explanation of the problem is apparent, repeat Spectral Response Design Specifications Verification Procedure (6.2.3) and recalibrate the transmission filter.

7.11 *Calibration Device Value and Repeatability:*

NOTE 37—The purpose of this specification is to verify that the upscale calibration device response is repeatable and provides results consistent with the use of external filters. This specification may also be applied to additional internal calibration check devices (values), if provided in the instrument.

7.11.1 *Specification*—The 95 % confidence coefficient for repeated measurements of the upscale calibration device must

be less than 1.5 % opacity. The upscale calibration device must be assigned a value relative to the calibration error test results for the specific opacity monitor.

7.11.2 *Calibration Device Repeatability Test Procedure*—Perform this procedure immediately after successfully completing the calibration error test for the opacity monitor. Do not make any adjustments to the opacity monitor until after this procedure has been completed. Make five non-consecutive measurements of each internal device and record the opacity monitor responses.

7.11.2.1 Calculate the 95 % confidence coefficient using the same procedures as that used in the calibration error test. (See 7.8.2.4).

7.11.2.2 Determine conformance to the specification in 7.11.1.

7.11.2.3 Assign the average value(s) to the upscale calibration device(s).

8. **Quality Assurance Guidelines for Opacity monitor Manufacturers**

8.1 *General*—The products shall be manufactured under a quality program that ensures that like products, subsequently made, have the same reliability and quality as those originally examined to determine compliance with this design specification. To establish and maintain such a program, the manufacturer shall be guided by industry practice, its quality controls, and by this set of guidelines. These guidelines are supported by various standards and by industry practice.

8.1.1 *Applicable Documents*—This document is an adaptation of and the referred to the following standards for additional guidance:

ISO/DIS 9004 Quality Management and Quality System Elements-Guidelines

ANSI/NCSL Z 540-1-1994, Calibration Laboratories and Measuring Equipment - General Requirements

8.1.2 *General Vocabulary*—Terms used in this document are defined by:

ISO 842, Quality Vocabulary

8.2 *Quality System:*

8.2.1 *Management Responsibility:*

8.2.1.1 *Quality Policy*—The management of a company shall develop and promulgate a corporate quality policy. Management shall ensure that the corporate policy is understood, implemented and maintained.

8.2.1.2 *Quality Objectives*—Based on this policy, key quality objectives shall be defined, such as fitness for use, performance, reliability, safety, and so forth.

8.2.1.3 *Quality Management Systems*—A documented system shall be developed, established and implemented for the product as a means by which stated quality policies and objectives can be realized. The quality system should ensure that: (1) it is understood and effective; (2) products actually do satisfy customer expectations; (3) emphasis is placed on problem prevention rather than dependence on detection after occurrence; (4) causes, not only symptoms, of a problem are found, and that corrections are comprehensive, touching any activity that has a bearing on quality; and (5) feedback is generated that can be used at the product or process design

stage for correcting problems and improving product. Management shall provide the resources essential to the implementation of quality policies and objectives.

8.2.2 Quality System Documentation and Records—The elements requirements and provisions adopted for the quality management system shall be documented in a systematic and orderly manner.

8.2.2.1 Documentation shall be legible, clean, readily, identifiable and maintained in an orderly manner.

8.2.2.2 The quality management system shall establish and require the means for identification, collection, filing, storage, maintenance, retrieval and disposition of pertinent quality documentation and records. Methods shall be established for making changes, modifications, revisions or additions to the contents of applicable documentation in a controlled manner.

8.3 Corrective Action Program:

8.3.1 Introduction— There shall be a comprehensive defect analysis/corrective action program for reporting and following-up on product and program deficiencies.

8.3.2 Assignment of Responsibility:

8.3.2.1 The responsibility and authority for instituting corrective action shall be defined as part of the quality system.

8.3.2.2 The coordination, recording and monitoring of corrective action shall be assigned to a specific person or group within the organization. (The analysis and execution of any corrective action may involve a variety of people from such areas as sales, design, production engineering, production, or quality control, or both.)

8.3.3 Deficiencies:

8.3.3.1 Deficiencies shall be evaluated in terms of their potential impact on product quality, reliability, safety, performance and customer satisfaction.

8.3.3.2 The relationship between cause and effect should be determined. The root cause should be determined before planning and implementing corrective measures. Careful

analysis shall be given to the product and all related processes, operations, records, and so forth.

8.3.3.3 Controls of processes and procedures shall be implemented to prevent recurrence of the problem. When the corrective measures are implemented, their effect shall be monitored in order to ensure desired goals are met.

8.3.3.4 Permanent changes resulting from corrective action shall be incorporated into the work instructions, manufacturing processes, product specifications and/or the quality manual.

8.4 Quality System Certification—Companies with ISO 9001/9002 certification, companies meeting the requirements of ANSI/ASQC Q90 (Q91 or Q92), companies meeting the requirements of nationally recognized test laboratories where the manufactured product bears the mark (or marks) of the recognized test laboratory, or companies with an equivalent independently and periodically verified quality system, and which adopt this specification as part of their product definition shall be deemed to meet all of the above quality assurance guidelines. Companies meeting these conditions shall attach the applicable certification to the manufacturer's certification of conformance report as proof of such designation.

9. Report

9.1 Summarize the design and performance (see **Table 1**, **Table 2** and **Table 3**) data in the report. See **X3**, **Fig. X3.1** for an example.

9.2 Include all descriptive information, such as:

- 9.2.1** Manufacturer or supplier information,
- 9.2.2** Opacity monitor information,
- 9.2.3** User information, and
- 9.2.4** Installation information.

10. Keywords

10.1 continuous opacity monitor; design specification; performance specification; transmissometer

ANNEXES

(Mandatory Information)

A1. ADDITIONAL OR ALTERNATIVE SPECIFICATIONS FOR CERTIFYING OPACITY MONITORS FOR USE BELOW 10 % OPACITY (LOW LEVEL OPACITY MONITORS)

A1.1 General

A1.1.1 This annex is applicable to opacity monitors intended for use where the applicable opacity standard is less than 10 % opacity, or where the user expects the opacity to be less than 10 % and elects to use the more restrictive criteria in this annex (also known as "Low Level Opacity Monitors.").

A1.1.2 This annex must be read in association with the main text of the standard. All of the requirements stated in the main text are applicable to Low Level Opacity Monitors except where explicitly stated or amended in this annex.

A1.1.3 Because many of the error sources addresses by this annex approach the limiting factors of noise and resolution,

conformance to these design specifications can be assessed by means of averaged data up to 1-minute averages.

A1.2 Procedure—Design Specification Verification

A1.2.1 Insensitivity to Supply Voltage Variations:

A1.2.1.1 Specification: The opacity monitor output (measurement and calibration check responses, both with and without compensation, if applicable) must not deviate more than ± 0.2 % single pass opacity for variations in the supply voltage over ± 10 % from nominal or the range specified by the manufacturer, whichever is greater.

