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GUIDELINES FOR DEVELOPMENT OF A QUALITY ASSURANCE PROGRAM: VOLUME IX - VISUAL DETERMINATION OF OPACITY EMISSIONS FROM STATIONARY SOURCES

by

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ABSTRACT

Guidelines for the quality control of the visual determination of the opacity of emissions from stationary sources are presented.

These include:

1. Good operating practices.

2. Directions on how to assess performance and to qualify data.

3. Directions on how to identify trouble and to improve data quality.

4. Directions to permit design of auditing activities.

The document is not a research report. It is designed for use by operating personnel.

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1.0 INTRODUCTION

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This document presents guidelines for implementing a quality assurance program for the visual determination of the opacity of emissions from stationary sources.

The objectives of this quality assurance program are to:

1. Provide routine indications for unsatisfactory performance of personnel and/or equipment,
2. Provide for prompt detection and correction of conditions that contribute to the collection of poor quality data,
3. Collect and supply information necessary to describe the quality of the data.

To accomplish the above objectives, a quality assurance program must contain the following components:

1. Routine monitoring of training and qualification procedures,
2. Routine monitoring of the variables and/or parameters which may have a significant effect on data quality,
3. Development of statements and evidence to qualify data and detect defects,
4. Action strategies to increase the level of precision in the reported data and/or to detect training equipment defects or degradation and to correct same.

Implementation of a quality assurance program will result in data that are more uniform in terms of precision and accuracy. It will enable each observation team or individual to continuously generate data that approach the highest level of accuracy attainable with the visual method.

This document is divided into three sections, as follows:

1. 1.0 INTRODUCTION--This lists the overall objectives of a quality assurance program and delineates the program components necessary to accomplish the given objectives.
2. 2.0 VISUAL DETERMINATION OF THE OPACITY OF EMISSIONS FROM STATIONARY SOURCES--This section includes the method description, plan activity matrix, operational procedures, and auditing procedures. Subsection numbering is consistent with section 5.8 of a larger document, The Quality Assurance Handbook for Air Pollution Measurements, Volume III, Stationary Sources Specific Methods.
3. 3.0 FUNCTIONAL ANALYSIS--This section includes an estimate of the precisions and biases of the various measurements which collectively comprise Method 9, and an estimate of the total precision and bias of the method.

2.0 VISUAL DETERMINATION OF THE OPACITY OF EMISSIONS FROM STATIONARY SOURCES*

*In this section, subsection numbering is consistent with section 5.8 of a larger document, The Quality Assurance Handbook for Air Pollution Measurements, Vol. III--Stationary Sources Specific Methods.

5.8 VISUAL DETERMINATIONS OF THE OPACITY OF EMISSIONS FROM STATIONARY SOURCES

This section describes a quality control program designed specifically to check the validity of opacity data generated from routine visual determinations. To present the quality control program more systematically, the section has been divided into the following subsections:

The formal reference method for Visual Determination of the Opacity of Emissions from Stationary Sources is included in section 5.8.1 for convenient reference. Also included in that section is figure 5.8.1, which delineates the procedures for Method 9 in a block diagram. Basically, the method can be broken down into a series of operational categories defined as:

1. Observer training,
2. Observer testing and certification,
3. Field observations,
4. Data analysis.

Within each category both routine and nonroutine procedures are described. The routine procedures form the basic criteria needed for a school to adequately train, test, and certify the observer, and for an observer to generate data. The nonroutine procedures provide characteristic checks for each of the routine procedures to insure that valid data will be ultimately collected and to properly assess the quality of that data.

The Plan Activity Matrix in section 5.8.2 includes the characteristic checks for each of the operating procedures;

the procedures themselves are outlined in section 5.8.3. The audit procedures described in section 5.8.4 provide a basis for assessing the performance in each operational category.

5.8.1 Reference Method

METHOD 9--VISUAL DETERMINATION OF THE OPACITY OF EMISSIONS FROM STATIONARY SOURCES

Reproduced from Appendix A, "Reference Methods,"
Federal Register, Vol 39, No. 219; Tuesday, November 12, 1974

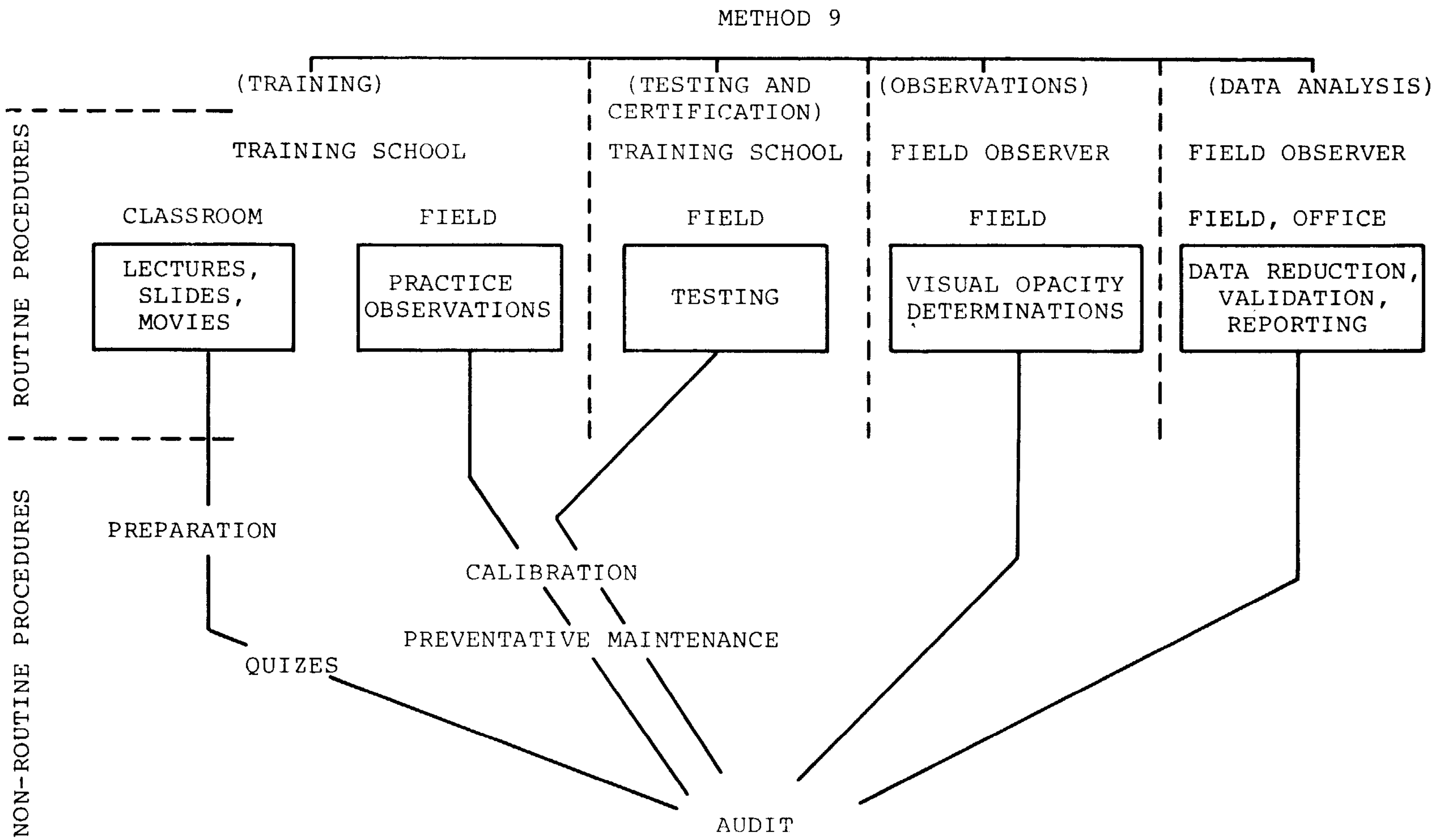

Figure 5.8.1. Method procedures relationship.

5.8.1.1 Variables Accuracy-

Many stationary sources discharge visible emissions into the atmosphere; these emissions are usually in the shape of a plume. This method involves the determination of plume opacity by qualified observers. The method includes procedures for the training and certification of observers, and procedures to be used in the field for determination of plume opacity. The appearance of a plume as viewed by an observer depends upon a number of variables, some of which may be controllable and some of which may not be controllable in the field. Variables which can be controlled to an extent to which they no longer exert a significant influence upon plume appearance include: Angle of the observer with respect to the plume; angle of the observer with respect to the sun; point of observation of attached and detached steam plume; and angle of the observer with respect to a plume emitted from a rectangular stack with a large length to width ratio. The method includes specific criteria applicable to these variables.

Other variables which may not be controllable in the field are luminescence and color contrast between the plume and the background against which the plume is viewed. These variables exert an influence upon the appearance of a plume as viewed by an observer, and can affect the ability of the observer to accurately assign opacity values to the observed plume. Studies of the theory of plume opacity and field studies have demonstrated that a plume is most visible and presents the greatest apparent opacity when viewed against a contrasting background. It follows from this, and is confirmed by field trials, that the opacity of a plume, viewed under conditions where a contrasting background is present can be assigned with the greatest degree of accuracy. However, the potential for a positive error is also the greatest when a plume is viewed under such contrasting conditions. Under conditions presenting a less contrasting background, the apparent opacity of a plume is less and approaches zero as the color and luminescence contrast decrease toward zero. As a result, significant negative bias and negative errors can be made when a plume is viewed under less contrasting conditions. A negative bias decreases rather than increases the possibility that a plant operator will be cited for a violation of opacity standards due to observer error.

Studies have been undertaken to determine the magnitude of positive errors which can be made by qualified observers while reading plumes under contrasting conditions and using the procedures set forth in this method. The results of these studies (field trials) which involve a total of 769 sets of 25 readings each are as follows:

(1) For black plumes (133 sets at a smoke generator), 100 percent of the sets were read with a positive error[1] of less than 7.5 percent opacity; 99 percent were read with a positive error of less than 5 percent opacity.

(2) For white plumes (170 sets at a smoke generator, 168 sets at a coal-fired power plant, 298 sets at a sulfuric acid plant), 99 percent of the sets were read with a positive error of less than 7.5 percent opacity; 95 percent were read with a positive error of less than 5 percent opacity.

The positive observational error associated with an average of twenty-five readings is therefore established. The accuracy of the method must be taken into account when determining possible violations of applicable opacity standards.

[1] For a set, positive error = average opacity determined by observers' 25 observations – average opacity determined from transmissometer's 25 recordings.

5.8.1.2 Principle and Applicability-

1. *Principle and applicability.*

1.1 Principle. The opacity of emissions from stationary sources is determined visually by a qualified observer.

1.2 Applicability. This method is applicable for the determination of the opacity of emissions from stationary sources pursuant to § 60.11(b) and for qualifying observers for visually determining opacity of emissions.

5.8.1.3 Procedures for Opacity Observations-

2. *Procedures.* The observer qualified in accordance with paragraph 3 of this method shall use the following procedures for visually determining the opacity of emissions:

2.1 Position. The qualified observer shall stand at a distance sufficient to provide a clear view of the emissions with the sun oriented in the 140° sector to his back. Consistent with maintaining the above requirement, the observer shall, as much as possible, make his observations from a position such that his line of vision is approximately perpendicular to the plume direction, and when observing opacity of emissions from rectangular outlets (e.g. roof monitors, open baghouses, noncircular stacks), approximately perpendicular to the longer axis of the outlet. The observer's line of sight should not include more than one plume at a time when multiple stacks are involved, and in any case the observer should make his observations with his line of sight perpendicular to the longer axis of such a set of multiple stacks (e.g. stub stacks on baghouses).

2.2 Field records. The observer shall record the name of the plant, emission location, type facility, observer's name and affiliation, and the date on a field data sheet (Figure 9–1). The time, estimated distance to the emission location, approximate wind direction, estimated wind speed, description of the sky condition (presence and color of clouds), and plume background are recorded on a field data sheet at the time opacity readings are initiated and completed.

2.3 Observations. Opacity observations shall be made at the point of greatest opacity in that portion of the plume where condensed water vapor is not present. The observer shall not look continuously at the plume, but instead shall observe the plume momentarily at 15-second intervals.

2.3.1 Attached steam plumes. When condensed water vapor is present within the plume as it emerges from the emission outlet, opacity observations shall be made beyond the point in the plume at which condensed water vapor is no longer visible. The

FIGURE 9-1
RECORD OF VISUAL DETERMINATION OF OPACITY

PAGE___of___

COMPANY____________________
LOCATION____________________
TEST NUMBER____________________
DATE____________________
TYPE FACILITY____________________
CONTROL DEVICE____________________

HOURS OF OBSERVATION____________________
OBSERVER____________________
OBSERVER CERTIFICATION DATE____________________
OBSERVER AFFILIATION____________________
POINT OF EMISSIONS____________________
HEIGHT OF DISCHARGE POINT____________________

21

CLOCK TIME	Initial			Final
OBSERVER LOCATION Distance to Discharge				
Direction from Discharge				
Height of Observation Point				
BACKGROUND DESCRIPTION				
WEATHER CONDITIONS Wind Direction				
Wind Speed				
Ambient Temperature				
SKY CONDITIONS (clear, overcast, % clouds, etc.)				
PLUME DESCRIPTION Color				
Distance Visible				
OTHER INFORMATION				

SUMMARY OF AVERAGE OPACITY

Set Number	Time	Opacity	
	Start--End	Sum	Average

Readings ranged from ____ to ____ % opacity

The source was/was not in compliance with ____ at the time evaluation was made.

