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A Compilation of Opacity Monitor Performance Audit Results

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ABSTRACT

Opacity monitor performance audit procedures and devices have been developed and field tested on 93 opacity monitors. The results of this test program indicate that opacity monitoring systems achieve high levels of availability, and are capable of providing accurate emissions data. The results also show that problems impacting data quality are generally limited to monitor miscalibration and/or misadjustment, as well as improper or inadequate operating and maintenance practices. It is believed that improved monitor performance and data reliability can be achieved with additional training of monitor operators and more frequent performance audits.

This document describes the audit program for continuous emission monitors (CEMs) of effluent opacity. Detailed explanations of the audit methodology, monitor analyses, and analytical criteria are included, and both criteria- and monitor-specific results of installed opacity monitor audits are delineated. Finally, conclusions are drawn as to the adequacy of monitor performance and data reliability, and recommendations are offered that can optimize opacity monitoring system performance.

II. PERFORMANCE AUDIT PROGRAM

Audit Program Description

Performance audits of 93 opacity monitors were conducted at 41 sources in EPA Regions IV, V, and VII through July 1982. All monitors were located at coal-fired steam generators, with the exception of one that was located at a petroleum refinery catalytic regenerator. These test sites were selected according to the following audit criteria:

> The test site had at least one of the four representative monitor types in current use (Lear Siegler, Contraves Goerz, Dynatron, Esterline Angus).
>
> The monitor had been in operation for a minimum of one year.
>
> The monitor had undergone a PST that indicated initial compliance with Performance Specification 1, Appendix B, 40 CFR 60.

The opacity monitor audit program was designed to provide accurate, reliable analyses of monitor performance through a simple, quick field test procedure which can be performed by a single technician with a basic understanding of transmissometry. Equipment necessary for a typical audit includes a specialized retroreflector for the specific monitor being tested to simulate clear stack conditions. In addition, three neutral density filters, traceable to the National Bureau of Standards (NBS), are included to evaluate both the linearity and the calibration error of the monitor. All of the necessary equipment can be transported in a small suitcase.

Audit Methodology

Opacity monitor field audits consist of two sequential procedures: (1) a general information survey and (2) the site monitor audit. The general information survey, typically conducted prior to the actual site visit, serves to gather information required to tailor the audit procedures and equipment to the specific source and monitor. This information includes:

1. Source identification, location, fuel used, emission control device(s) (before and after the monitor).

2. Opacity monitor manufacturer, model and serial numbers, dates of installation and certification (PST), stack diameters at monitor location and exit, proximity to upstream or downstream flow disturbances, types of opacity data recording equipment and recording intervals.

3. Date of most recent opacity monitor calibration and type of calibration (off-stack using neutral density filters, or on-stack during clear-stack conditions), recalibration criteria (zero/span error or scheduled recalibration), time interval between check/change of air purge filters, between check/change of optical surfaces, or between zero/span adjustment.

The field audit procedures are used to determine whether the monitor has been properly operated and whether the monitor accuracy and calibration are of sufficient quality to provide useful opacity data. Although these procedures may differ slightly in their order for each type of monitor, they all include the following three basic analyses:

1. Monitor Component Analysis,

   a. The fault lamp indicators on the monitor's control panel are checked to determine whether the monitor is operating within the manufacturer's prescribed limits.

   b. The stack exit diameter and monitor pathlength are determined to verify the accuracy of the monitor's preset stack exit opacity correction factor.

   c. Various internal electronic checks are performed using the controls in the monitor's control unit to further verify the operational status of the monitor.

   d. The control panel meter and chart recorder responses are compared to the monitor's internal span value, in order to determine the accuracy of the control panel meter and internal zero and span functions.

2. Monitor Maintenance Analysis,

   The optical alignment and dust accumulation on optical surfaces are checked to determine the adequacy of the monitor mounting and maintenance frequency.

3. Calibration Error Analysis,

   The calibration error and linearity of the monitor are checked using neutral density filters.

The Lear Siegler, Esterline Angus, and Contraves Goerz monitors require that an audit device with an adjustable retroreflector be mounted on the transceiver to simulate clear stack conditions. Neutral density filters are then inserted into the audit device to determine the calibration/accuracy of the monitor at three different opacity levels. For the Dynatron opacity monitor, the audit device neutral density filters must be inserted in front of the monitor's retroreflector. This methodology provides an incremental calibration check, because the filter opacity is combined with the effluent opacity.