A1.2.1.2 Design Specification Verification Procedure: 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 flange-to-flange separation pathlength of 3.00 m. Use a pathlength correction factor of 1.00. Calibrate the instrument using external attenuators at the nominal operating voltage. Insert an external attenuator with a nominal value between 2 and 10 % single-pass opacity into the measurement path and record the response. Initiate a calibration check cycle and record the low level and upscale responses.

A1.2.2 *Thermal Stability:*

A1.2.2.1 *Specification:* The opacity monitor output (measurement and calibration check responses, both with and without compensation, if applicable) must not deviate more than ± 0.3 % single pass opacity for every 22°C (40°F) change in ambient temperature over the range specified by the manufacturer.

A1.2.2.2 *Design Specification Verification Procedure:*

NOTE A1.1—If the climate chamber is not large enough to accommodate the complete measuring system, then the test procedure shall be performed twice, once with the transceiver or transmitter in the climate chamber and once with the reflector or receiver in the chamber; after the tests, the results achieved by the two parts of the instrument at each temperature shall be added before evaluation. To minimize the effect of its temperature coefficient, the attenuator should be placed outside the climate chamber, if possible. 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. Establish proper calibration of the instrument using external attenuators at a moderate temperature that is, $20 \pm 3^\circ\text{C}$ ($68 \pm 5^\circ\text{F}$). Insert an external attenuator with a single-pass value between 2 and 10 % opacity into the measurement path and record the response. Initiate a calibration check cycle and record the low level and upscale responses.

A1.2.3 *Insensitivity to Ambient Light:*

A1.2.3.1 *Specification:* The opacity monitor output (including zero and upscale reference calibration check values, and normal measurements of an upscale filter value) must not deviate more than ± 0.2 % single pass opacity when exposed to an artificial light source described herein as compared to the effect of normal room lighting. This artificial light source is deemed to be sufficiently equivalent to solar radiation to be used for the purpose of demonstrating insensitivity to ambient outdoor light.

A1.2.3.2 *Design Specification Verification Procedure:* Set-up the opacity monitor with the monitor's light path in a horizontal plane. Use mounting tubes and mounting flanges of normal length and diameter per standard manufacturer's instructions, and attach the flanges to mounting plates that extend at least 0.30 m (12 in.) above, below, and to both sides of the mounting flanges. These plates simulate the inside surfaces of the stack or duct of a typical installation configuration. Paint the interior surfaces of the mounting tubes, 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 flange-to-flange pathlength of 3.00 m. Use a pathlength correction factor of 1.00. Calibrate the instrument using external attenuators appropriate for a <10 % opacity limit prior to the test. Insert an external attenuator with

a single-pass value between 2 and 10 % opacity into the measurement path and record the response. Initiate a calibration check cycle and record the low level and upscale responses. These measurements, taken using normal room lighting constitute the reference readings against which subsequent readings will be compared. In all cases, document whether readings are taken with or without zero compensation.

A1.2.4 *External Zero Device*

A1.2.4.1 An external, removable device must be provided which can be used to check the zero alignment of the transmissometer.

NOTE A1.2—The External Zero Device is used for on-stack checks, over a wide range of ambient temperatures, and therefore is a key element in verifying the accuracy of the installed unit. Further, it is not tested by the daily span and zero checks.

A1.2.4.2 *Specification:* The opacity monitor output must not deviate more than ± 0.3 % single pass opacity for repeated installations of the external zero device on a transmissometer.

A1.2.4.3 *Temperature Range:* The minimum and maximum operating temperatures for the external zero device must be stated in the operating instructions. The opacity monitor output with the External Zero Device fitted must not deviate by more than ± 0.4 % single pass opacity over the specified temperature range.

NOTE A1.3—The minimum and maximum specified operating temperatures for the external zero device should cover as wide a range as possible.

A1.2.4.4 *Temperature Test Procedure:* Place the opacity monitor in a climate chamber and set it up as described in 6.5.3.2. Ensure that the opacity monitor is capable of indicating opacity values less than zero. Attach the external zero device to the opacity monitor and adjust it so that the opacity monitor reads zero. Reduce the chamber temperature to the minimum specified temperature and leave it at that temperature for one hour. Record the indicated opacity. Increase the temperature of the climate chamber to the maximum specified temperature and leave it at that temperature for one hour. Record the indicated opacity. Verify that the opacity indications at the minimum and maximum operating temperature limits are 0 ± 0.4 %.

A1.2.5 *Calibration Check Devices:*

A1.2.5.1 The optical surface(s) of the simulated zero device must be protected from contamination at all times when not in use.

A1.2.5.2 The upscale calibration device checks the pathlength corrected measurement system response where the energy reaching the detector is between the energy levels corresponding to 2 % opacity and the highest level filter used to determine calibration error.

A1.2.6 *Measurement Output Resolution:*

A1.2.6.1 Certify that the opacity monitor output, including visual measurement displays, analog outputs, or digital outputs, or combinations thereof, have a resolution ≤ 0.1 % opacity over the measurement range from -4.0 % opacity to 50 % opacity or higher value.

NOTE A1.4—The 0.1 % opacity resolution is required for determining calibration error or achieving conformance with applicable regulatory requirements.

A1.3 Procedure—Manufacturer's Performance Specifications

A1.3.1 For each of the tests shown in **Table A1.1**, the manufacturer must demonstrate that the monitor will pass the specification verification tests with a PLCF of 1.00. (**Warning**—In applications where the PLCF is greater than 1.00 the effect on measurement errors will be increased.)

A1.3.2 *Test Set-Up*: It is critical that the performance tests be performed in a dust free environment. The level of dust, smoke, mist, fume or any other particulate matter concentration that will affect the test results can not be detected by the human observer. Therefore, conduct the performance tests in a clean room environment or take necessary precautions to ensure that all air within the transmissometer measurement light path has been filtered with a HEPA filter or equivalent device.

A1.3.2.1 Connect the opacity monitor to an appropriate data recorder for documenting the performance test results. At a minimum, use a data recorder that is capable of resolving 0.05 % opacity.

A1.3.3 *Selection of Calibration Attenuators*: Using the applicable pathlength correction factor and opacity standard values from 7.2 (if possible) or 7.3 (if necessary), select calibration attenuators that will provide an opacity monitor

response corrected to single-pass opacity values for the emission outlet pathlength in accordance with the following:

Low level:	2 to 5 % opacity
Mid level:	5 to 10 % opacity
High level:	10 to 20 % opacity

A1.3.4 *Attenuator Calibrations*: Calibrate the attenuators using the procedures in **Annex A2**. After initial calibration, recalibrate the attenuators every six months, or more frequently.

A1.3.5 Calibration Error:

A1.3.5.1 *Specification*: The calibration error must be ≤ 1.0 % opacity as calculated as the sum of the absolute value of the mean difference and confidence coefficient for each of three test attenuators.