5.8.1.3 Procedures (cont.)-

observer shall record the approximate distance from the emission outlet to the point in the plume at which the observations are made.

2.3.2 Detached steam plume. When water vapor in the plume condenses and becomes visible at a distinct distance from the emission outlet, the opacity of emissions should be evaluated at the emission outlet prior to the condensation of water vapor and the formation of the steam plume.

2.4 Recording observations. Opacity observations shall be recorded to the nearest 5 percent at 15-second intervals on an observational record sheet. (See Figure 9-2 for an example.) A minimum of 24 observations shall be recorded. Each momentary observation recorded shall be deemed to represent the average opacity of emissions for a 15-second period.

2.5 Data Reduction. Opacity shall be determined as an average of 24 consecutive observations recorded at 15-second intervals. Divide the observations recorded on the record sheet into sets of 24 consecutive observations. A set is composed of any 24 consecutive observations. Sets need not be consecutive in time and in no case shall two sets overlap. For each set of 24 observations, calculate the average by summing the opacity of the 24 observations and dividing this sum by 24. If an applicable standard specifies an averaging time requiring more than 24 observations, calculate the average for all observations made during the specified time period. Record the average opacity on a record sheet. (See Figure 9-1 for an example.)

5.8.1.4 Qualifications and Testing-

3. *Qualifications and testing.*

3.1 Certification requirements. To receive certification as a qualified observer, a candidate must be tested and demonstrate the ability to assign opacity readings in 5 percent increments to 25 different black plumes and 25 different white plumes, with an error not to exceed 15 percent opacity on any one reading and an average error not to exceed 7.5 percent opacity in each category. Candidates shall be tested according to the procedures described in paragraph 3.2. Smoke generators used pursuant to paragraph 3.2 shall be equipped with a smoke meter which meets the requirements of paragraph 3.3.

The certification shall be valid for a period of 6 months, at which time the qualification procedure must be repeated by any observer in order to retain certification.

5.8.1.5 Certification Procedure-

3.2 Certification procedure. The certification test consists of showing the candidate a complete run of 50 plumes—25 black plumes and 25 white plumes—generated by a smoke generator. Plumes within each set of 25 black and 25 white runs shall be presented in random order. The candidate assigns an opacity value to each plume and records his observation on a suitable form. At the completion of each run of 50 readings, the score of the candidate is determined. If a candidate fails to qualify, the complete run of 50 readings must be repeated in any retest. The smoke test may be administered as part of a smoke school or training program, and may be preceded by training or familiarization runs of the smoke generator during which candidates are shown black and white plumes of known opacity.

FIGURE 9-2 OBSERVATION RECORD PAGE ___ OF ___

COMPANY ______________ OBSERVER ______________
LOCATION ______________ TYPE FACILITY ______________
TEST NUMBER ______________ POINT OF EMISSIONS ______________
DATE ______________

Hr.	Min.	Seconds 0	15	30	45	STEAM PLUME (check if applicable) Attached	Detached	COMMENTS
	0							
	1							
	2							
	3							
	4							
	5							
	6							
	7							
	8							
	9							
	10							
	11							
	12							
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	18							
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	20							
	21							
	22							
	23							
	24							
	25							
	26							
	27							
	28							
	29							

FIGURE 9-2 OBSERVATION RECORD PAGE ___ OF ___
(Continued)

COMPANY ______________ OBSERVER ______________
LOCATION ______________ TYPE FACILITY ______________
TEST NUMBER ______________ POINT OF EMISSIONS ______________
DATE ______________

Hr.	Min.	Seconds 0	15	30	45	STEAM PLUME (check if applicable) Attached	Detached	COMMENTS
	30							
	31							
	32							
	33							
	34							
	35							
	36							
	37							
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[FR Doc.74-26150 Filed 11-11-74;8:45 am]

5.8.1.6 Smoke Generator Specifications-

3.3 Smoke generator specifications. Any smoke generator used for the purposes of paragraph 3.2 shall be equipped with a smoke meter installed to measure opacity across the diameter of the smoke generator stack. The smoke meter output shall display in-stack opacity based upon a pathlength equal to the stack exit diameter, on a full 0 to 100 percent chart recorder scale. The smoke meter optical design and performance shall meet the specifications shown in Table 9–1. The smoke meter shall be calibrated as prescribed in paragraph 3.3.1 prior to the conduct of each smoke reading test. At the completion of each test, the zero and span drift shall be checked and if the drift exceeds ±1 percent opacity, the condition shall be corrected prior to conducting any subsequent test runs. The smoke meter shall be demonstrated, at the time of installation, to meet the specifications listed in Table 9–1. This demonstration shall be repeated following any subsequent repair or replacement of the photocell or associated electronic circuitry including the chart recorder or output meter, or every 6 months, whichever occurs first.

TABLE 9–1—SMOKE METER DESIGN AND PERFORMANCE SPECIFICATIONS

Parameter:	*Specification*
a. Light source	Incandescent lamp operated at nominal rated voltage.
b. Spectral response of photocell.	Photopic (daylight spectral response of the human eye—reference 4.3).
c. Angle of view	15° maximum total angle.
d. Angle of projection.	15° maximum total angle.
e. Calibration error.	±3% opacity, maximum.
f. Zero and span drift.	±1% opacity, 30 minutes.
g. Response time	≤5 seconds.

5.8.1.7 Calibration of Smoke Meter-

3.3.1 Calibration. The smoke meter is calibrated after allowing a minimum of 30 minutes warmup by alternately producing simulated opacity of 0 percent and 100 percent. When stable response at 0 percent or 100 percent is noted, the smoke meter is adjusted to produce an output of 0 percent or 100 percent, as appropriate. This calibration shall be repeated until stable 0 percent and 100 percent readings are produced without adjustment. Simulated 0 percent and 100 percent opacity values may be produced by alternately switching the power to the light source on and off while the smoke generator is not producing smoke.

5.8.1.8 Smoke Meter Evaluation-

3.3.2 Smoke meter evaluation. The smoke meter design and performance are to be evaluated as follows:

3.3.2.1 Light source. Verify from manufacturer's data and from voltage measurements made at the lamp, as installed, that the lamp is operated within ±5 percent of the nominal rated voltage.

3.3.2.2 Spectral response of photocell. Verify from manufacturer's data that the photocell has a photopic response; i.e., the spectral sensitivity of the cell shall closely approximate the standard spectral-luminosity curve for photopic vision which is referenced in (b) of Table 9–1.

3.3.2.3 Angle of view. Check construction geometry to ensure that the total angle of view of the smoke plume, as seen by the photocell, does not exceed 15°. The total angle of view may be calculated from: $\theta=2 \tan^{-1} d/2L$, where θ=total angle of view; d=the sum of the photocell diameter + the diameter of the limiting aperture; and L=the distance from the photocell to the limiting aperture. The limiting aperture is the point in the path between the photocell and the smoke plume where the angle of view is most restricted. In smoke generator smoke meters this is normally an orifice plate.

3.3.2.4 *Angle of projection.* Check construction geometry to ensure that the total angle of projection of the lamp on the smoke plume does not exceed 15°. The total angle of projection may be calculated from: $\theta=2 \tan^{-1} d/2L$, where θ= total angle of projection; d= the sum of the length of the lamp filament + the diameter of the limiting aperture; and L= the distance from the lamp to the limiting aperture.

3.3.2.5 Calibration error. Using neutral-density filters of known opacity, check the error between the actual response and the theoretical linear response of the smoke meter. This check is accomplished by first calibrating the smoke meter according to 3.3.1 and then inserting a series of three neutral-density filters of nominal opacity of 20, 50, and 75 percent in the smoke meter pathlength. Filters calibarted within ±2 percent shall be used. Care should be taken when inserting the filters to prevent stray light from affecting the meter. Make a total of five nonconsecutive readings for each filter. The maximum error on any one reading shall be 3 percent opacity.

3.3.2.6 Zero and span drift. Determine the zero and span drift by calibrating and operating the smoke generator in a normal manner over a 1-hour period. The drift is measured by checking the zero and span at the end of this period.

3.3.2.7 Response time. Determine the response time by producng the series of five simulated 0 percent and 100 percent opacity values and observing the time required to reach stable response. Opacity values of 0 percent and 100 percent may be simulated by alternately switching the power to the light source off and on while the smoke generator is not operating.

5.8.1.9 <u>Quality Control Program Specifications</u>--

5.8.1.9.1 <u>Quality control programs--purpose</u>. Each observer training school and/or law enforcement agency shall maintain a quality control program consistent with the procedures described in this manual. Such programs shall be designed to assure the quality and scientific reliability of visible emissions data.

5.8.1.9.2 <u>Quality control programs--provisions</u>. Each quality control program shall contain provisions for the management of quality, which shall include the following:

1. Requirements for the production of quality control data and the use of quality control records,
2. Control of technical documents, training methods, calibration instructions, and observation procedures,
3. Control of purchased material to include checks for conformance to specifications,
4. Audit of training procedures to include interschool and intraschool check programs,
5. Audit of observations to include inter- and intra-agency check programs,
6. Establishment of an organizational structure to carry out these provisions.

The intraschool quality control program shall provide for the establishment and maintenance of a system to assure continued certification of observers sufficiently trained to expertly handle the majority of situations that they might encounter. The system should include:

1. The checks and audits listed in table 5.8.1,
2. Routine use of nonscheduled observations made by an expert observer simultaneously with student observations,

Table 5.8.1 Methods of monitoring training variables

Variable	Method of monitoring (intraschool)
1. Student comprehension of material covered	Entertain questions between each lecture and give students a 1-hour quiz at the completion of the classroom training. See section 5.8.3.3 page 38 of 67.
2. Practice runs of smoke tests	Sufficiently cover at several values of opacity from 0 percent to 100 percent so that at least one-half of class feels confident enough to commence certification testing. See section 5.8.3.5 page 49 of 67.
3. Calibration of smoke meter	Check calibration error prior to each school using neutral density filters. See section 5.8.3.4 page 47 of 67.
4. Zero and span drift	Make zero and span checks and adjustments prior to each practice or certification run. See section 5.8.3.4 page 47 of 67.
5. System noise	Check the strip chart record trace for signs of noise after each certification run as part of routine operating procedure. See section 5.8.3.4 page 47 of 67.
6. Placement of smoke generator	Choose a location unaffected by downwash from obstacles in the area and where the students can observe the plume with the sun behind them. A contrasting background for the plume is also important. See section 5.8.3.4 page 47 of 67.
7. Transmissometer readings simultaneous with blowing of the horn	Mark the reading on the strip chart as the signal is given. See section 5.8.3.5 page 49 of 67.
8. Smoke test sheets	Students should record their readings in duplicate; the original to be turned in to the instructor prior to announcing the correct values. See section 5.8.3.6 page 51 of 67.

3. The use of NBS traceable filters to verify proper smoke generator operation during certification testing,

The intra-agency quality control program shall provide for the establishment and maintenance of a system to assure continued precision and accuracy of the documented results from visual determinations. The system should include:

1. The checks and audits listed in table 5.8.2,

Table 5.8.2. Methods of monitoring field variables

Variable	Method of monitoring (intra-agency)
1. Observer position with respect to sun and plume	Position should be diagrammed prior to making observations. See section 5.8.3.6 page 51 of 67.
2. Prevailing meteorological conditions	Use small hand-held instruments to determine and document wind speed and direction, ambient temperature, dewpoint or relative humidity, and barometric pressure.
3. Point of observation in plume	Opacity observations should be made at the point of greatest opacity at a point in the plume where no condensed water vapor is present. The distance of the point from the stack should be documented. See section 5.8.3.5 page 49 of 67.
4. Number of observations per set	Confirm the applicable legal requirements prior to commencement of observations. See section 5.8.3.6 page 51 of 67.
5. Data reduction errors	Check all calculations of average opacity when the possibility of violation of the standard exists.
6. Documentation of all necessary information	Check for completion of observational records after each average opacity determination.

2. Routine use of nonscheduled replicate and/or duplicate observations to check questionable observations,
3. Recertification of observers at 6-month intervals,
4. The use of $\bar{X}$ (mean) or R (range) or other control charts and tests for significance or differences to gain more information about controllable and noncontrollable variables.

5.8.1.9.3 Quality control programs--records. Each laboratory should keep quality control records sufficient to demonstrate adherence to the requirements in this manual.

5.8.1.10 Bibliography--

4. *References.*
4.1 Air Pollution Control District Rules and Regulations, Los Angeles County Air Pollution Control District, Regulation IV, Prohibitions, Rule 50.
4.2 Weisburd, Melvin I., Field Operations and Enforcement Manual for Air, U.S. Environmental Protection Agency, Research Triangle Park, N.C., APTD-1100, August 1972, pp. 4.1-4.36.
4.3 Condon, E. U., and Odishaw, H., Handbook of Physics, McGraw-Hill Co., N.Y., N.Y., 1958, Table 3.1, p. 6-52.

5.8.2 Plan Activity Matrix

5.8.2.1 Purpose--Quality assurance procedures and checks are designed to identify invalid data and to assure that reported data are of acceptable quality. These procedures and checks should be integral parts of the normal training, testing, and field functions. Special quality control excercises may be required of the instructors or the field observers by their supervisors.