Audit Procedures and Terminology

Each opacity monitor field audit comprises up to 10 specific analyses which encompass the monitor's accuracy, precision, and the quality of monitor operation and maintenance practices. These procedures and their associated terminology are detailed as follows:

Fault Lamp Analysis. The transceiver unit of a typical opacity monitor has several fault monitors that warn of monitor system malfunctions and/or impending conditions of excessive opacity. Monitor fault lamps are indicative of a variety of conditions, depending on the manufacturer, but most units use fault lamps to monitor the intensity of the optical beam, the quantity of dust on monitor optical surfaces, the status of internal circuitry that maintains monitor calibration, and/or the magnitude and rate of increase of opacity. In general, a fault lamp error exists if, at the time of a performance audit, any of the fault lamps are illuminated. However, the absence of illuminated fault lamps does not preclude malfunctions in the fault lamp circuits or the lamp bulbs.

Automatic Gain Control (AGC) Circuit Analysis. Lear Siegler opacity monitors employ an AGC circuit to compensate electronically for reductions in the optical beam intensity resulting from power supply fluctuations or normal bulb deterioration. This compensation prevents beam intensity variations from being interpreted as variations in measured opacity. Thus, a fault condition exists when a Lear Siegler monitor's AGC circuit is not functional, and is indicated when the AGC lamp is not lit. However, an AGC circuit fault does not necessarily diminish the accuracy of opacity measurements, provided that the reference signal value is within the specified range.

Monitor Alignment Analysis. The optical alignment of the transceiver/retroreflector system is critical in maintaining accurate opacity measurements. Misalignment of the beam can cause erroneously high opacity readings, because a significant portion of the measurement beam is not returned to the transceiver. Most opacity monitor manufacturers include provisions for an optical alignment check, as either a standard feature or an option. Monitor alignment errors are indicated by an off-center beam image on the transceiver and/or retroreflector.

Stack Exit Correlation Analysis. Typically, the cross-stack optical pathlength of the installed opacity monitor is not equal to the diameter of the stack exit. To obtain a true stack exit opacity value, the measured opacity at the monitor location is corrected to stack exit conditions through the use of a pathlength correction factor. The stack exit correlation error is the percent error of the pathlength correction factor, as preset by the manufacturer, relative to a pathlength correction factor calculated through the use of actual measurements, blueprints, etc.

Control Panel Meter Analysis. Most opacity monitors have a panel meter located on their control or transceiver units to monitor opacity readings or to adjust an internal monitor parameter. The control panel meter correction factor is the meter readings compared to the specified opacity value for the internal span filter.

Reference Signal Analysis. The Lear Siegler monitor reference signal is an internal monitor electrical signal output that indicates the electronic alignment of the transceiver circuitry (usually 20 ma). The reference signal error is the percentage difference between the measured current value of the signal and the specified 20-ma value.

Internal Zero and Span Analysis. The zero and span errors are the percentage difference between the internal reference filter opacities that the monitoring system should record and those opacity values actually displayed on the chart recorder. These errors occur due to one or a combination of reasons: (a) the values for the internal zero and span functions are wrong, (b) the internal electronics responding to the zero and span functions are not working properly, (c) the signal from the transceiver to the chart recorder is being altered, and (d) the chart recorder is not displaying the incoming signal correctly.

Zero Compensation Analysis. The zero compensation circuit of the Lear Siegler monitor automatically adjusts the monitor's zero to compensate for dust accumulation on the transceiver's optical surfaces. The zero compensation analysis is based on recording the zero compensation before and after cleaning the transceiver and retro-reflector optical surfaces.

Optical Surface Dust Accumulation Analysis. The optical surface dust accumulation analysis determines the amount of dust (measured in terms of percent opacity) found on the optical surfaces, based on the reduction in opacity before and after cleaning of the optical surfaces. To obtain a reliable assessment, this audit analysis should be performed when the stack opacity is relatively constant.

Calibration Error Analysis. This analysis involves comparison of the monitor responses to the known opacity values for a series of three reference neutral density filters (as modified in opacity value by the optical pathlength correction factor). The calibration of the reference filters used in this analysis is traceable to the NBS.