A1.3.6 *Optical Alignment Indicator (Uniformity of Light Beam and Detector)*:

A1.3.6.1 *Specification*: The alignment sight must clearly indicate that the unit is misaligned when an error of ± 0.5 % single-pass opacity occurs due to shifts in the optical alignment of the transmissometer components. The misalignment at which this occurs must be greater than or equal to 0.25° for angular misalignment and $\tan(0.25^\circ)$ times the installation

TABLE A1.1 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	$\leq 4^\circ$ for all radiation above 2.5 % of peak
Insensitivity to supply voltage variations	± 0.2 % opacity max. change over specified range of supply voltage variation, or ± 10 % variation from the nominal supply voltage
Thermal stability	± 0.3 % opacity change per 20°C (40°F) change over specified operational range
Insensitivity to ambient light	± 0.2 % opacity max. for solar radiation level of ≥ 900 W/m ²
External audit filter access	required
External zero device repeatability	± 0.3 % opacity
Thermal stability of External zero device	± 0.4 % opacity
Automated calibration checks	check of all active analyzer internal optics with power or curvature, all active electronic circuitry including the light source and photo detector 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 110 % 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 2 % 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	0.1 % opacity over measurement range from -5 % to 50 % opacity, or higher value
Measurement and recording frequency	sampling and analyzing at least every 10 seconds: calculate averages from at least 6 measurements per minute
Instrument response time	≤ 10 s to 95 % of final value
Calibration error	≤ 1.0 % 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 ± 0.5 % due to misalignment as system is misaligned both linearly and rotationally in horizontal and vertical planes
Optical misalignment, transmitter and receiver (single-pass) or transceiver and retro (double-pass)	≤ 0.5 % opacity change for $\pm 0.25^\circ$ rotational misalignment or equivalent lateral misalignment
Calibration device repeatability	≤ 0.5 % opacity

pathlength for lateral misalignment. For opacity monitor designs that include automatic beam steering (that is, beam position sensing and an active means for adjusting alignment so that centered alignment is maintained even with slowly changing misalignment conditions), an alarm must be activated when the alignment is varied beyond the manufacturer's specified range of angular tolerance over which the monitor is able to maintain alignment. This range must be at least $\pm 0.25^\circ$.

A1.3.7 Transceiver or Transmitter Misalignment:

A1.3.7.1 Slowly tilt the transceiver (double-pass opacity monitor) or transmitter (single-pass opacity monitor) upward in the vertical plane (for example, adjust the appropriate alignment bolts or mounting mechanism) relative to the reflector (double-pass opacity monitor) or receiver (single-pass opacity monitor) until an error of $\pm 0.5\%$ opacity is first indicated on the data recorder. Verify that the alignment indicator shows misalignment and that the misalignment is greater than 0.25° .

A1.3.8 Reflector or Receiver Misalignment:

A1.3.8.1 Slowly tilt the reflector (double-pass opacity monitor) or receiver (single-pass opacity monitor) in the vertical plane (for example, adjust the appropriate alignment bolts or mounting mechanism) until an error of $\pm 0.5\%$ opacity is first indicated on the data recorder. Verify that the alignment indicator shows misalignment and that the misalignment is greater than 0.25° .

NOTE A1.5—Some transmissometer designs require an alignment jig or a modification to the reflector position in order to check the misalignment. This is acceptable provided the reflector or receiver has been designed so that it can be precisely returned to its previous condition after the jig or modification has been removed.

A1.3.9 Lateral Misalignment:

A1.3.9.1 Achieve lateral misalignment of the transceiver or transmitter relative to the reflector or receiver by slowly moving either assembly linearly to the left until a positive or negative error of $\pm 0.5\%$ opacity is first indicated on the data recorder. Verify that the alignment indicator shows lateral misalignment of the transceiver or transmitter relative to reflector or receiver and that the misalignment is greater than $\tan(0.25^\circ)$ times the installation pathlength.

A1.3.10 Assessment: Determine conformance with the specification in **A1.3.6.1**.

NOTE A1.6—The performance of the alignment indicator is acceptable if: (1) for each case of rotational or translational misalignment, misalignment is clearly shown when an error of $\pm 0.5\%$ single-pass opacity first occurs in each direction, and (2) proper alignment status is consistently indicated when the opacity monitor is optically aligned. A clear indication of misalignment is one that is objectively apparent relative to reference marks or conditions; an alignment device that requires a subjective judgment of the degree of misalignment is not acceptable.

A1.3.11 Automatic Beam Steering:

A1.3.11.1 If the design includes automatic beam steering, investigate each case of rotational and translational misalignment. Vary the alignment over the manufacturer's specified range of angular tolerance for which the alignment is maintained and for which the opacity is maintained within $\pm 0.5\%$ single pass opacity.

A1.3.12 Calibration Device Value and Repeatability—

A1.3.12.1 Specification: The 95 % confidence coefficient for repeated measurements of the upscale calibration device must be less than 0.3 % opacity. The upscale calibration device must be assigned a value relative to the calibration error test results for the specific opacity monitor.

(Mandatory Information)

A2. GUIDELINES FOR CALIBRATING ATTENUATORS

A2.1 General

A2.1.1 Calibration attenuators are optical filters with neutral spectral characteristics. Calibration attenuators must be of sufficient size to attenuate the entire light beam received by the detector of the opacity monitor.

A2.1.2 This annex covers the calibration or recalibration of primary and secondary attenuators used to establish the correct calibration of opacity monitors.

A2.2 Calibration Spectrophotometer

A2.2.1 The attenuators must be calibrated using a spectrophotometer, which covers the wavelength range 300 nm to 800 nm and with a spectral resolution better than 10 nm. The detector angle of view must be less than 10° .

A2.2.2 Verify the spectrophotometer calibration through use of a NIST Standard Reference Material (SRM) 2031 which consists of three individual neutral density glass filters in separate metal holders and a blank (empty filter holder) stored

in a black anodized aluminum container. The SRM must have nominal transmittance values of 10 %, 30 % and 90 %. The wavelengths and temperature to be used in the calibration are listed on the NIST certificate that accompanies the reported values.

A2.2.3 Determine and record the transmittances of the SRM at the NIST wavelengths for all three filters at five wavelengths each for a total of 15 determinations. Calculate the difference between the NIST certified values and the spectrophotometer responses. All of the 15 differences must be within $\pm 0.25\%$ transmittance of the NIST SRM values.

A2.2.4 If the calibration results fail the test criteria then the spectrophotometer should be serviced, or the SRM recalibrated, or both.

A2.3 Primary Attenuator Calibration

A2.3.1 Insert the attenuators into the spectrophotometer which has been calibrated in accordance with **A2.2** at the same

angle as they will be used in the opacity monitor. This angle must appear on the calibration certificate.

NOTE A2.1—Normal incidence should be avoided to prevent errors caused by specular reflection in a double-pass transmissometer.