An auditing or checking level of one check in every 10 training courses, or one check per year, whichever occurs most frequently, is used in this manual for the audit of smoke-reading schools. All apparatus used in the certification testing program should satisfy the specifications defined in the *Federal Register*, November 12, 1974, and the manufacturer's recommendations should be followed whenever possible.

An auditing level of one check in every 10 sources observed by the field observer or one check per month, whichever is more frequent, is used in this manual for the audit of individual field observers. The observer may be required to perform special quality control checks routinely as prescribed by his supervisor.

This section presents, in tabular matrix form, a synopsis of control procedures for important sources of variation associated with each of the five operational categories. Some control procedures, such as the calibration of the smoke meter, are performed periodically. Others, such as verification of the smoke meter design specifications, are performed upon purchase of the instrumentation or upon modification of a process or of equipment. The information in the columns across the page indicate:

1. Characteristic of an item of equipment or a component of the system under discussion,

2. Scope of the characteristic or acceptance limits for determining the adequacy of the characteristic or component,
3. Frequency of check or measurement for determining conformance with requirements specified in column 2,
4. Action required if the characteristic or component does not conform with description or meet the acceptance limits,
5. Deposition of the record of check, action required, and date.

Stepwise instructions for performing each operation in the matrix appear in the corresponding subsection of Section 5.8.3, "Operational Procedures," or, in the case of audit instructions, refer to Section 5.8.4, "Auditing Procedures."

The operational categories have been subdivided into the following operational areas, which more readily lend themselves to a tabular information:

5.8.2.2 Observer Training
5.8.2.3 Observer Testing and Certification
5.8.2.4 Field Observations
5.8.2.5 Data Reduction
5.8.2.6 Procurement of Training Apparatus and Supplies
5.8.2.7 Calibration of Training Equipment
5.8.2.8 Regular and Preventative Maintenance of the Smoke Generator
5.8.2.9 Auditing Procedures

PLAN ACTIVITY MATRIX

5.8.2.2 Observer Training

Characteristic	Scope/Limits	Frequency of Performance Check	Method of Check	Action Requirements	Record
Classroom Work	Subjects covered should include: 1. Principles of "smoke reading" 2. Procedures for certification testing 3. Basic meteorology 4. Pollution sources 5. Combustion processes 6. Legal aspects of smoke reading 7. Behavior of an expert witness 8. Data recording 9. Calculation of averages	To obtain first certification, smoke reader must attend classroom training. Every six months thereafter he should attend an abbreviated seminar briefly discussing each of those topics.	Study course agenda and the qualifications of the instructors	Training school procedures must be reviewed and appropriate improvements made.	Course agenda
Practice Runs	At least one set each of 25 black plumes and 25 white plumes	Every school	Visual	Training schedule must be revised	Course agenda
Meteorological data and fixed entry data	Judgment by each student must be reasonable	Repeat judgment tests at various intervals throughout the training session	Check student test form to affirm that the data is reasonable and comparable to instrument readings when available (compass, sling psychrometer, wind meter, etc.)	Repeat the check	Instructor's log book

PLAN ACTIVITY MATRIX

5.8.2.3 Observer Testing and Certification

Characteristic	Scope/Limits	Frequency of Performance Check	Method of Check	Action Requirements	Record
Qualification run	Emission from smoke generator of 25 white and 25 black shades of smoke	Each run	Count the number of readings marked on the strip chart as the signal is given	Invalidate run	Operator's log book
Resolution of Determinations	Opacity values must be assigned in 5 percent increments	Each run	Check each student test sheet	Student must repeat the test for certification	Student test sheet
Certification Requirement	For every reading of the 50 plumes: $O_{T_j} - O_j \leq 15\%$ and for each category: $\frac{\sum_{j=1}^{25} (O_{T_j} - O_j)}{25} \leq 7.5\%$ where O_{T_j} and O_j are the transmissometer and the observer readings respectively for the jth observation.	Each run	Calculate range and average of differences between observer's readings and transmissometer's values	Student must repeat the test for certification	Student test sheet
Test Sheets	One carbon copy of each test sheet	Each run which qualifies a student for certification	Student must turn in the original copy to the instructor before correct answers are read to the class	Student must repeat test for certification	Original copy of student's test sheet
Validation Transmissometer Reading at Time of Reading	Each reading must be marked on strip chart when signal is given for reading	After each run	Count the marked readings	Invalidate run	Operator's log book

PLAN ACTIVITY MATRIX

5.8.2.4 Field Observations (cont.)

Characteristic	Scope/Limits	Frequency of Performance Check	Method of Check	Action Requirements	Record
Plume Background	Should contrast with plume as much as possible	Each run	Visual estimation	Note background and repeat observations at a later date	Observation Information Form and Observer's daily log book
Observation Intervals	The observer should glance at the plume once every 15 seconds	Each run	Visual	Invalidate run	Observation Data Record
Photographs of Plume Background	Taken before and/or after visual determination but not during the determination	Each run where a violation is suspected	Record of date and time of each shot with comments		Observer's log book

5.8.2.5 Data Reduction

Characteristic	Scope/Limits	Frequency of Performance Check	Method of Check	Action Requirements	Record
Set of observations	Set is composed of any 24 consecutive readings; sets need not be consecutive in time and no two sets shall overlap	After all readings are completed for a given source	Analyze Observation Record and record start and end times for each set	Another set of reading must be used to determine average opacity	Summary of Average Opacity
Average Opacity	Must be determined from a set as defined above or from a set consisting of more than 24 readings	After all readings are completed for a given source	Average $= \frac{\sum_{i=1}^{m} O_j}{m}$ where m = number of readings	Disregard data for enforcement calculations if an entire set of data is not available	Summary of Average Opacity

PLAN ACTIVITY MATRIX

5.8.2.6 Procurement of Training Apparatus and Supplies

Characteristic	Scope/Limits	Frequency of Performance Check	Method of Check	Action Requirements	Record
Visual Aids	As required by lecturers	Prior to commencement of classroom instruction	Visual check for adequacy	Repair or replace as necessary	Classroom checklist
Public Address System	Speaker must be audible throughout the classroom	Prior to commencement of classroom instruction	Set up and operate system	Repair or replace as necessary	Classroom checklist
Smoke Generator:					
(a) Light source	Incandescent lamp operated at nominal voltage	Upon receipt	Verify from manufacturer's data and visual check	Reject and replace	Procurement log
(b) Photocell	Spectral sensitivity must be photopic (400-700 nm band)	Upon receipt and upon subsequent repair of the photocell or associated electronic equipment	Verify from manufacturer's data and check any filters used on a spectrophotometer	Reject and replace	Procurement log
(c) Angle of View	Should not exceed 15°	Upon receipt and following repair or replacement of any associated equipment	$\theta = 2 \tan^{-1} \frac{d}{2L}$ where θ = total angle of view; d = sum of photocell diameter plus the limiting aperture; L = distance from the photocell to the limiting aperture. See section 5.8.3.2	Identify and correct discrepancy or return to supplier	Procurement log and operator's log

PLAN ACTIVITY MATRIX

5.8.2.6 Procurement of Training Apparatus and Supplies (cont.)

Characteristic	Scope/Limit	Frequency of Performance Check	Method of Check	Action Requirements	Record
(d) Angle of Projection	Should not exceed 15°	Upon receipt and following repair or replacement of any associated equipment	$\theta = 2 \tan^{-1} \frac{d}{2L}$ where θ = total angle of projection; d = sum of the length of the lamp filament plus the diameter of the limiting aperture; L = distance from the lamp to the limiting aperture. See section 5.8.3.3	Identify and correct discrepancy or return to supplier	Procurement log and operator's log
(e) Response Time	≤ 5 seconds	Upon receipt and following repair or replacement of any associated equipment	Simulate 0 percent and 100 percent opacity values and observe the time required to reach stable response	Identify and correct discrepancy or return to supplier	Procurement log and operator's log
Fuel for Generation of Black Smoke	5 gallons of industrial grade benzene or as specified by manufacturer	Prior to each school	Visual	Purchase fuel prior to scheduled time for practice smoke runs	Operator's log book
Fuel for Generation of White Smoke	5 gallons of #2 fuel oil or as specified by manufacturer	Prior to each school	Visual	Purchase fuel prior to scheduled time for practice smoke runs	Operator's log book
Fuel for the Power Generator	2 gallons gasoline; good grade, regular or as recommended by manufacturer	Prior to each school	Visual	Purchase fuel prior to scheduled time for practice smoke runs	Operator's log book

PLAN ACTIVITY MATRIX

5.8.2.6 Procurement of Training Apparatus and Supplies (cont.)

Characteristic	Scope/Limits	Frequency of Performance Check	Method of Check	Action Requirements	Records
Engine Oil	1 qt. MS classification oil. Above 32°F use SAE 30. Below 32°F use SAE 10w, or as recommended by manufacturer	Should be checked before each smoke school and changed after every 25 hours of operations	Visual	Purchase oil prior to scheduled time for practice smoke runs	Generator log book
Three Neutral-Density Filters	Calibration traceable to NBS; with nominal opacity of 20, 50, and 75 percent	Upon receipt and before each smoke school	Check calibration with spectrophotometer using NBS traceable filters as a reference	Reject	Procurement log book and Operator's log book

5.8.2.7 Calibration of Training Equipment

Characteristic	Scope/Limits	Frequency of Performance Check	Method of Check	Action Requirements	Record
Smoke Meter (a) Calibration of transmissometer-recorder system	Maximum error for any one reading shall be 3% opacity	Prior to each smoke school	Place each of the three neutral density filters, one at a time, between the light source and the photocell. Make a total of 5 nonconsecutive readings for each filter	Repair or replace defective part	Operator's log book
(b) Zero and Span Calibration	Drift less than 1% opacity, 30 minutes	Prior to each run	Simulate 0 and 100% opacity. Check reading on strip chart	Adjust the smoke meter. If fluctuation persists, check recorder and meter for the source of the problem	Operator's log book

PLAN ACTIVITY MATRIX

5.8.2.8 Regular and Preventative Maintenance of the Smoke Generator

Characteristic	Scope/Limits	Frequency of Performance Check	Method of Check	Action Requirements	Record
Engine	Free from dirt and corrosive materials	Before each school	Visual	Follow manufacturer's instructions	Smoke Generator Log
Oil	Free from contaminants	Check before each school and change after every 25 hours of operation	Visual	Not applicable	Smoke Generator Log
Air Cleaner	Free from particulate buildup	Clean after every 50 hours of operation	Visual	Follow manufacturer's instructions	Smoke Generator Log
Electrical Connections	Absence of loose connections	Before each smoke school	Visual	Follow manufacturer's instructions	Smoke Generator Log
Recorder	No evidence of malfunction, sufficient ink supply, no undue wearing of mechanical parts, no deterioration of circuitry	Before each smoke school	Visual	Follow manufacturer's instructions	Smoke Generator Log
Trailer	No undue deterioration of tire tread, correct pressure in tires, no evidence of leaks in shock absorbers	Once per month or as recommended by manufacturer	Visual	Replace or repair tires or shock absorbers as needed	Smoke Generator Log
Neutral Density Filters	Must remain free from degradation such as fading or scratches	Prior to each use	Visual	Replace	Smoke Generator Log

5.8.2.9 Auditing Procedures

Field Observations	$L \le d_j \le U$ where $d_j = \bar{O}_j - \bar{O}_{aj}$, $L = -7.33$ percent opacity, $U = +7.33$ percent opacity	One check for every 10 observational sessions performed by the observer or once per month, whichever is greater (see section 5.8.4)	Simultaneous observations by a second expert observer	Using the Audit Data Form (figure 5.8.8) and the audit observational results, determine the sources of error. More frequent certification may be required	Audit Data Form, Data Assessment Form, and Quality Control Chart
Training School	Absence of serious irregularities and at least a "fair" rating as judged by auditor; generator must meet specifications stated in section 5.8.1.6	One check for every 10 training courses or one check per year, whichever is greater	Visual evaluation	Increase the Auditing levels until the situation is corrected	Course Evaluation Form

5.8.3 Operation Procedures

5.8.3.1 General Considerations--In the subsections immediately following, specific procedures for the operational categories involved in method 9 are described. The sequence of operations to be performed is given in figure 5.8.2. Two sets of columns are used. The left-hand set, with items numbered 1 through 47, lists routine procedures in sequential order for smoke reading from training of the observer, through certification, to actual field observations. Items A through N depict the testing, calibration, maintenance, and procurement procedures that are performed periodically. Quality checkpoints in each of the procedural categories for which appropriate quality control limits have been assigned are represented by blocks enclosed by heavy lines. Other checkpoints involve decisions by the instructor or observer, which are based on good judgment and documented guidelines.

5.8.3.2 Procurement and Acceptance Testing of the Smoke Generator--The smoke generator shall have the capability of generating discrete levels of both white smoke and black smoke and emitting the smoke through a stack. Installed on the generator must be a smoke meter designed to measure the opacity across the diameter of the stack. The smoke meter must conform to those specifications detailed in section 5.8.1.6. Procedures for the acceptance testing are described below.

5.8.3.2.1 The light source must be an incandescent, low voltage lamp, with as short a filament as possible.

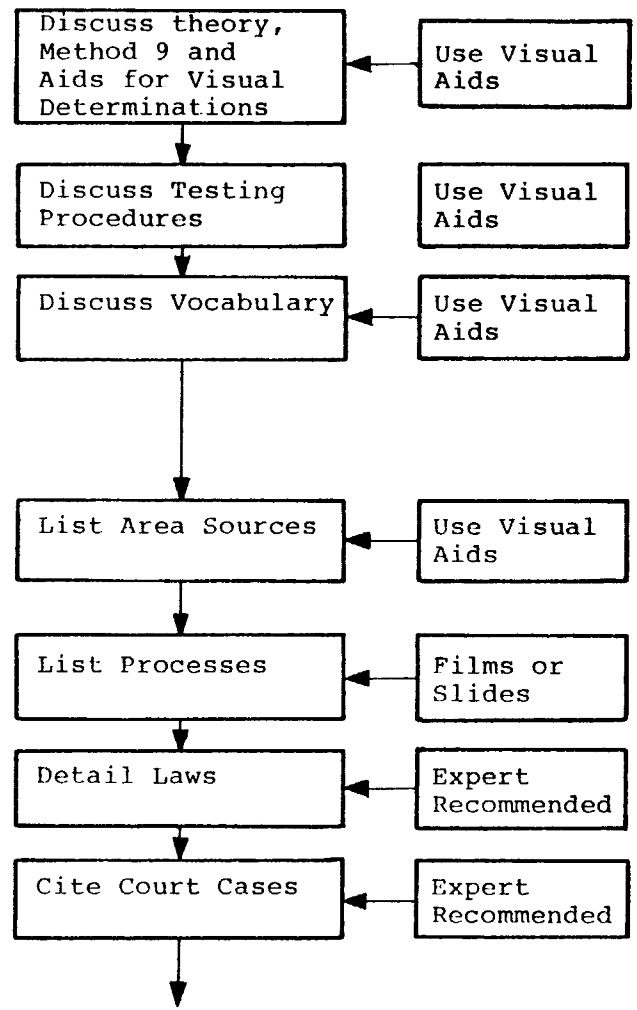
5.8.3.2.2 The photocell which will sense the light transmitted across the stack by the source, must have a photopic spectral sensitivity (the 400-700 nm wavelengths). Verify the proper sensitivity from the characteristic curve supplied by the manufacturer.

5.8.3.2.3 The angle of view of the smoke plume, as seen by the photocell, must not exceed 15°. The total angle

Sequence of Operations

Observer classroom training

1. Discuss principles of smoke reading
2. Discuss procedures for certification testing
3. Lecture on meteorology
4. Discuss various types of pollution sources
5. Discuss combustion process related to the sources described above
6. Lecture on the legal aspects of smoke reading
7. Discuss the behavior of an expert witness



A. Allow time for brief question and answer periods after each subject is covered.

Figure 5.8.2. Sequence of operations in training, certification, and field observations for determinations of visual emissions.

Sequence of Operations

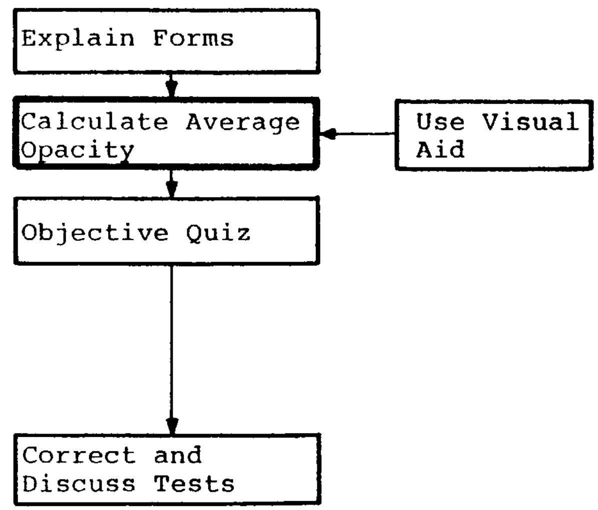
Observer classroom training (con)

8. Describe data forms

9. Define a run of observations and average opacity

10. Administer 1-hour quiz on subjects covered above

11. Determine students' understanding of material

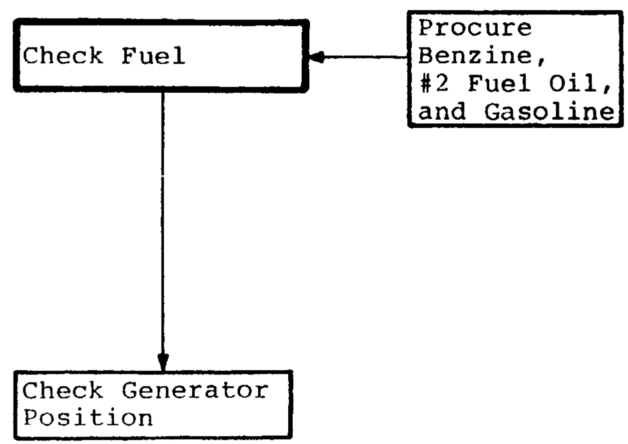


B. Original copy of each student's quiz to be filed with certification records.

Preparation for observer field training (prior to beginning of course)

12. Check for sufficient fuel in the fuel tanks or in reserve

13. Check position of generator for advantageous viewing of plume



C. Procure smoke generator manufactured to meet specifications stated in the Federal Register, Vol 39, No. 219, Tuesday, November 12, 1974.

Figure 5.8.2 (con) Sequence of operations in training, certification, and field observations for determinations of visual emissions.

Sequence of Operations

Preparation for observer field training (con)

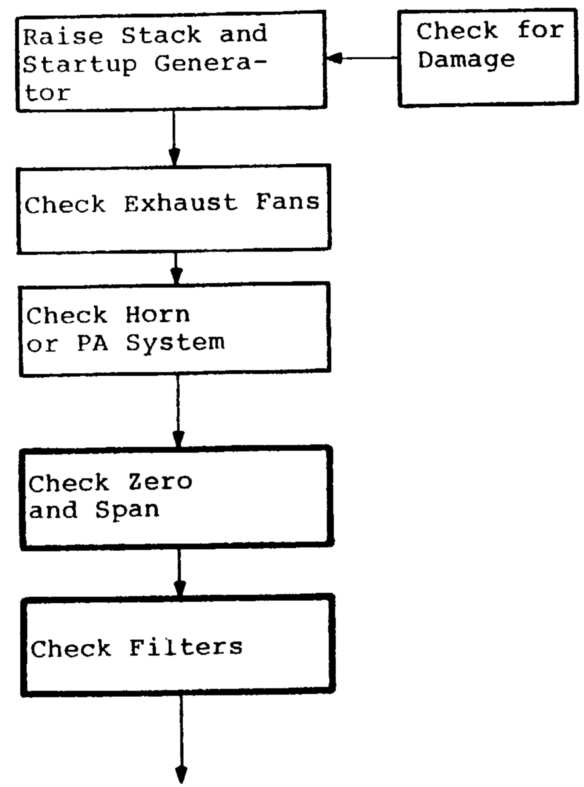
14. Raise stack and startup generator per manufacturer's recommended procedures

15. Check for proper operation of exhaust fans and induced draft fan

16. Check observation signal system for proper operation

17. Calibrate transmissometer readout system for 0 percent and 100 percent readings

18. Check neutral density filters for physical damage



D. Perform maintenance as scheduled.

E. Procure neutral density filters and calibrate filters against NBS calibrated filters.

Figure 5.8.2 (con). Sequence of operations in training, certification, and field observations for determinations of visual emissions.

Sequence of Operations

Preparation for observer field training (con)

19. Determine error between actual response and theoretical linear response of smoke meter using neutral density filters	Determine Calibration Error ↓	
20. Confirm that response time meets specifications	Confirm Response Time	

Observer field training

21. Test students on the description of weather conditions	Determine Weather Conditions ↓	F. Repeat weather determinations throughout the day.
22. Start up smoke generator for practice observations after 30-minute warmup period	Check Zero and Span ↓	G. Repeat zero and span check before each run.
23. Discuss proper observer positioning with respect to plume and sun	Check Student's Positions ↓	H. Continually check for shifts in plume direction and changes in sun location.

Figure 5.8.2 (con). Sequence of operations in training, certification, and field observations for determination of visual emissions.

Observer field training (con)	Sequence of Operations	
24. Discuss plume background	Check for Contrasting Background →	I. Changes in plume background should be noted.
25. Demonstrate entire shade scale for both black and white plumes	Announce Opacity Values →	J. When meter stabilizes at each reading, signal for reading, and mark opacity value on strip chart.
26. Run through several shades of black and white plumes with emphasis on shades just above and below the legal limits	Display Shades Near Legal Limits →	K. Second certified observer or instructor should view and record opacities as a test for reasonableness of smoke generator operation.
27. Give students a practice run of certification test (described below)	Students Record Readings →	

Figure 5.8.2 (con). Sequence of operations in training, certification, and field observations for determination of visual emissions.

Sequence of Operations

<u>Observer field training</u> (con)

28. Each student grades his own observation data	Compare Results ↓	L. Repeat practice runs if a majority of the students request it.
29. Generate 25 different black plumes	Students Record Black Plume Opacities ↓	M. Instructor marks each value on strip chart when horn blows.
30. Switch to white smoke and generate 25 different white plumes	Students Record White Plume Opacities ↓	
31. At completion of run (steps 18 and 19), students turn in originals to test sheets, and then the instructor reads smoke meter readings	Tests Corrected ↓	
32. Students calculate average error	Determine Test Scores ↓	

Figure 5.8.2 (con). Sequence of operations in training, certification, and field observations for determination of visual emissions.

	Sequence of Operations	
<u>Observer field training</u> (con)		
33. Students failing to meet requirements repeat certification test (steps 18 through 21)	Repeat Test if Necessary	N. Repetition of certification procedure is a function of time and number of students needing to qualify.
<u>Field observations</u>		
34. Check position with respect to sun and plume direction	Check Position ↓	
35. Document position in as much detail as possible	Document Position ↓	
36. Record all available information on emitting facility	Record Fixed Information ↓	
37. Record date and time of viewing	Record Date and Time ↓	
38. Document estimated wind speed, wind direction, sky condition	Document Meteorological Conditions ↓	

Figure 5.8.2 (con). Sequence of operations in training, certification, and field observations for determination of visual emissions.

Sequence of Operations

Field observations (con)	
39. Document plume background	Document Plume Background ↓
40. Determine and record type and color of plume	Describe Plume ↓
41. Record approximate distance from emission outlet to point in plume where the observations are made	Record Point of Observation ↓
42. Photograph stack and plume	Photograph Facility Under Observation ↓
43. Observe and record opacity values	Make Observations and Record ↓
44. Note any changes in the ambient conditions	Record Significant Changes in Conditions ↓
45. Photograph stack and plume	Photograph Facility Under Observation ↓

Figure 5.8.2 (con). Sequence of operations in training, certification, and field observations for determination of visual emissions.

Sequence of Operations

Field ob rvations (con)

46. Calculate average opacity over the legally required observational period

47. Obtain and record any additional data required on form

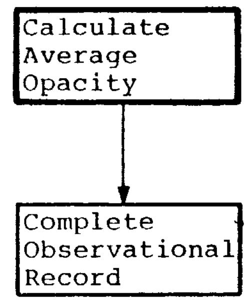


Figure 5.8.2 (con). Sequence of operations in training, certification, and field observations for determination of visual emissions.

of view can be calculated from the following equation:

$$\theta = 2 \tan^{-1} \frac{d}{2L} \qquad (1)$$

where θ = total angle of view

d = diameter of the limiting aperture minus the diameter of the photocell

L = distance from the photocell to the limiting aperture.

The limiting aperture is the orifice plate or equivalent in the path between the photocell and the smoke plume which limits the angle of view. All of the physical measurements called for in equation 1 can be readily measured in the laboratory using inside/outside calipers. Record the calculated value in the Smoke Generator Logbook (see figure 5.8.3)

5.8.3.2.4 The total angle of projection of the lamp on the smoke plume should not exceed 15°. The total angle of projection can be calculated from:

$$\theta = 2 \tan^{-1} \frac{d}{2L} \qquad (2)$$

where θ = total angle of projection

d = diameter of the limiting aperture minus the length of the lamp filament

L = distance from the lamp of the limiting aperture plus the length of filament.

The measurement of the length of the filament is critical in the determination of the angle of projection using equation 2 and cannot be done in the average laboratory with the required accuracy. To avoid the need for this measurement, the following procedure is recommended for this portion of the acceptance test.

1. Remove the source and aperture apparatus from the transmissometer.
2. Set up the apparatus on a flat, horizontal surface making sure that the distance between the light source and aperture is the same as it is in the

SMOKE GENERATOR LOG

GENERATOR NUMBER ________ OPERATOR ______________
DATE ________________ OWNER ______________
MANUFACTURER ______________

Calibration Error:

20%	50%	75%
___	___	___
___	___	___
___	___	___

Zero Drift _______%
Span Drift _______%
Response Time _______ seconds

Check the following procedures if accomplished during this maintenance and calibration period:

- Change Light Bulb ☐
- Changed Photocell ☐
- Changed Strip Chart Paper ☐
- Check Oil ☐
- Check Recorder for Malfunctions ☐
- Checked Air Cleaner ☐
- Checked Electrical Connections ☐
- Checked Trailer ☐

List any other checks which are made: ______________________

____

____

List minor or major repairs performed on any part of the equipment: ______________________

____

____

List recommendations for future checks or possible repairs which may be necessary in the near future: ______________________

____

____

Figure 5.8.3. Sample smoke generator log.

transmissometer.