A2.3.2 Record the spectrophotometer transmittance readings at 10 nm intervals from 380 nm to 780 nm. Test in this sequence: blank filter, tested filter, tested filter rotated 90 degrees in the plane of the filter, blank filter. Calculate the average transmittance at each 10 nm interval. If any pair of the tested filter transmittance values (for the same filter and wavelength) differ by more than ± 0.25 percent, transmittance, rescan the tested filter.

A2.3.3 Recalibrate primary attenuators at least once in each 6-month period if used for the required calibration error tests of opacity monitors. Recalibrate primary attenuators at least once in each 12-month period if they are only used for calibration of secondary attenuators.

A2.4 Calculation of Equivalent Transmittance Values

NOTE A2.2—The equivalent transmittance values may be calculated by the calibration laboratory, but this is not essential.

A2.4.1 If the filter is to be used in an opacity monitor whose spectral response has a full width at half maximum (FWHM) of 20 nm or less, use the transmittance value closest to the peak response of the opacity monitor.

NOTE A2.3—This is appropriate for an opacity monitor employing a laser light source.

A2.4.2 If the filter is to be used in an opacity monitor whose spectral response has a full width at half maximum (FWHM) greater than 20 nm but less than 100 nm, calculate the weighted filter transmittance by multiplying each transmittance value by the corresponding normalized response factor for the opacity monitor. The normalized response factor at each wavelength is calculated by dividing the spectral response at that wavelength by the sum of all of the spectral response values.

NOTE A2.4—This is appropriate for most opacity monitors employing a spectrally narrow LED light source.

A2.4.3 If the filter is to be used in an opacity monitor whose spectral response has a full width at half maximum (FWHM) of 100 nm or more, calculate the weighted filter transmittance by multiplying each transmittance value by the corresponding response factor shown in Table 4, to obtain the Source C Human Eye Response.

NOTE A2.5—This is appropriate for an opacity monitor employing an incandescent lamp or white LED

A2.4.4 The filter calibration certificate, or manufacturer's determination, or both, must state which weighting has been applied to the measured filter transmittance. Both the raw and the weighted values shall be given.

A2.4.5 If the weighting calculation is not performed by the calibration laboratory then the original calibration certificate

must be supplied along with the opacity monitor manufacturer's weighting calculations.

A2.5 Manufacturers' Data

A2.5.1 Opacity monitor manufacturers must document and publish the necessary spectral response information for their transmissometer model(s) so that this information can be used by all parties involved in the calibration of attenuators, certification of monitors, and performance of audits of installed systems.

A2.5.2 Opacity monitor manufacturers must document and publish the appropriate angle of insertion of attenuators for their transmissometer model(s) so that this information can be used by all parties involved in the calibration of attenuators, certification of monitors, and performance of audits of installed systems.

NOTE A2.6—For this purpose, publication on a public-accessible web page is adequate. These public-accessible records would not need to document customer-specific changes that might occur due to factors such as use of replacement parts subsequent to certification.

A2.6 Secondary Attenuator Calibration

A2.6.1 Secondary attenuators may be used for conducting the required calibration error tests for opacity monitors if the transmittance values for these attenuators are established using a laboratory-based transmissometer that is calibrated in accordance with **A2.6.2**.

NOTE A2.7—Calibration error test results of an opacity monitor may be adversely affected if the laboratory-based transmissometer which is used for calibration of secondary attenuators has a different spectral response or other performance characteristics differing from the opacity monitor that is tested using the secondary attenuators.

A2.6.2 Use at least three primary attenuators with transmittance values of 10, 30, and 90 percent as determined in accordance with **A2.4** to calibrate the laboratory-based transmissometer. Determine and record the slope of the of the calibration line using linear regression through zero opacity. The slope of the calibration line must be between 0.99 and 1.01, and the laboratory-based transmissometer reading for each primary filter can not deviate by more than 2 % of the measured value from the linear regression calibration line. If the calibration of the laboratory-based transmissometer does not meet these criteria, calibration of the secondary attenuators can not be performed.

A2.6.3 Immediately following the laboratory-based transmissometer calibration, insert each of the secondary attenuators in the light path. Determine and record the single-pass percent transmittance of each secondary attenuator from the response of the laboratory-based transmissometer and the linear regression calibration line.

A2.6.4 Recalibrate secondary attenuators at least once in each 6-month period.

APPENDIXES

(Nonmandatory Information)

X1. ERROR BUDGET FOR OPACITY MONITOR

X1.1 Discussion—This practice specifies permissible limits for specific categories of measurement uncertainty that are evaluated during the manufacturer's certification of conformance with the design and performance specifications. Other factors that are beyond the control of the manufacturer such as scintillation and refractive effects, as well as installation-specific factors such as stability of optical alignment and quality assurance procedures, will also affect the uncertainty of opacity measurements from installed opacity monitoring systems. Representative estimates of the measurement uncertainties that are beyond the control of the manufacturer can be developed. The suitability of an opacity monitor for a specific measurement task can be determined through consideration of its specified uncertainty for the parameters included in the manufacturer's certification together with estimates of the uncertainty due to other factors.

X1.2 The overall uncertainty of a measurement made by an opacity monitor at the time it is demonstrated to meet all of the requirements of this practice can be calculated by taking the square root of the sum of the squared values of the individual uncertainties. The results of this calculation are shown in **Table X1.1**. The results in **Table X1.1** do not include drift that occurs after initial calibration and installation on the particular facility.

X1.3 Where an uncertainty is not explicitly specified in this practice, a representative value has been used in **Table X1.1**. Such values are shown with an asterisk.

X1.4 Measurements have shown that the transmittance of coated neutral density filters commonly used as calibration attenuators changes by no more than 0.2 % opacity over a temperature range of 5°C (41°F) to 40°C (104°F). However, the opacity monitor manufacturer should recommend the range of ambient temperatures over which the neutral density filters meet the specification.

X1.4.1 It is not within the scope of this practice to provide a method for verifying conformance with the specification for long-term stability of the external zero device, maintenance of optical alignment after installation, or prescription of drift limits or other factors that will affect the accuracy and precision of data provided by an installed continuous opacity monitoring system.