3. Turn on light source and focus the light on a bare wall at a distance L from the aperture. L should be large compared to the distance between the source and the aperture.
4. Measure the distance from the source to the wall, L.
5. Measure the diameter of the circular projection on the wall, d.
6. Substitute these measured values in equation 2 and calculate θ.
7. Record the calculated θ value in the Smoke Generator Logbook.

5.8.3.2.5 Replace the source and photocell in proper position in the smoke meter; perform a zero and span check after allowing a minimum of 30 minutes' warm-up. Simulate opacities of zero and 100 percent alternately. When a stable response is evident for either of the values, adjust the smoke meter to produce the appropriate output. The zero percent opacity value can be simulated by turning on the light source with no obstruction in the stack. The 100 percent opacity value can be simulated by placing a 99.99 percent neutral density filter in the smoke meter pathlength.

5.8.3.2.6 The calibration error is determined using neutral density filters of known opacity which are inserted, one at a time, in the smoke meter pathlength. These filters must be calibrated, within $\pm$ 2 percent, on a spectrophotometer using equivalent NBS calibrated filters as standards. The filters should have nominal opacities of 20, 50, and 75 percent.

Make a total of five nonconsecutive readings for each filter and record the data in the Smoke Generator Logbook. The maximum acceptable error on any one reading shall be 3 percent opacity.

5.8.3.2.7 Determine the zero and span drift by calibrating the smoke meter and operating the smoke generator for 30 minutes. Check the zero and span at the end of this operating period. Neither the zero nor span drift should be greater than $\pm$ 1 percent after a 30-minute operating period.

5.8.3.2.8 Check the response time with a stopwatch by determining the time it takes the smoke meter to reach a stable resonse when a 100 percent opacity is simulated directly following a 0 percent opacity value. For this purpose, using the power switch to turn the light source on and cff is adequate to simulate 0 percent and 100 percent opacity values respectively. Repeat this determination five times and record the response times on the same page in the logbook as used for the calibration data. The response time for each of the five determinations must be less than 5 seconds to be acceptable.

5.8.3.3 Observer Classroom Training--Each of the following subjects is to be covered in a 1- to 2-day visible-emissions classroom training schedule. Preparation by the instructor is a function of both his experience in the field of air pollution and his experience in teaching the course. Each instructor must gear his lectures or the lectures of guest speakers to the degree of competence exhibited by each individual class.

5.8.3.3.1 Principles of "smoke reading." This lecture should discuss the evolution of visual determinations from using the Ringelmann Chart to the present accepted means of determining "equivalent opacity." Method 9 as duplicated in Section 5.8.1 of this manual should be discussed in detail. Special emphasis should be placed on the importance of observer position, precise determination of weather conditions (see section 5.8.3.2.3), and the choice of a contrasting background when viewing a plume. Visual aids may be very useful in depicting actual observer situations (ref. 1).

The following guidelines are suggested:

1. The sun should be in the 140° sector at the rear of the observer.
2. Readings should be made at right angles to the wind direction from a point not less than two stack heights and not more than .25 miles from the source. (A triangulator should be used by

a field observer to determine the actual distance from the source.)

3. The observer should have a clear, unobstructed view of both the stack and the background.
4. The background should be as contrasting as possible with the color of the plume.
5. If the source has a rectangular outlet, the observer's view should be at right angles to the longer side of the outlet.
6. If possible, the observer's line of sight should not include more than one plume if two or more stacks are involved.
7. If guideline number 6 requirements cannot be met, the observer should make his observation with his line of sight perpendicular to the longer axis of such a set of multiple stacks.
8. The observer should view the portion of the plume nearest the stack which does not contain water vapor.

Experimental data (ref. 2) have shown that the viewing position influences the accuracy of the opacity data. The opacity value determined by the observer will generally increase as the angle between the viewer plume and sun increased. This is because the light scattered by the plume in the direction of the viewer increases causing a decrease in contrast between objects viewed through the plume and an increase in contrast between the plume and its sky background (ref. 3). The amount of light scattered in the direction of the observer is not only dependent upon the observer's position, but also on the clarity of the sky and the color of the plume. A discussion of these parameters is found in reference 3.

5.8.3.3.2 <u>Procedures for the certification testing</u>. General procedures for certification testing should be discussed as detailed in Method 9. Procedures characteristic of a particular training school should be covered. These might include: the number and procedure for practice runs, the data recording process, grading methods, repeat testing, certification procedures, and recertification requirements.

5.8.3.3.3 Basic meteorology Each student is to gain sufficient meteorological expertise so as to perform an assessment of the weather at a particular point in time. He must be aware of all the meteorological factors that affect the plume density and direction, and acquire ample vocabulary to describe the weather conditions thoroughly and accurately. The factors most relevant to the dispersion of contaminants include temperature, humidity, wind speed, and wind direction. Methods for determining each of these factors are to be discussed in the classroom. For example, the recommended equipment list might include a sling psychrometer, a wind gage with compass, and a barometer.

The student is also taught to accurately differentiate between and describe background sky conditions. For instance, precise definitions of terms such as "clear" and "partly cloudy" should be made available. The instructor should demonstrate the use of photographs and moving pictures to complete a description of the atmosphere surrounding a plume.

5.8.3.3.4 Pollution sources. The purpose of this lecture is to enable the observer to identify various types of industrial and commercial sources (ref. 2). Particular emphasis is placed on the types of sources prevalent in the areas to be observed. The observer must learn to describe the composition of the emissions, i.e., fume, dust, vapor, smoke, oil; the approximate sizes of the particulates involved; and the color. The differentiation should be made between combustion and noncombustion sources.

5.8.3.3.5 Combustion processes. The instructor explains efficient combustion and the conditions that produce incomplete combustion. Both the combustion of fuel oil and the combustion of coal should be covered along with any other combustion emissions prevalent in the area to be observed. As a result of the lecture, the student is able to identify types of fuels, the elements that affect the amounts of smoke produced, and the types of pollution control equipment available.

5.8.3.3.6 Legal aspects of smoke reading. A short history of visual determinations helps the student understand the meaning and usage of opacity measurements. Documents discussing the validity and accuracy of visual determinations can be referenced in discussions concerning the constitutionality of health and safety codes which are based on the equivalent opacity principle (refs. 5 and 6). Any regulations pertaining to the prevention, abatement, and control of visible emissions in effect in the region or area where the course is being given must be defined. Any outstanding court proceedings that can be discussed would prove beneficial. It is highly recommended that a lawyer or legal expert either give this lecture or be present to entertain questions upon completion of the lecture.

Emphasis should be made in this lecture on the importance of documenting all information available on the source in question, the weather conditions, background, and viewing position. In the event that a set of observations is the basis for court action, the observer will have to rely on the information documented at the time of the violation.

5.8.3.3.7 Behavior of the expert witness. Quite often a smoke reader is required to act as an expert witness in a court case (ref. 7). The lectures must discuss the preparation for giving testimony, which includes the review of all reports, photographs, and correspondence related to the case. In addition, topics such as dress, responsiveness to questions, and definition of court procedures are to be covered.

5.8.3.3.8 Data forms. The classroom instructor is to outline each of the data that should be documented before and/or after an observation. Samples of forms which can be used in reporting the data are shown on the following pages.

The Observation Information Form (see figure 5.8.4) has blanks for information concerning the company under observation, the observer's credentials, the observer's position, and a summary of the opacity data collected. On the back of this form is a diagram, which should be used to describe the relative positions of the stack under observation, the observer, and any significant natural or manmade features of the region.

The following is a list of each of the items that must be filled in on the Observation Information Form at the observation or shortly thereafter.

1. Date;
2. Company--name in full, including the name of the division;
3. Location--street name, number, and city or county where the source is located;
4. Type Facility--the category of the source, i.e., coal-fired electric generating plant, sulfuric acid plant, steel mill, pulp and paper mill, etc.;
5. Stack Number or Designation--a definition of the particular stack under observation in the ease of multiple stacks at a single facility;
6. Control Device--the type of equipment used to collect particles prior to emission from stacks;
7. Height of Discharge Point--approximate height of stack above ground;
8. Point of Emission--approximate distance from stack lip to point in plume where observation is made;
9. Type of Fuel;
10. Stack Dimensions--diameter of circular stack or length of sides of rectangular stacks;
11. Observer--name;
12. Observer Affiliation;

COMPANY ____________

LOCATION ____________

TYPE FACILITY ____________

STACK NUMBER or DESIGNATION ____________

CONTROL DEVICE ____________

HEIGHT OF DISCHARGE POINT ____________

POINT OF EMISSIONS ____________

TYPE OF FUEL ____________

STACK DIMENSIONS ____________

DATE ____________

OBSERVER ____________

OBSERVER AFFILIATION ____________

OBSERVER CERTIFICATION DATE ____________

TIME OF ARRIVAL ____________

TIME OF DEPARTURE ____________

BACKGROUND DESCRIPTION ____________

WEATHER CONDITIONS

Wind Speed ____________
Wind Direction ____________
Ambient Temperature ____________
Relative Humidity ____________

PLUME DESCRIPTION

Color ____________
Distance Visible ____________

Note any changes in weather conditions ____________

OBSERVER POSITION DIAGRAM (on the back of this page)

Locate the following on the diagram:

1. The stack configuration with the stack under observation in the center.
2. Observer position.
3. Arrow pointing in the direction the wind is blowing.
4. Any large structures or significant topographical features.

NOTE: Stack configuration is not in proportion to distances from stack in the diagram.

SUMMARY OF AVERAGE OPACITY

Set No.	TIME		OPACITY	
	Start	End	Sum	Average

Figure 5.8.4. Sample observation information form (front side).

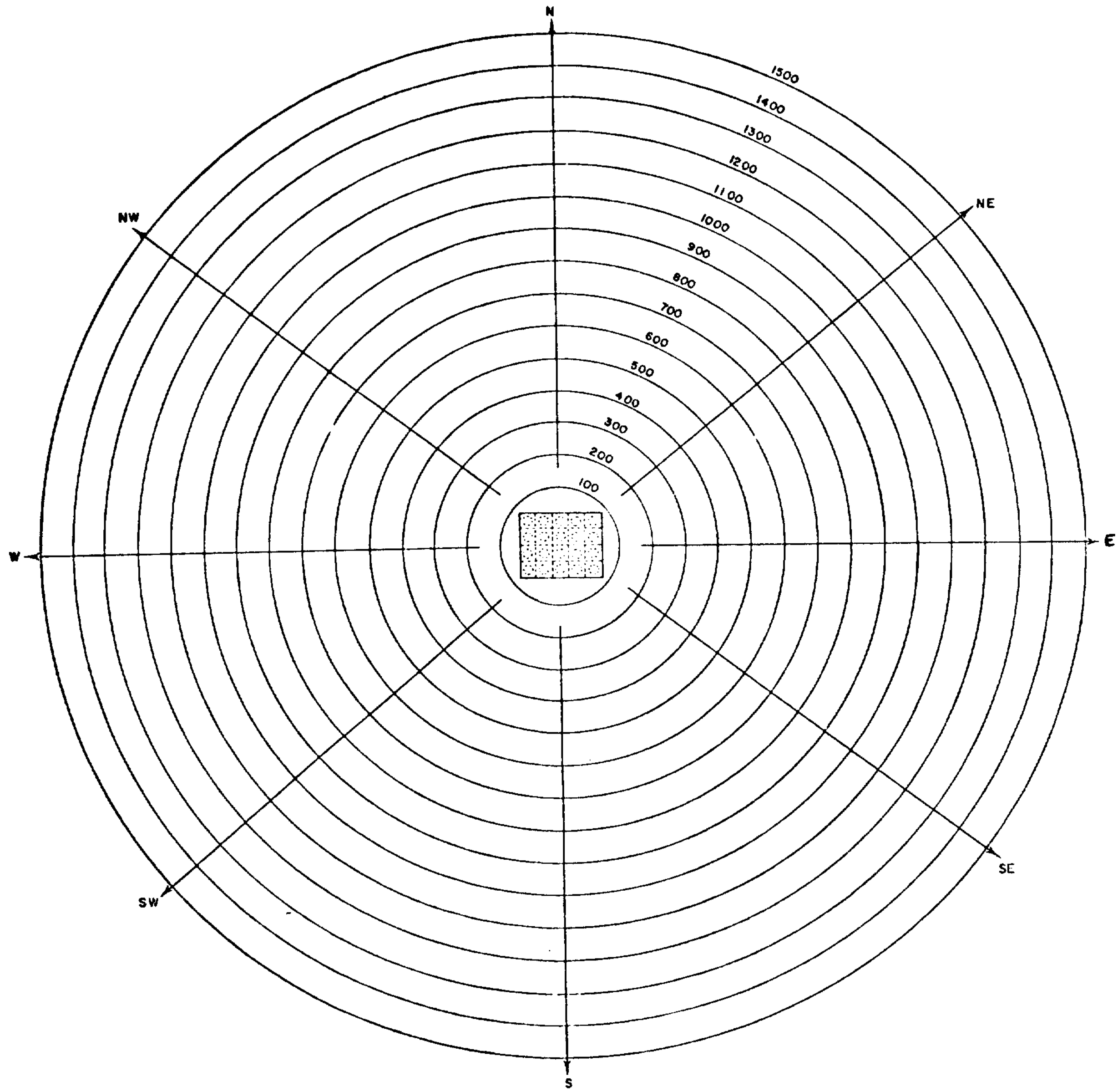


Figure 5.8.4 (con). Sample observation information form (reverse side).

13. Observer Certification Date--last time the observer was certified;
14. Time of Arrival--time the observer arrived at the position from where he observed the plume;
15. Time of Departure--the time the observer left his position after making the observations;
16. Background Description--brief description of what is in the observer's line of sight behind the plume;
17. Weather Conditions--estimated, read from instrumentation, or taken from weather station data,
18. Plume Description--color of the plume and the approximate distance from the stack where the plume is still visible;
19. Observer Position Diagram--locate the stack under observation, any surrounding stacks, the observer position, the wind direction, and any significant topographical features;
20. Summary of Average Opacity--use the data recorded on the "Observation Data Record" to determine the sum and average opacity for each set.

The Observation Data Record (see figure 5.8.5) has a heading which asks for information from the Observation Information Form for quick reference. The observer should record opacity every 15 seconds in the box under the appropriate second heading and check whether or not the plume was attached or detached.

5.8.3.3.9 Data reduction. The instructor should go through several opacity calculations based on the number of readings per set required by the law enforcement agency.

5.8.3.3.10 Testing. The instructor is to give the students a 1- to 2-hour written objective test. The test should serve two purposes: (1) to determine the effectiveness of the teaching procedures used, and (2) to highlight the more important information presented in the course. The

OBSERVATION DATA RECORD

COMPANY ______________________
LOCATION ______________________
TYPE FACILITY ______________________
STACK NO. OR DESIGNATION __________
POINT OF EMISSIONS ______________

OBSERVER ______________________
DATE ______________________
HOUR ______________________
TEST NO. ______________________

MIN.	SECONDS				STEAM PLUME		MIN.	SECONDS				STEAM PLUME	
	0	15	30	45	ATTACHED	DETACHED		0	15	30	45	ATTACHED	DETACHED
0							30						
1							31						
2							32						
3							33						
4							34						
5							35						
6							36						
7							37						
8							38						
9							39						
10							40						
11							41						
12							42						
13							43						
14							44						
15							45						
16							46						
17							47						
18							48						
19							49						
20							50						
21							51						
22							52						
23							53						
24							54						
25							55						
26							56						
27							57						
28							58						
29							59						

COMMENTS: ____

Figure 5.8.5. Sample data log.

test should be graded and discussed in the class. Each student can keep his test, but the grade should be entered in the student's permanent file.

5.8.3.4 Preparation for Observer Field Training--The following procedures are recommended for the smoke generator operator in his preparation for a training session:

5.8.3.4.1 Locate the generator on a very level ground using the third wheel at the front of the generator to compensate for slightly sloping ground. Consider the background for the plume, making sure that the most contrasting sky background available is behind the generator. Watch for large buildings or tree stands which may cause considerable downwash motions affecting the plume near the discharge point.

5.8.3.4.2 Check the generator for any obvious damage in transport.

5.8.3.4.3 Raise the stack following the manufacturer's instructions. If high winds are a possibility, take the necessary precautions to secure the stack. If it is evident that high winds will persist through the testing period, an elbow can be added to the top of the stack so that the smoke will be emitted horizontally. This will prevent shearing of the plume and avoid loss of training time.

5.8.3.4.4 Check the levels of all fuels and lubricants required by the smoke generator. In the case of a gasoline engine: the gasoline tank should be filled to its 1/2-gallon capacity; fill the benzene tank with at least 5 gallons of industrial grade benzene or benzol; fill fuel oil tank with at least 5 gallons of #2 fuel oil; and fill the motor crankcase with 1 quart of oil. Lubricate the main blower motor with several drops of oil. See reference 1 for additional information.

5.8.3.4.5 Make the necessary electrical connections; and then turn all of the necessary switches on the control panel to the "on" position (i.e., main power switch, stack fans, main blower, recorder, and light source).

5.8.3.4.6 Simulate 0 percent and 100 percent opacity values. The zero opacity can be simulated by turning on the light source with no obstruction between the source and photocell. Zero the recorder as necessary. It is recommended that the 100 percent opacity be simulated by placing a 99.99 percent neutral density filter in the smoke meter pathlength. Adjust the recorder for 100 percent opacity. Before each run, then, the operator should follow the same procedure for 0 percent opacity and do a check for 100 percent opacity by turning off the light source. Again the recorder should be adjusted based on the results from these checks.

5.8.3.4.7 Insert the 20 percent, 50 percent, and 75 percent neutral density filters one at a time in the smoke meter pathlength for one set of calibration readings. Make a total of five sets of calibration readings and record the data as it is taken (figure 5.8.3). If the error on any one reading within a set proves greater than 3 percent, commence troubleshooting procedures which should include checks for:

1. recorder malfunction,
2. photocell malfunction,
3. reflective light getting into photocell,
4. intensity of bulb.

5.8.3.4.8 Check the zero and span drift after a 30-minute warmup period and record (figure 5.8.3).

5.8.3.4.9 Complete the Smoke Generator Log (figure 5.8.3). The log shown here is merely a sample. Any items which may be inappropriate may be deleted or items which may be more appropriate may be added to meet the characteristic requirements of the particular generator in use.

5.8.3.5 Observer Field Training--This training is to consist of two parts: (1) developing judgment skills in the area of weather data, and (2) developing judgment skills in the evaluation of smoke opacities.

Several times throughout the field training, the instructor should request that the students fill out a form such as shown in figure 5.8.6. After the students complete the forms, the forms are collected and the answers compared with the instructor's evaluation of the weather at the same time. Any major variations are discussed immediately.

The instructor should describe again the correct observer positions with respect to the plume and the sun. The background for the plume should be discussed so that the students are capable of describing it on their test data forms.

The smoke generator operator starts up the generator (see section 5.8.4.3) and explains the procedures he will follow. He then demonstrates at least 20 different shades of white smoke and then 20 different shades of black smoke. Repeating the procedure he should place particular emphasis on those shades just above and below the legal limit. During these demonstrations, the operator should set the output of the generator, and when the strip chart reading stabilizes, he calls out the value for all the students to hear.

Following the demonstration, the instructor is to hand out test data forms for the practice certification runs. As the operator signals when the strip chart has stabilized at each value, the students are to glance at the plume and record their determination on the test data. The operator himself must mark the reading on the stripchart simultaneously with the signal which can be vocal or through the use of a horn. An event marker is suggested if the recorder can be equipped with one.

WEATHER DATA

NAME ______________________

DATE ______________________

TEST NO. ______________________

TIME ______________________

ESTIMATED DISTANCE FROM THE GIVEN LOCATION ______________________ feet

ESTIMATED WIND SPEED ______________________ mph

APPROXIMATE WIND DIRECTION ______________________

CONDITION ______________________

PLUME BACKGROUND ______________________

List any changes in the weather conditions:

____

____

____

____

Figure 5.8.6. Sample form for testing determination of weather data.

Each practice run should consist of 25 different white plumes and 25 different black plumes. After each run, the students should grade their own paper as the operator reads the transmissometer values aloud. The number of practice runs is determined by the level of skill demonstrated by the students' grades.

5.8.3.6 Certification Procedures--Following the practice runs, the instructor hands out the test data forms (figure 5.8.7) for the certification testing. Each form has a carbon copy attached. With an announcement that certification tests will follow, the operator should adjust the generator to generate black plumes. At each different opacity value, the operator waits for the recorder needle to stabilize, blows the horn, and simultaneously marks the reading on the stripchart. The same procedure is followed for the white plumes.

A set of 25 different shades of black plumes and 25 different shades of white plumes makes up one certifying test. After each test every student must turn in the original copy of the test data sheet, keeping a carbon copy. The instructor then reads aloud the 50 opacity values marked on the stripchart. The students grade their own papers and calculate the deviations from the transmissometer readings.

If any of the plumes were read with a deviation greater than 15 percent opacity, that student does not qualify. The student then calculates the average deviation for each category (black and white) using the formulas given. If either of the average deviations exceeds 7.5 percent opacity, the student does not qualify.

Repeat the testing procedure until all of the students or a sufficient number of the students qualify for cerfication. Prior to official certification, the instructor

SMOKE EVALUATION PROFICIENCY EXAMINATION

NAME OF OBSERVER ______________ OBSERVER'S POSITION ______________

AFFILIATION ______________ TIME ______________

Wind Speed ______________ Sky Condition ______________

Wind Direction ______________ ______________

Temperature ______________

Humidity ______________ Run Number ______________

BLACK PLUMES						WHITE PLUMES					
Reading Number	Observer Reading	Trans. Reading	+ Dev.	- Dev.	≥15% Dev.	Reading Number	Observer Reading	Trans. Reading	+ Dev.	- Dev.	≥15% Dev.
1						1					
2						2					
3						3					
4						4					
5						5					
6						6					
7						7					
8						8					
9						9					
10						10					
11						11					
12						12					
13						13					
14						14					
15						15					
16						16					
17						17					
18						18					
19						19					
20						20					
21						21					
22						22					
23						23					
24						24					
25						25					
TOTALS:											

$$\text{Av. dev.} = \frac{(\text{Sum of +Dev.})+(\text{Sum of -Dev.})}{25}$$

Av. dev. for Black Plumes ______________ Av. dev. for White Plumes ______________

Figure 5.8.7. Sample certification test form.

must recheck the original of each qualifying test sheet to confirm qualification.

5.8.3.7 <u>Field Observations</u>--The certified field observer shall follow the procedures listed in this section upon arrival at a source location.

5.8.3.7.1 Position yourself at a distance where you have a clear view of the emissions. The sun should be in the 140° sector at your back. Your line of sight should be perpendicular to the plume direction. In the case of a rectangular stack, the line of sight shall be approximately perpendicular to the longer axis of the outlet. If there is more than one stack in view, your line of sight should be perpendicular to the longer axis of the group of stacks.

5.8.3.7.2 Record all of the information asked for on the Observational Data Form, including the completion of the Observer Position Diagram.

5.8.3.7.3 Fill in the information at the top of the Observation Data Record.

5.8.3.7.4 Be sure to wear the same corrective lenses that were worn for certification. It is recommended that you remove any sunglasses and allow time for the eyes to adjust to the daylight as the case may be. This avoids biasing the data.

5.8.3.7.5 With stopwatch in hand, observe the plume momentarily at 15-second intervals for at least the number of intervals required by law. Opacity observations shall be made at the point in the plume of greatest opacity where condensed water vapor is not present.

If an attached steam plume exists, readings shall be taken at the point in the plume closest to the outlet where the condensed water vapor is no longer visible. In the event of a detached steam plume, the opacity should be evaluated at the stack outlet prior to the condensation of water to form a steam plume.

5.8.3.7.6 The data will be recorded for each set on the Observation Data Record. Upon completion of a set or sets of observations, the observer shall calculate the average opacity by summing the opacities determined in a given set and dividing by the number of readings in the set. This information shall be recorded in the Summary of Average Opacity on the Observation Information Form (figure 5.8.4).

Depending on the organizational structure, the observer may or may not be responsible for these computations of the average opacity. In the case that he is not, an alternate to the above procedure would require the deletion of the Summary of Average Opacity from the Observation Information Form and the generation of a separate form to be filled out by the person responsible for the calculations.

5.8.4 Auditing Procedures

In making special checks for auditing purposes, it is important that the checks be accomplished independent of and without disturbing the normal operating procedures.

Two audit checks are recommended to properly assess the quality of visually determined opacity data:

1. Assessment of field observations, and
2. Evaluation of training schools.

Each audit check is treated separately in the ensuing sections. A detailed discussion of auditing procedures including acceptance sampling plans and the use of control charts is contained in the Quality Assurance Handbook for Air Pollution Measurement Systems, Volume I--Principles, published by EPA.

5.8.4.1 Auditing of Field Observations--The method recommended for auditing field performance requires that a second expert observer make an observation of a given source simultaneously with the field observer being audited. The audit should include an assessment of all variables that in some way affect the accuracy of the opacity data.

It is recommended that field observations be grouped by observers and/or organizations to yield a group or lot size of about 100 (i.e., N = 100) to be performed over a time period of one calendar quarter when possible. An auditing level of 10 percent is recommended; that is, from the 100 field observations projected for a given calender quarter, 10 should be randomly selected for auditing. In situations where obtaining a lot size of 100 is impractical, an auditing level of one audit check for each 10 field observations or one audit per month, whichever is greater, is recommended.

An audit is defined as not less than 3 runs of 24 readings, each performed simultaneously by the auditor and the observer being audited.

5.8.4.1.1 Method of auditing field observations.

The auditor, i.e., the individual performing the audit, should be a currently certified smoke reader and should have extensive background experience in all areas of smoke reading. The following procedural guidelines are recommended for the auditor in monitoring field performance:

1. Accompany the observer to the field site;
2. Choose an appropriate position for viewing the plume independent of the observer's choice;
3. Fill out the Observation Information Form (figure 5.8.4) independently, but at the same time that the observer fills out his form;
4. Using individual stop watches, commence a run of readings for the same time period observed by the observer. Repeat this operation to obtain simultaneous readings for a series of three runs.
5. Record the determined opacity values for each run on separate Observation Data Records (figure 5.8.5);
6. Calculate the sum and/or the average of the opacities for each set of readings that cover the same time period as used by the observer to make his calculation;
7. Complete an Audit Data Form (figure 5.8.8) for each run. If more space is required, use a blank sheet of paper and attach it to the audit data form;
8. Inform the field observer of the comparison results, specifying any area(s) needing special attention or improvement;
9. File the record for future data quality assessment (section 5.8.4.1.2).