X1.5 Certain unavoidable optical and aerodynamic effects have been tested and have demonstrated that it is impossible to establish a perfect correlation between a clear-path setup in a laboratory environment and a zero-dust situation when the same monitor is installed on a stack with hot flowing gas. Scintillation and lensing effects can create biases that cannot be tested by the calibration check mechanism or the cal jig. Reports based on older opacity monitor designs suggest biases, primarily negative, as large as 2 % opacity. These effects can be minimized, but not eliminated, by appropriate design of the transmissometer. Laboratory tests and some computer modeling indicate that these effects can be limited to 1.0 % opacity

TABLE X1.1 Opacity Monitor Measurement Uncertainty

Parameter	D6216 Tolerance	Annex A1 Tolerance for PLCF = 1.00	Reference or Note
Sensitivity to Supply Voltage Variations	1.0 %	0.2 %	6.4.2, A1.2.1.1
Thermal Stability	2.0 %	0.3 %	6.5.2, A1.2.2.1
Sensitivity to Ambient Light	2.0 %	0.2 %	6.6.2, A1.2.3.1
Indication of Optical Misalignment in the Transmitter or Transceiver	2.0 %	0.5 %	7.9.4, A1.3.7
Effect of Misalignment in the Receiver or Retro	2.0 %	0.5 %	7.9.5, A1.3.8
Calibration Error Test	3.0 %	1.0 %	7.8.1, A1.3.5
Accuracy of Window Dirt Compensation	2.0 % ^A	0.2 %	A1.2.5.1
Repeatability of the External Zero Device	1.0 %	0.3 %	6.8.2, A1.2.4.2
Thermal Drift of the External Zero Device	1.0 % ^A	0.4 %	A1.2.4.3
Long-term Stability of External Zero Device	0.5 % ^A	0.5 % ^A	X1.4.1, X2.4
Temperature and Spectral Characteristics of the Audit Filters	0.2 % ^A	0.2 % ^A	X1.4
Scintillation and Refractive Effects Causing Systematic Bias (0.25–1.5 % opacity)	1.0 % ^A	1.0 % ^A	X1.6
Maximum PLCF for which this practice applies	2.0	NA	3.2.23.3, A1.3.1
Probable Measurement Uncertainty			
Root-sum-square Error Total	5.8 %	1.8 % ^B	

^ANot explicitly limited by the standards. Therefore, a representative value based on the technical judgment of the technical committee has been used.

^BThe estimates for uncertainty for monitors meeting **Annex A1** are for PLCF values ≤1.00. For applications where the PLCF is greater than 1.00 the effect on measurement errors will be increased. If the PLCF is greater than 1.00, the uncertainty in the measured opacity values can be estimated using the following equation:

$$U_2 = \{1 - 10^{PLCF [\log_{10} (1 - U_1/100)]}\} \times 100$$

where:

U_1 = the uncertainty at the measurement path length in % opacity, and

U_2 = the uncertainty in values corrected to the stack exit diameter.

or less. However, the practical implication for installed units is not well demonstrated.

X1.6 The user of opacity monitors, particularly in those applications with very low opacity levels, along with the reviewer of the data, should realize that a negative opacity reading should not be interpreted to mean that the monitor is

not functioning as specified by this practice. Properly operating and well maintained opacity monitors can exhibit negative opacity measurements when the actual effluent opacity is “zero” or at low levels due to the biases described above and the allowed measurement uncertainties contained in the main part of this practice and in **Annex A1**.

(Nonmandatory Information)

X2. GUIDELINES FOR ENSURING ADEQUATE PERFORMANCE OF OPACITY MONITORS

X2.1 *Discussion:* The ongoing quality assurance of opacity monitors is outside the scope of this practice because of the many factors that are beyond the control of the manufacturer but are encountered during field installation and operation. However, the quality of data produced by any opacity monitor, and especially by the low-level monitors covered by **Annex A1**, depends critically on careful attention to ongoing matters of quality assurance.

X2.1.1 All opacity monitors require ongoing maintenance, and any valid quality assurance program must adequately address the procedures and frequency of such maintenance.

X2.1.2 Any opacity monitor may suffer from a breakdown as a result of age, component failure, or inadequate routine maintenance. Where such a breakdown occurs, procedures are required to ensure that the monitor is operating correctly before it is returned to service.

X2.2 Recommendations for Ongoing Maintenance of Opacity Monitors

X2.2.1 Routine maintenance should occur at predetermined intervals. The service interval should be as recommended by the opacity monitor manufacturer, or more frequently if the monitor location is subject to high levels of dust, vibration or other adverse conditions.

X2.2.2 Routine maintenance should address the following issues:

X2.2.2.1 Visual inspection of the transmissometer for obvious defects or corrosion,

X2.2.2.2 Alignment stability,

X2.2.2.3 Cleanliness of all optical surfaces,

X2.2.2.4 Stability of External Zero Device,

X2.2.2.5 Operation of fail-safe shutters, if fitted, and

X2.2.2.6 Maintenance of ancillary equipment such as purge air blowers and air filters.

X2.3 Recommendations for Corrective Action Following a Breakdown

X2.3.1 Where an opacity monitor suffers a component failure for any reason, the component should be replaced with an equivalent, but not necessarily identical design.

X2.3.2 The amount of recalibration and re-testing required following a breakdown will depend on the nature of the breakdown, the number and type of components replaced.

X2.3.3 Consideration should be given to the following when deciding the amount of re-testing required:

X2.3.3.1 Do any electronic components have individual characteristics which affect the operation or calibration of the opacity monitor?

X2.3.3.2 Were any optical components are replaced?

X2.3.3.3 Were any components replaced or adjusted which could affect the linearity of the opacity monitor?

X2.3.3.4 Could the repair have contaminated or displaced any key components?

X2.3.4 It is not within the scope of this practice to provide a mechanism to test for failure of the EZD to meet the long-term stability requirement; nor does this practice recommend a corrective action for the same.

X2.4 Additional Recommendations

X2.4.1 Clear path calibrations and zero alignment procedures should not be performed for opacity monitors while installed at the measurement location in the stack or duct because there are no effective procedures to ensure that the actual opacity is zero for an installed monitor. Removal of the opacity monitor from its installation and performance of clear path calibrations and zero alignment procedures in a dust free environment is necessary to achieve proper calibration of the measurement system.

X2.4.2 The calibration error specification in 40 CFR 60, Appendix A, Performance Specification 1 (3 % opacity) is inappropriate for opacity monitors demonstrated to meet the requirements of **Annex A1** for low level opacity measurements. Difficulty may be encountered in attempting to demonstrate conformance with the 1.0% calibration error specification in **Annex A1** during field tests or audits due to the effects of ambient dust, ambient temperature, vibration or other environmental conditions.

X2.4.3 Contemporary opacity monitors meeting the requirements in the main part of this practice or the more restrictive requirements in **Annex A1** that are properly installed should surpass the zero and upscale drift test requirements in 40 CFR 60, Appendix A, Performance Specification 1 (2 % opacity). A properly designed and installed opacity monitor meeting this practice should operate for at least 168 hours without necessity for operator intervention for calibration drift adjustments or cleaning of optical windows, etc., and should not exhibit zero or upscale drift exceeding 1.0 % opacity at any time during the 168 hour test period.

X3. DATA SUMMARY FORM

X3.1 Fig. X3.1 is an example data form to summarize data to certify conformance with design and performance specifications. This example may be used as a starting point for the development of an appropriate monitor-specific report. This example may not include all of the relevant or necessary information for particular opacity monitors. Those organizations involved with the manufacturer's certification of conformance with the requirements of this practice are encouraged to

examine carefully all of the requirements as they apply to the specific models tested and expand or modify this example to include all information necessary to support certification of the subject opacity monitors. The example data form must be modified to be consistent with the requirements and specifications in Annex A1 if used to report results for an opacity monitor that will be used in an application with an opacity standard less than 10 % opacity.