5.8.4.1.2 Data quality assessment of field observations.

Three aspects of data quality assessment are considered here. They are:

AUDITOR'S SIGNITURE ______________ DATE ______________

OBSERVER ______________ TIME ______________

PARAMETER	CHECK IF IN AGREEMENT	OBSERVER'S DETERMINATION	AUDITOR'S PREFERENCE OR COMMENTS
1. Type facility			
2. Control device(s)			
3. Height of discharge point			
4. Point of emissions			
5. Type of fuel			
6. Approximate stack dimensions			
7. Background description			
8. Wind speed			
9. Wind direction			
10. Ambient temperature			
11. Relative humidity			
12. Plume description			
13. Observer position			
14. Start time of run			
15. Stop time of run			
16. Sum of opacities			
17. Average opacity			
18. Existence of attached steam plume			
19. Existence of detached steam plume			

Figure 5.8.8. Audit Data Form.

1. The use of control charts for plotting audit data as they are obtained to allow for corrective action to be taken, if necessary, after each audit.
2. The use of audit data to estimate the precision and bias of the field observations on a lot-by-lot basis.
3. Testing the data quality against given upper (U) and lower (L) limits using sampling by variables to monitor and thereby help control the average percentage of reported field observations falling outside the limits.

Each aspect is treated separately in the following paragraphs.

A. Use of Control Charts

A form such as shown in figure 5.8.9 is suggested for recording individual audit data as they are obtained. Fill in the clerical information which includes the name of the auditor, date of the audit, name of the observer being audited, audit number, date that the audit period ends, and date that the Data Assessment Form is filled out.

Both the observer and the auditor are to calculate the average opacity, $\bar{O}_j$ and $\bar{O}_{aj}$, respectively, for each of the 3 runs of 24 consecutive readings each. Using the following equation, calculate the difference between the auditor's and observer's values for each run (j = 1 to 3):

$$d_j = \bar{O}_j - \bar{O}_{aj}.$$

The three values of d_j can then be plotted on a control chart as shown at the bottom of the sample data assessment form in figure 5.8.9. The control chart is a quick visual check to determine if the d_j values are within acceptable limits.

The values used in figure 5.8.9 for the upper control limit (UCL) and lower control limit (LCL) represent $\pm$ 3 standard

AUDITOR'S SIGNATURE _______________ AUDIT DATE ___________

OBSERVER'S NAME ___________________ TODAY'S DATE ___________

AUDIT NO. ______________ of Audit Period Ending _____________

DATA:

Opacity Values	Audit Run Number		
	1	2	3
$\bar{O}_j$			
$\bar{O}_{aj}$			
$d_j = \bar{O}_j - \bar{O}_{aj}$			

$$S_1 = \sum_{j=1}^{3} d_j = \_\_\_\_\_\_$$

$$\bar{d}_i = \frac{S_1}{3} = \_\_\_\_\_\_$$

Check if $|d_i| > 3\sigma_{\bar{d}} = 6$ ☐

Plot d; values

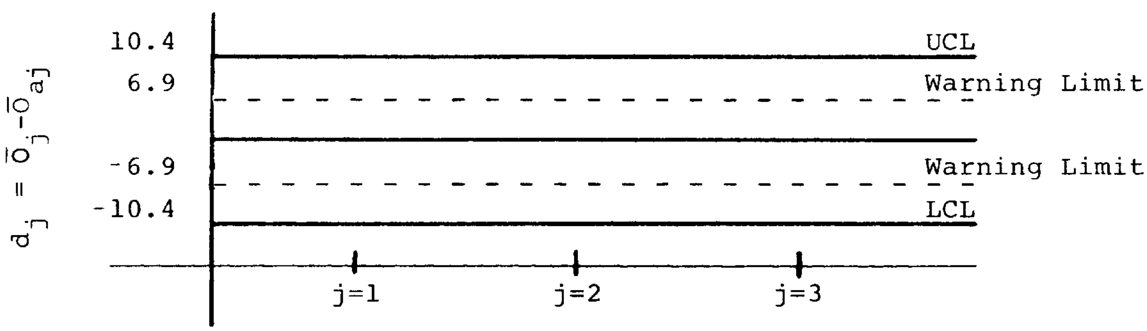


Figure 5.8.9. Sample data assessment form for each audit.

deviations of the differences based on the between-observer standard deviation, σ_b = 2.45 percent opacity, reported from a collaborative test of the method (ref. 3) and thus a standard deviation of the differences of $\sigma_d = \sqrt{2}\ \sigma_b = 3.46$ percent opacity. These limits should be recalculated and adjusted if necessary as actual field data become available.

If one or more d_j values fall outside the UCL and LCL limits or if the average difference of the three runs $|\bar{d}_i| > 6$, action to correct possible deficiences should be taken before the audited observer performs future field observations. Such action should include either informal or formal retraining of the observer.

The auditor should complete the data assessment audit form or equivalent form and forward copies to his supervisor and to the field observer's supervisor with appropriate comments if either of the above performance criteria were exceeded.

B. Estimating Precision and Bias of Field Observations

The average difference, $\bar{d}_i$, for the ith audit as recorded on the sample data assessment audit form of figure 5.8.9 is used to fill in the data in the table at the top of figure 5.8.10 for a given auditing period. That is, values for $\bar{d}_i$ for i = 1, 2, 3, ..., n are recorded in the table for each audit period.

Bias of the field observations for that lot of field observation data, obtained during the audit period, is estimated by $\bar{\bar{d}}$ calculated as shown in figure 5.8.10.

The precision is estimated in terms of the standard deviation of the average differences of the i audits, i.e., $s_{\bar{d}_i}$. The standard deviation of the differences is calculated as shown in figure 5.8.10 and used as an estimate of the standard deviation of differences for that lot of data.

AUDITOR'S SIGNATURE ________________ AUDIT PERIOD ______ to ______

OBSERVER'S NAME ________________ TODAY'S DATE ________________

DATA:
Average difference

Audit Number i

	1	2	3	4	5	6	7	8	9	10	. . .	n
$\bar{d}_i$											. . .	

$$S_2 = \sum_{i=1}^{n} \bar{d}_i$$

$$\bar{\bar{d}} = \frac{S_2}{n} = \underline{\qquad}$$

AUDIT NO	1	2	3	4	5	6	7	8	9	10		n
$\bar{d}_i - \bar{\bar{d}}$											...	
$(\bar{d}_i - \bar{\bar{d}})^2$											...	

$$S_3 = \sum_{i=1}^{n} (\bar{d}_i - \bar{\bar{d}})^2 = \underline{\qquad}$$

$$s_{\bar{d}_i}^2 = \frac{S_3}{n-1} = \underline{\qquad}$$

$$s_{\bar{d}_i} = \sqrt{s_{\bar{d}_i}^2} = \underline{\qquad}$$

DATA LIMITS $ks_{d_i} = \underline{\qquad}$ with $k = \underline{\qquad}$

$U_c = \bar{\bar{d}} + k\, s_{\bar{d}_i} = \underline{\qquad}$ Check if $U_c < U$ ☐

$L_c = \bar{\bar{d}} - k\, s_{\bar{d}_i} = \underline{\qquad}$ Check if $L_c > L$ ☐

Remarks: ____

____

Figure 5.8.10 Auditing period data assessment form.

The field data for that lot or group of field observations are reported with the calculated values for bias τ and standard deviation of differences σ_d.

C. Testing data quality against given standards

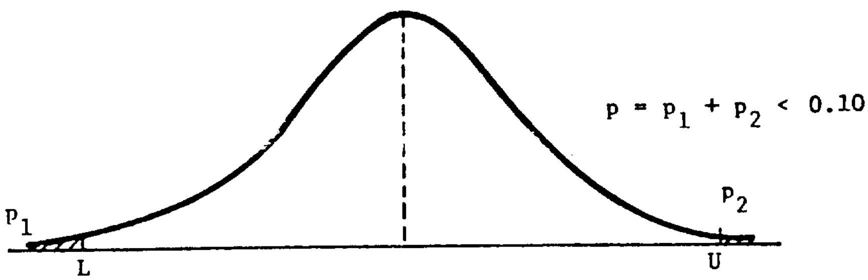
Because the lot size is generally small, $N \leq 100$, and the sample size is small, say of the order $n \leq 10$, it is important to assess the quality of the data with respect to prescribed limits using sampling by variables to make as much use as possible of the audit data.

Some of the background concerning the assumptions and the methodology will be repeated below for convenience. However, a number of publications can be referred to for a more detailed discussion of sampling by variables (see refs. 8, 9, and 10). The discussion below will be given in regard to the specific problem of analyzing visible opacity data which has some unique features as compared with the usual sampling plans.

The plan as illustrated here is designed to provide a probability of 0.9 of detecting a lot or group of field data in which 10 percent or more of the differences, if all observations had been audited, fall outside the limits L and U.

Using the data from a collaborative study on this method (ref. 3), the mean difference of opacity measurements made by different observers has a standard deviation of 3.45 percent opacity. Assuming $3\sigma_{\bar{d}}$ limits, the values of -10.4 and +10.4 are used to define lower and upper limits, L and U, respectively, outside of which it is desired to control the portion of differences, $\bar{d}_i$. Following the method given in reference 10, a procedure for applying the variables sampling plan is described below. Figures 5.8.11 and 5.8.12 illustrate satisfactory and unsatisfactory data quality with respect to the prescribed limits L and U.

The variables sampling plan requires the following:



Example 5.8.11. Example illustrating $p < 0.10$ and satisfactory data quality.

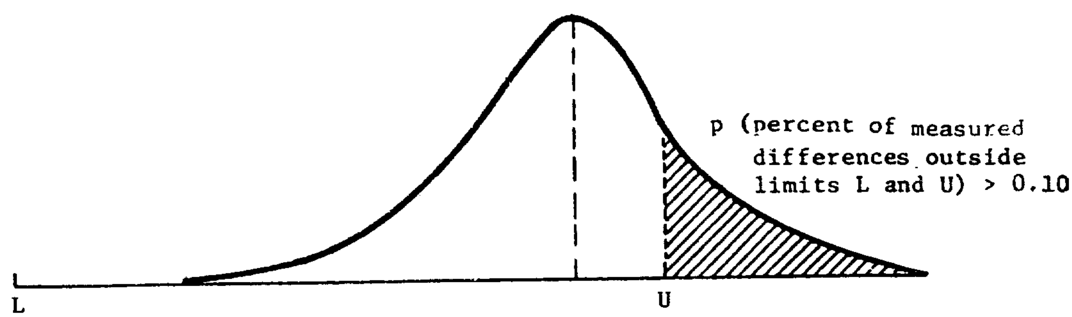


Figure 5.8.12. Example illustrating $p > 0.10$ and unsatisfactory data quality.

$\bar{\bar{d}}$, the sample mean difference

$s_{\bar{d}}$, the standard deviation of the differences

k, a constant whose value is a function of p and n for a given sampling plan, and

p, the portion of the differences outside the limits L and U at which we want to detect with a probability P.

For example, to control at 0.9 the probability of detecting lots with data quality p equal to or greater than 0.10 (or 10% of the differences outside of L and U) for a sample size of n = 10, then the value of k = 2.112 is obtained from table 5.8.3. Additional values of k for other sampling plans can be determined from table II of reference 10. The values of $\bar{\bar{d}}$ and $s_{\bar{d}}$ are calculated as shown in figure 5.8.10.

Given the above information the test procedure is applied and subsequent action is taken in accordance with the following criteria:

a. If both the following conditions are satisfied,

$$U_c = \bar{\bar{d}} + ks_{\bar{d}} \leq U$$

$$L_c = \bar{\bar{d}} - ks_{\bar{d}} \geq L$$

then the measurements are considered to be consistent with prescribed data quality limits and no corrective action is prescribed.

b. If one or both of the inequalities is violated, possible deficiencies exist in the opacity determination process as carried out for that particular lot of field observations. These deficiencies should be identified and corrected before future field observations are performed.

Table 5.8.3 contains a few selected values of n, p, and k for convenient reference.

Table 5.8.3 Sample plan constants, k for P {detecting a lot with proportion p outside limits L and U} ≥ 0.9

Sample Size n	p = 0.2	p = 0.1
3	3.039	4.258
5	1.976	2.742
7	1.721	2.334
10	1.595	2.112
12	1.550	2.045

5.8.4.2 Evaluation of Training Schools-- The method recommended for monitoring a given training school requires that an auditor attend one complete training course for every 10 training courses held by the school. If less than 10 training courses are held in 1 year, at least one of the courses must be audited. The audited courses are randomly selected.

5.8.4.2.1 Method of auditing training schools. The auditor, i.e., the individual performing the audit, should have extensive background experience in all of the areas listed in sections 5.8.3.2 and 5.8.3.3. In addition, the auditor must be a currently certified observer and have had experience in the preparation and implementation of a training course.

Attend all of the lectures and/or seminars, using a Course Evaluation Form as shown in figure 5.8.13 as a guideline for making quality evaluations. Upon completion of the course, document the evaluation with the designated grading system.

Check the smoke generator for any obvious malfunctions, following procedures similar to those in section 5.8.3.3. Using appendix A as a guideline, confirm that the generator meets those specifications. Document all results on a Smoke Generator Log (figure 5.8.5).

5.8.4.2.2 Course-quality assessment. It is recommended that the audit level be increased by a factor of two if either of the following situations occurs:

METHOD 9

COURSE EVALUATION

GRADING SYSTEM: 1 - Excellent 3 - Fair
2 - Good 4 - Poor

QUALITY CHECK	1	2	3	4	COMMENTS
1. Definition of course objectives					
2. Choice of subjects					
3. Lecturer(s)' knowledge of subjects covered					
4. Relevancy of the material covered					
5. Proper emphasis on important facts					
6. Presentation of the lectures					
7. Choice of visual aids					
8. Use of visual aids					
9. Organization					
10. Field-lecture balance					
11. Condition of smoke generator					
12. Calibration and operation of smoke generator					
13. Testing procedures					

14. Other comments ______________________

Figure 5.8.13. Sample course evaluation form.

1. Any of the quality checks in figure 5.8.13 falls below a grade 2;
2. The auditor notices any other serious irregularity in the course proceedings.

The training school should be audited continuously until either or both of the following situations are corrected:

1. Any of the quality checks is rated a grade 4, and
2. The smoke generator does not meet the specifications stated in appendix A.

3.0 FUNCTIONAL ANALYSIS OF TEST METHOD

3.0 FUNCTIONAL ANALYSIS OF TEST METHOD

Test Method 9--Visual Determinations of the Opacity of Emissions from Stationary Sources, is described in the Federal Register, November 12, 1974, and is reproduced in section 5.8.1 of this document. This method pertains to the determination of the opacity of visible emissions by qualified observers. It requires the proper training and certification of the observers and the use of defined procedures in the field when making the determinations.

This method has been subjected to collaborative testing (ref. 3); therefore, some quantitative information on the precision and bias is available. In some areas of variable evaluation, though, quantitative data is not available, and the functional analysis is forced to be somewhat general. In these cases, engineering judgments were used in estimating variable limits. The subject of error analysis is discussed in references 11 and 12.

3.1 VARIABLE EVALUATION AND ERROR RANGE DATA

The opacity of the visible emissions from a stationary source where Method 9 is applicable is reported for enforcement purposes in terms of the average opacity over a given period. A set of at least 24 consecutive readings is generally observed, with each reading taken at 15-second intervals. From this set, the average opacity can be calculated with the following equation:

$$\bar{O} = \frac{\sum_{j=1}^{m} O_j}{m} \qquad (1)$$

where:

$\bar{O}$ = calculated average opacity, percent opacity,

O_j = determined opacity for the jth reading, percent opacity,

m = number of consecutive intervals required by the law enforcement agency for computing average opacity to determine a violation of the applicable opacity standards.

The plume at the time and point of the readings will have a specific but unknown percent opacity (O'). The difference in the $\bar{O}'$ (average of the true opacity over the same time interval) and $\bar{O}$, as calculated in equation 1 above, is due to a combination of errors in the observation process, some of which are controllable, while others are not. A short description of each source of error is given in the following list.

1. Position of the observer with respect to the plume. The reference method (section 5.8.1) states that the observer should locate himself at a sufficient distance from the source such that he shall have a clear view of the plume. It also states that the observer should be perpendicular to the plume direction in the case of a single stack. Error due to a deviation from this ideal positioning would depend on the exact position, the shape of the plume, and the wind speed and direction at the time of the readings.

The reference method (section 5.8.1) also states that, in the case of multiple stacks, the observer is to position himself so that his line of sight is perpendicular to the longer axis of the set of stacks. Also, his line of sight should not include more than one plume at a time. A deviation from either of these requirements could cause the data to be biased.

Although error can result from an improper observer position, his position can be considered a controllable variable in the observational process. Proper positioning can almost always be realized at some point in time with appropriate weather conditions.

2. Position of the observer with respect to the sun. The qualified observer should be positioned so that the sun is oriented in the 140° sector to his back. Just as in the source of error discussed above, the observer's position with respect to the sun is a controllable variable, and the errors due to this source can be minimized. Test data (ref. 1) has shown that the closer the sun is to being directly behind the observer, the more accurate the observation values will be.

3. Determination of the weather data. Good judgment and proper documentation of the weather data play an important role in interpreting opacity data at a later date. Inaccurate weather information or the lack of weather information can serve to discredit the data in a court of law. The use of weather measurement instrumentation, weather station data, or charts, can greatly reduce error in judgment.

4. Corrective or colored lenses. The use of corrective or colored lenses can be a major source of observational error if they were not worn during the certification testing. This source of error can be eliminated if the observer takes the precaution of removing any sunglasses or unnecessary lenses while performing the visual determinations.

5. Background against which the plume is viewed. The plume is most visible and the observer will determine the highest opacity value for a given plume when the background is contrasting with the color of the plume. It is with the contrasting background that the plume opacity can be determined with the greatest degree of accuracy. However, the probability of positive error is also the greatest under these conditions. As the background becomes less contrasting

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the apparent plume opacity diminishes and determinations tend to assume a negative bias (which actually favors the plant operator). The results of studies undertaken to determine the magnitude of the positive errors are given in the Federal Register, November 12, 1974.

6. Momentary observations. The observer should not study the plume continuously, but instead should observe the plume momentarily at 15-second intervals. More than a momentary glance can not only allow the observer to lose his concentration but may also cause eye fatigue.

7. Point of observation. Error can occur if the observer exercises poor judgment in his determination of the point of observation. The point of observation should be the point in the plume closest to the stack where condensed water vapor is not present. The point should also be where the plume exhibits the greatest opacity. Error, if any, due to readings taken at a point where condensed water vapor is present is usually positive. However, after comprehensive training, a certified observer can readily identify the portion of the plume which contains condensed water vapor and will avoid assigning an opacity to a plume which contains any visible (condensed) water droplets. Thus the probability of error due to the presence of condensed water vapor is negligible (ref. 13). Readings taken at points other than the point of greatest opacity cause the average opacity value to be less than the actual opacity. The probability of this source of error, too, is a function of the quality of training and the observer's experience, and can be considered almost nonexistent in observations made by certified observers. where!

8. Experience of the observer. The term "experience" as used here refers to length of time the observer has been

certified, which can dictate his personal biases. Collaborative tests have shown that the readings of the more experienced observer are consistently more accurate than the readings of the less experienced observer. However, the less experienced observer's error is almost always negative, which is in the favor of the emission source.

9. Nighttime observations. Visible emission monitoring is difficult to apply at night. Any observer who must make observations at night should receive special training to calibrate his eye for night conditions. The background under these conditions will generally be less contrasting, hence the error will tend to be negative. See number 6 above.

10. Calibration of the observer's eye. The readings are subject to error from inaccuracies in the calibration of the observer's eye. Such an error would bias all observations made until the observer is tested and recertified. This can be avoided with frequent auditing of the observer's performance, stringent specifications on the smoke generator used for certification, and frequent recertification.

11. Data processing. Errors can occur in the calculation of the average opacity over a given time interval. These errors can be avoided by consistently rechecking the data.

3.2 COMBINING ERROR TERMS

All of the error terms discussed thus far are independent; at least there are no obvious reasons why they should not be independent. Therefore, the total bias in the visual determination of opacity is the algebraic sum of the biases of the individual terms. The variance of the observational data is the sum of the variances of the individual error terms:

$$\sigma_T^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \ldots . + \sigma_n^2 .$$

3.3 PRECISION ESTIMATES

The variability will be larger when the measurements to be compared are performed by different observers than when they are carried out by a single observer performing replicates. Many different measures of variability are conceivable according to the circumstances under which the measurements are performed. Only two situations will be discussed here. They are as follows:

1. Repeatability, r, is the value below which the absolute difference between duplicate results, i.e., two observations made on the same plume by the same observer over a short interval of time, may be expected to fall with a 95-percent probability.
2. Reproducibility, R, is the value below which the absolute difference between the observations made on the same plume by different observers may be expected to fall with a 95-percent probability.

The above definitions are based on a statistical model, according to which each observation is the sum of three components:

$$O = \bar{O} + b + e \qquad (2)$$

where

- O = the measured value, percent opacity,
- $\bar{O}$ = the true average, percent opacity,
- b = an error representing the differences between observers, percent opacity,
- e = a random error occurring in each observation, percent opacity.

In general, b can be considered as the sum

$$b = b_r + b_s \tag{3}$$

where b_r is a random component and b_s a systematic component. The term b is considered to be constant during any series of observations performed under repeatability conditions, but to behave as a random variate in a series of observations performed under reproducibility conditions. Its variance will be denoted as

$$\text{var } b = \sigma_L^2, \tag{4}$$

the observer bias variance.

The term e represents a random error occurring in each measurement. Its variance

$$\text{var } e = \sigma_r^2 \tag{5}$$

will be called the repeatability variance.

For the above model, the repeatability, r, and the reproducibility, R, are given by

$$r = 1.96\ \sqrt{2}\ \sigma_r = 2.77\ \sigma_r \tag{6}$$

and

$$R = 2.77\ \sqrt{\sigma_r^2 + \sigma_L^2} = 2.77\ \sigma_R. \tag{7}$$

where σ_R^2 will be referred to as the reproducibility variance. Using the data available from a collaborative study (ref. 3) the reproducibility standard deviation, σ_R, is taken to be 3.46 percent opacity. The repeatability standard deviation, σ_r, is assumed to be 2.0 percent opacity. The repeatability and reproducibility can be calculated with these values as follows:

$$r = (2.77)(2.0) = 5.54 \text{ percent opacity} \tag{8}$$

and

$$R = (2.77)(3.46) = 6.79 \text{ percent opacity.} \quad (9)$$

Using the same data, the observer bias variance, σ_L^2, is assumed to be 1.99. When compared with the value of the within-observer or repeatability variance, $\sigma_r^2 = 4.0$, the observer bias variance makes up only a small portion of the composite between observer or reproducibility variance, $\sigma_R^2 = \sigma_r^2 + \sigma_L^2$. Hence the major sources of error are not items 8, 9, and 10 above, but rather the other sources of error which can be more readily controlled as discussed above.

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APPENDIX A

APPENDIX A

GLOSSARY OF SYMBOLS

This is a glossary of the symbols used in this document. Symbols used and defined in the reference method (section 5.8.1) are not repeated here.

m	Number of readings in a given run.
O_j	Opacity value measured by the observer when the jth reading is taken.
O_{T_j}	Opacity value recorded by the transmissometer recorder at the jth reading during a certification test.
O_{aj}	Average opacity value calculated from the auditor's data for the jth run.
d_j	Difference in the audit average opacity value and the value determined by the observer for the jth run.
S_1	Summation of the d_j value for the three runs per audit.
$\bar{d}_i$	Average of the differences d_i for the ith audit.
N	Lot size, ie., the number of field observations to be treated as a group.
n	Sample size for the auditing period.
S_2	Summation of $\bar{d}_i$ values for the n audits under assessment.
$\bar{\bar{d}}$	Bias of the field observations for a given lot or auditing period.
S_3	Intermediate summation used in the calculation of $S_{\bar{d}_i}$.
$s_{\bar{d}_i}$	Estimated standard deviation of the average of the differences between $\bar{O}_j$ and $\bar{O}_{a_j}$.
σ_b	Between-observer standard deviation computed from collaborative test data.
σ_d	Standard deviation of the differences computed from collaborative test data.
L	Lower quality limit used in sampling by variables.
U	Upper quality limit used in sampling by variables.
L_c	Lower quality limit value calculated from audit data.
U_c	Upper quality limit value calculated from audit data.

k	Constant used in sampling by variables.
P	Percent of differences outside of specified limits L and U.
LCL	Lower control limit of quality control chart.
UCL	Upper control limit of a quality control chart.
σ_T^2	Total variance of the observational data.
r	Repeatability.
R	Reproducibility.
b	Error representing the differences between observers
e	Random error occurring in each observation.
b_r	Random component of b.
b_s	Systematic component of b.
σ_L^2	Observer bias variance, also denoted by var b, calculated from collaborative test data.
σ_r^2	Repeatability variance, also denoted by var e, calculated from collaborative test data.
σ_R	Reproducibility standard deviation calculated from collaborative test data.
σ_r	Repeatability standard deviation calculated from collaborative test data.
σ_R^2	Reproducibility variance calculated from collaborative test data.

APPENDIX B

APPENDIX B

GLOSSARY OF TERMS

The following glossary lists and defines the technical and statistical terms as used in this document.

Bias	The systematic or nonrandom component of system error.
Duplicate results	The results from two observations made on the same plume by the same observer.
Lot	A specified number of objects to be specified as a group.
Observation	A run or series of runs of visual determinations made at a given source during a single visit.
Quality audit	A management tool for independently assessing data quality.
Quality control check	Checks made by training school personnel or observers on certain items of equipment and procedures to assure data of good quality.
Precision	A measure of mutual agreement among individual measurements of the same opacity under prescribed similar conditions and expressed in terms of the standard deviation.
Reading	A single instantaneous glance at the plume for the purpose of making a determination of plume opacity.
Repeatability	The value below which the absolute difference between duplicate results may be expected to fall with a 95-percent probability.
Reproducibility	The value below which the absolute difference between the observations made on the same plume by different observers may be expected to fall within a 95-percent probability.
Run	A series of consecutive readings from which an average opacity can be determined.

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13. TYPE OF REPORT AND PERIOD COVERED

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16. ABSTRACT

Guidelines for the quality control of opacity determination by the Federal reference method are presented. These include:

1. Good operating practices.
2. Directions on how to assess performance and to quality data.
3. Directions on how to identify trouble and to improve data quality.
4. Directions to permit design of auditing activities.

The document is not a research report. It is designed for use by operating personnel.

17.

Quality assurance		13H
Quality control		14D
Air pollution		13B
Stack gases		21B

Unlimited	Unclassified	95
	Unclassified	