This document is provided by (company name), an (original manufacturer, supplier, re-manufacturer, or service facility), of/for opacity monitoring systems that are intended to comply with standards of performance established by the US EPA 40CFR60, Appendix B, Performance Specification 1, Performance Specifications for Opacity Monitors. This EPA specification references the above ASTM Standard Practice, which may be used by the manufacturer or supplier to demonstrate that the designated opacity monitor meets those performance requirements that can be tested and verified by the supplier prior to field installation. Data in this summary document (Part I) have been generated in compliance with the procedures and specifications shown in the ASTM Standard Practice, D 6216. These data confirm that the designated opacity monitor meets or exceeds the requirements of this Standard Practice.

I. MANUFACTURER/SUPPLIER INFORMATION

Company name _____
Location _____

II. OPACITY MONITOR INFORMATION

Model _____
Transceiver type _____
Transceiver serial no. _____
Reflector type _____
Reflector serial no. _____
Control unit serial no. _____
Software version(s) no. _____

III. USER INFORMATION

Company _____
Plant _____
Process/boiler _____
Location _____

IV. INSTALLATION INFORMATION

Monitoring pathlength (depth of effluent) _____
Installation pathlength (flange to flange) _____
Emission outlet pathlength (stack exit) _____
PLCF or (OPLR) _____
Facility opacity standard, % opacity _____
Opacity full scale, % opacity _____

FIG. X3.1 Data Summary Form

PART I—DESIGN AND PERFORMANCE SPECIFICATIONS-TESTED AT MANUFACTURER'S FACILITY

Conformance with design specifications is demonstrated by testing two separate opacity monitors, each of which is representative of standard production. One opacity monitor is selected and tested annually and the other is selected from either a production lot of instruments not to exceed 20 in size, or from monthly production, and tested in accordance with procedures described in the D 6216. The tests associated with each of the above selected analyzers is required to be repeated anytime there is a critical component change that is substantial, hardware or software change, or manufacturing process change that could affect performance with respect to said design specifications. The test data derived from each of the above two described analyzers is summarized below.

1. Design Specifications Verified Through Tests Prescribed For An Annually, or More Often, Selected Opacity Monitor

The opacity monitor that tested to demonstrate the following design parameters was selected on the basis of an annual selection _____, or following a major change in the design or construction of the monitor _____.

OPACITY MONITOR INFORMATION

Model _____
 Transceiver type _____
 Transceiver serial no. _____
 Reflector type _____
 Reflector serial no. _____
 Control unit serial no. _____
 Software version no. _____

TESTS PERFORMED BY:

_____ DATE: _____

TEST DATA REVIEWED AND CERTIFIED BY:

_____ DATE: _____

1.1 *Spectral Response*

Data listed below were obtained by calculation _____, or by actual measurement using a monochrometer _____. A description of either the calculations or the measurement test setup are included in Attachment A.

Parameter	Specification	Actual Test Result
Peak response	Between 500-600 nm	
Mean response	Between 500-600 nm	
Max response beyond 700 nm	Less than 10% of peak	
Max response less than 400 nm	Less than 10% of peak	

FIG. X3.1 Data Summary Form (continued)

1.2 Thermal Stability

Parameter	Specification	Actual Test Result
Tested range, min temp	Mfgr specified, °C (°F)	
Tested range, max temp	Mfgr specified, °C (°F)	
Nominal measurement value	10-20% opacity	
Measurement drift, max deviation from nominal measurement value	≤ 2% opacity/22 °C (40°F)	
Zero drift from nominal without compensation	≤ 2% opacity/22°C (40°F)	
Zero drift from nominal with compensation	≤ 2% opacity/22°C (40°F)	
Upscale drift from nominal without compensation	≤ 2% opacity/22°C (40°F)	
Upscale drift from nominal with compensation	≤ 2% opacity/22°C (40°F)	

1.3 Insensitivity to Ambient Light

Parameter	Specification	Actual Test Result
Max solar intensity	900 W/m ²	
Nominal measurement value	10-20% opacity	
Measurement drift, max deviation from nominal measurement value	≤ 2% opacity	
Drift was corrected for thermal effects, yes or no	Mfgr specified	
Zero drift from nominal without compensation	≤ 2% opacity	
Zero drift from nominal with compensation	≤ 2% opacity	
Upscale drift from nominal without compensation	≤ 2% opacity	
Upscale drift from nominal with compensation	≤ 2% opacity	

1.4 Calibration Device Availability

Parameter	Specification	Availability/Value
External zero device	Optional	
Ext zero device repeatability	≤ 1% opacity	
External filter access	To be available	

FIG. X3.1 Data Summary Form (continued)

1.5 Zero/upscale calibration check apparatus

Parameter	Specification	Test Result
Indicated response to simulated zero calibration device	$0 \pm 0.5\%$ opacity	
Simulated Zero Check	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 *	
Response to upscale calibration device without electronic hardware or software modification	+10% opacity to highest calibration error attenuator value	
Do automatic zero and upscale calibration check devices check all active optics and electronics?	Required	
Is automatic correction provided for zero drift?	Mfgr to specify (Y/N)	
	If yes, specify frequency	
Is automatic correction provided for dust accumulation on exposed optics?	Mfgr to specify (Y/N)	
	If yes, specify frequency	
Is automatic correction provided for upscale calibration drift?	Mfgr to specify (Y/N)	
	If yes, specify frequency	

Note: * Negative opacity values of this magnitude can be calculated from the detector or preamplifier output by measuring the equivalent optical energy detected in the clear path condition and that produced by the zero calibration check device.

1.6 PLCF (OPLR) Security Precautions

Condition	Specification	As Supplied (Y/N)
Original certified value is fixed and not adjustable by user without assistance from manufacturer	One or more of listed conditions to be provided	
Value is output with zero and upscale drift values during each calibration cycle	One or more of listed conditions to be provided	
Alarm (Flag)is activated when changed from original certified or permanently recorded value	One or more of listed conditions to be provided	

FIG. X3.1 Data Summary Form (continued)

1.7 Faults and Alarm (Mfgr to specify)

Fault Conditions (Note 1&3)	Specified Indication	Actual Indication
Conditions tested	Audible or visual, and electrical	Tested output
	Same	
	Same	
	Same	
Alarm Conditions (Note 2&3)	Specified Indication	Actual Indication
Conditions tested	Audible or visual, and electrical	Tested output
	Same	
	Same	
	Same	
	Same	
	Same	

Note 1) Fault conditions are those conditions which, when they occur, are deemed by the manufacturer to result in performance which is not in compliance with this performance specification.

Note 2) Alarm conditions are those conditions for which the manufacturer recommends review and/or corrective action by trained service personnel as appropriate to prevent further deterioration of instrument performance which could result in performance not in compliance with this specification.

Note 3) Manufacturer may use other nomenclature to designate either general or specific alarms and/or faults, as long as they are appropriately defined in the operators manual.

FIG. X3.1 Data Summary Form *(continued)*

1.8 Miscellaneous

Parameter	Specification	Test Result
Resolution of visual measurement indication, if provided	$\leq 0.5\%$ opacity	
Resolution of analog output measurement indication	$\leq 0.5\%$ opacity	
Resolution of serial digital output, if provided	$\leq 0.5\%$ opacity	
Bipolar range of visual measurement indication	+50% opacity or more to -4% opacity or less	
Capability of analog output measurement indication to indicate negative values to at least -4% opacity	Required	
Are means available to monitor daily zero and upscale calibration drift before correction?	Optional	
Is upscale calibration drift corrected for zero drift in above method?	Optional	
Are means available to monitor dust accumulation on exposed optical surfaces?	Optional	
What surfaces are monitored for dust accumulation?	Mfgr to specify, if applicable	
Is an alarm provided for excessive dust accumulation?	Mfgr to specify, if automatic correction is provided	
What level of dust accumulation triggers the above alarm?	Mfgr to specify, if applicable	
Is dust level measured separately from the accumulative zero drift?	Mfgr to specify	
Are all dust (if provided), zero, and upscale calibration values corrected to stack exit conditions?	Required	
What is the normal update interval for opacity measurements?	10 sec max	
Do longer term opacity averages include at least 6 approximately equally distributed individual measurement values per minute?	Required	

FIG. X3.1 Data Summary Form (continued)

2. Design Specifications Verified Through Tests Prescribed for an Opacity Monitor Selected on a Monthly Basis, or From Each Production Lot

The opacity monitor that was selected and tested to demonstrate the following design parameters was selected on the basis of a monthly selection ____, a manufacturing lot not to exceed 20 in size ____, or following a major change in the design or construction of the monitor ____.

OPACITY MONITOR INFORMATION

Model _____
 Transceiver type _____
 Transceiver serial no. _____
 Reflector type _____
 Reflector serial no. _____
 Control unit serial no. _____
 Software version no. _____

TESTS PERFORMED BY:

 DATE: _____

TEST DATA REVIEWED AND CERTIFIED BY:

 DATE: _____

2.1 Angle of View

Transmissometer is exempt from angle of view specification because the angle of projection has been demonstrated to be less than ____ degrees.

Portion of opacity monitor included in the test: _____

Portion of opacity monitor excluded in the test: _____

Light source used in the test: directional ____, or non-directional ____

Were detector/measurement electronics modified to measure response to designated light source: (Y/N) _____. If so, describe modifications in attachment B.

Parameter	Specification	Actual Test Result
Angle of view, horizontal	$\leq 4^\circ$ for all radiation providing a response of $\geq 2.5\%$ of peak response	
Angle of view, vertical	$\leq 4^\circ$ for all radiation providing a response of $\geq 2.5\%$ of peak response	

FIG. X3.1 Data Summary Form (continued)

2.2 Angle of Projection

Transmissometer is exempt from angle of projection specification because the angle of projection has been demonstrated to be less than _____ degrees.

Option 1 Procedure

Portion of opacity monitor included in the test: _____

Portion of opacity monitor excluded in the test: _____

Photodetector used in test: _____

_____ If tests were conducted with dc coupled measurement circuit, was ambient light level less than 0.5% of peak light intensity? (Y/N) _____

_____ If tests were conducted with ac coupled measurement circuit, was it demonstrated that ambient light levels did not saturate the detector? (Y/N) _____; and was it demonstrated that turning on/off ambient lights did not affect measurements? (Y/N) _____.

Parameter	Specification	Actual Test Result
Angle of projection, horizontal	$\leq 4^\circ$ for all radiation providing a response of $\geq 2.5\%$ of peak response	
Angle of projection, vertical	$\leq 4^\circ$ for all radiation providing a response of $\geq 2.5\%$ of peak response	

Option 2 Procedure (For transmissometer designs that have previously met the AOP specification using Option 1 procedure during the preceding 12 months)

Distance from transceiver/transmitter to target _____

Beam dimension (diameter) in the vertical direction _____

Beam dimension (diameter) in the horizontal direction _____

Option 2 Result: (total subtended angle): _____ degrees.

Option 1 Result (angle of projection): _____ degrees

Difference (Option 1 result minus Option 2 result) _____ degrees. If the results do not agree within 0.3 degrees, repeat the test using Option 1.

FIG. X3.1 Data Summary Form (continued)

2.3 Insensitivity to supply voltage variations

Manufacturers specified nominal voltage: _____

Manufacturers specified operating voltage range, if specified: _____

Parameter	Specification	Actual Test Value
Min test voltage	-10% from nom, or mfgs min specified operating voltage, whichever is lesser	
Max test voltage	+10% from nom, or mfgs max specified operating voltage, whichever is greater	
Nominal measurement value	10-20% opacity	
Measurement drift, max deviation from nominal measurement value from nominal to max ac voltage	$\pm 1\%$ opacity	
Measurement drift, max deviation from nominal measurement value from nominal to min ac voltage	$\pm 1\%$ opacity	
Zero drift from nominal to min ac voltage without compensation	$\pm 1\%$ opacity	
Zero drift from nominal to min ac voltage with compensation	$\pm 1\%$ opacity	
Upscale calibration drift from nominal to min ac voltage without compensation	$\pm 1\%$ opacity	
Upscale calibration drift from nominal to min ac voltage with compensation	$\pm 1\%$ opacity	
Zero drift from nominal to max ac voltage without compensation	$\pm 1\%$ opacity	
Zero drift from nominal to max ac voltage with compensation	$\pm 1\%$ opacity	
Upscale calibration drift from nominal to max ac voltage without compensation	$\pm 1\%$ opacity	
Upscale calibration drift from nominal to max ac voltage with compensation	$\pm 1\%$ opacity	

FIG. X3.1 Data Summary Form (continued)

3. Performance Specifications Verified by Tests Prescribed for Each Specific Opacity Monitor.

The following tests were performed individually on the specific instrument described in the beginning of this test report. Further, the following signatures attest to the fact that the design and performance specifications tested on previous opacity monitors, as described in Sections 1 and 2, are representative of the design and performance of this specific monitor.

TESTS PERFORMED BY: _____

DATE: _____

TEST DATA REVIEWED AND CERTIFIED BY: _____

DATE: _____

3.1 Calibration error

Filter	Specify Group, Group I or II	Actual Filter Value	Specified Cal Error	Actual Cal Error
Low	Group		3%	
Mid	Group		3%	
High	Group		3%	

Note: Group I filters are 5-10, 10-20, 20-40 percent opacity (low, mid, high)

Group II filters are 10-20, 20-30, 30-60 percent opacity (low, mid, high)

3.2 Response Time Test

Test Number	Upscale Response (sec)	Downscale Response (sec)
1		
2		
3		
4		
5		
Mean		

3.3 Misalignment indication

This opacity monitor uses (a) manual alignment and visual alignment sighting device (Y/N) ____, or b) automatic beam steering (Y/N) ____.

FIG. X3.1 Data Summary Form (continued)

3.3.1 For manually aligned opacity monitors with visual alignment sighting indicator:

A. Rotational misalignment

Parameter	Specification	Test Result
Nominal measurement value	0-10% opacity	
Indication of centered alignment	Acceptable? (Y/N)	
Clear indication of misalignment for rotational misalignment for transceiver/transmitter in upward vertical direction which causes 2% opacity change	Acceptable? (Y/N)	
Clear indication of misalignment for rotational misalignment for transceiver/transmitter in downward vertical direction which causes 2% opacity change	Acceptable? (Y/N)	
Clear indication of misalignment for rotational misalignment for transceiver/transmitter in horizontal right direction which causes 2% opacity change	Acceptable? (Y/N)	
Clear indication of misalignment for rotational misalignment for transceiver/transmitter in horizontal left direction which causes 2% opacity change	Acceptable? (Y/N)	

B. Lateral misalignment, same test conditions

Parameter	Specification	Test Result
Clear indication of misalignment for lateral movement to the left which causes 2% opacity change	Acceptable? (Y/N)	
Clear indication of misalignment for lateral movement to the right which causes 2% opacity change	Acceptable? (Y/N)	
Clear indication of misalignment for lateral movement in upward direction which causes 2% opacity change	Acceptable? (Y/N)	
Clear indication of misalignment for lateral movement in downward direction which causes 2% opacity change	Acceptable? (Y/N)	

FIG. X3.1 Data Summary Form (continued)

3.3.2 For opacity monitors with automatic beam steering,

Parameter	Specification	Test Result
Nominal measurement value	0-10% opacity	
Indication of centered alignment	Acceptable? (Y/N)	
Degree of rotational misalignment for transceiver/transmitter in upward vertical direction which triggers alarm	Mfgr to specify	
Degree of rotational misalignment for transceiver/transmitter in downward vertical direction which triggers alarm	Mfgr to specify	
Degree of rotational misalignment for transceiver/transmitter in horizontal right direction which triggers alarm	Mfgr to specify	
Degree of rotational misalignment for transceiver/transmitter in horizontal left direction which triggers alarm	Mfgr to specify	
Lateral movement of transceiver/transmitter in upward vertical direction which causes an indication of misalignment	Mfgr to specify movement	
What is maximum deviation of opacity from nom when opacity monitor is misaligned as above from centered to value noted?	$\leq 2\%$ opacity	
Lateral movement of transceiver/transmitter in downward vertical direction which causes an indication of misalignment	Mfgr to specify movement	
What is maximum deviation of opacity from nom when opacity monitor is misaligned as above from centered to value noted?	$\leq 2\%$ opacity	
Lateral movement of transceiver/transmitter in horizontal right direction which causes an indication of misalignment	Mfgr to specify movement	
What is maximum deviation of opacity from nom when opacity monitor is misaligned as above from centered to value noted?	$\leq 2\%$ opacity	
Lateral movement of transceiver/transmitter in horizontal left direction which causes an indication of misalignment	Mfgr to specify movement	
What is maximum deviation of opacity from nom when opacity monitor is misaligned as above from centered to value noted?	$\leq 2\%$ opacity	

FIG. X3.1 Data Summary Form (continued)

3.4 Spectral Response Repeatability

Date of spectral response transmission filter calibration _____

Monotonically decreasing transmission filter between 500 and 600 nm calibration date: _____

Wavelength (nm)	Specification (Transmittance)	Actual (Transmittance)
500	> 80%	
510		
520		
530		
540		
550	50% transmission point (550-575 nm)	
560	50% transmission point (550-575 nm)	
570	50% transmission point (550-575 nm)	
580		
590		
600	< 20%	
625	< 5% above 625	

Calculated nominal response of analyzer to transmission filter _____, % opacity

Calculated allowable variation of the response to transmission filter:

OP, high _____, OP, low _____

Above opacity values converted to stack exit values according to the specific PLCF (OPLR) established for this installation: PLCF (OPLR) _____

OPc, nom _____, OPc, high _____, OPc, low _____

Actual measured response of the instrument to transmission filter _____ % opacity

Is measured response within previously calculated range (Y/N) _____

3.5 Upscale Calibration Device Repeatability

Mean value of five measurements: _____

95% Confidence Coefficient: _____ (%opacity) Specification is <1.5% opacity

36 Intrinsic opacity monitor settings/adjustments

List all configurable parameters to obtain the performance described in this report. These parameters typically include calibration check intervals, calibration check correction, procedure settings relating to flange-to-flange separation distance, range, averaging time, alarms, etc.

FIG. X3.1 Data Summary Form (continued)

4. Quality Assurance Program

4.1 ISO, ANSI/ASQC, or other Quality System Certification

Is the company which prepared this report certified according to ISO quality standards, ANSI/ASQC (QC 90 or 91) or other applicable quality standard (Y/N) _____. If so, to what classification _____ and on what date _____. Attach certificate of such designation as attachment C.

4.2 QA Guideline Compliance

Has the company which prepared this document established and maintained a QA/QC program that is in compliance with the guidelines specified in the ASTM D6216, (Y/N) _____. If so, please attach a description of the quality program in attachment C, and indicate the person responsible for the integrity of this quality program

Suppliers who comply with 4.1 and not 4.2 are required to supply all supporting test data with this report.

FIG. X3.1 Data Summary Form (continued)

SUMMARY OF CHANGES

Committee D22 has identified the location of selected changes to this standard since the last issue (D6216 - 07) that may impact the use of this standard. (October 1, 2012)

(1) Corrected **Annex A1, Table A1.1** requirement for the simulated zero check device to be consistent with the previously approved change to the main standard at **6.9.1.1** and **Table 1**.

(2) Changed NIST Standard Reference Material designation from “2031a” to “2031” in **Annex A2** “Guidelines for Calibrating Attenuators.”

Committee D22 has identified the location of selected changes to this standard since the last issue (D6216 - 03) that may impact the use of this standard. (October 1, 2007)

(1) The main text of this practice has had minor typographical and cross-reference errors corrected, but the substance remains unchanged.

(2) **Annex A1** has been added to permit extension of this practice to cover opacity monitors intended for use where the applicable opacity limit is less than 10 %.

(3) **Annex A2** has been added to give guidance on the calibration of standard attenuators.

(4) **X1** has been added, showing the error budget for an opacity monitor whose performance is in accordance with this practice.

(5) **X2** has been added, giving outline recommendations on the ongoing maintenance of opacity monitors covered by this practice.

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