Audit Criteria

Specific criteria have been developed for the determination of opacity monitor performance based on (1) Performance Specification 1, Appendix B, 40 CFR 60, (2) manufacturer's recommendations, and (3) extensive practical experience. For the previous analytical procedures, these criteria are:

Fault Lamp Analysis. A fault lamp error is indicated when one or more of the control unit fault lamps are illuminated. Under performance audit conditions, these lamps provide an indication of monitor systems and parameters that may be out-of-specification prior to the audit, thereby signifying the level of monitor operation and maintenance.

Automatic Gain Control (AGC) Circuit Analysis. A Lear Siegler AGC circuit error occurs when the AGC circuit is not operating. The AGC LED, located on the transceiver head, is illuminated when the AGC circuit is operating.

Monitor Alignment Analysis. The optical beam path should be properly aligned as indicated by checking the centering of the beam image on the transceiver and/or retroreflector.

Stack Exit Correlation Analysis. The percent error of the optical pathlength correction factor, as preset by the monitor manufacturer, relative to that calculated from actual measurements, should be no greater than ±2 percent.

Control Panel Meter Analysis. The control panel meter correction factor, based on a comparison of opacity values between the meter and that of the internal span filter, should fall within the range of 0.98 to 1.02, or ±2 percent opacity (differences of more than 10 percent opacity may be indicative of other monitor problems).

Reference Signal Analysis. The Lear Siegler reference signal error, as indicated by the percentage difference in the internal reference signal value and the manufacturer's specified value of 20 ma, should not exceed ±10 percent of the specified value.

Internal Zero and Span Analysis. Internal zero and span errors, based on comparing the monitor internal filter opacity values with those indicated by the opacity recorder, should not exceed ±2 percent opacity.

Zero Compensation Analysis. The zero compensation analysis, based on a comparison of zero compensations before and after cleaning of monitor optics, should result in an automatic zero adjustment range of ±0.018 optical density (not in excess of ±4 percent opacity) The zero compensation should approach 0.000 optical density after cleaning.

Optical Surface Dust Accumulation Analysis. The optical surface dust accumulation, based on the difference in opacity readings before and after cleaning of monitor optics, should not exceed 4 percent opacity.

Calibration Error Analysis. Transmissometer calibration error, based on the sum of the absolute value of the mean difference and 95 percent confidence interval observed for the differences in opacity indicated by the monitor and that of the given reference neutral density filters, should be no greater than 3 percent opacity.

III. SUMMARY AND DISCUSSION OF AUDIT RESULTS

Opacity monitor audit results are summarized and discussed in this section for the four representative types of monitors evaluated. Table 1 summarizes results of the audit analyses of the four monitors. Figure 1 illustrates the relationship between actual and measured opacity for all monitor types, and Figures 2 through 5 illustrate the same relationship for each type of monitor tested.

Results of Criteria-Specific Analyses

General Operation and Maintenance Survey. At the initiation of the opacity monitor field audit program, all of the monitors were believed to be functioning properly. However, of the 93 monitors audited, only 89 were fully operational. Monitor availability, as determined by reviewing the previous month's data, was 100 percent for 69 of the 93 monitors, and the average monitor availability was approximately 95 percent.

The general audit survey includes a variety of factors affecting monitor operation and maintenance (e.g., the accessibility for maintenance, the supply of spare parts, etc.). In general, these factors had little correlation with monitor performance. However, one factor of significant importance was whether the monitor maintenance was performed by plant personnel or by a monitor-servicing contractor. Nearly all (six of seven) of the monitors serviced by monitor-servicing contractors had calibration errors of $\leq$3 percent opacity. In contrast, monitors serviced by site personnel often lacked necessary maintenance, and two sources were identified at which monitor manufacturer's specifications for maintenance were not followed.

During the audit program, 30 opacity monitors that were installed in exhaust ducts transporting effluent streams to a common exhaust stack were audited. None of these common stacks had an installed opacity monitor. To determine the stack exit opacity, the source combined the duct opacities measured by the respective monitors without weighting them according to duct flowrate. In addition, a few of these sources simply arithmetically-averaged the duct opacities to obtain a stack exit opacity. Thus, in cases where the duct flowrates were unequal, the total opacities measured for combining duct systems were determined incorrectly.

Fault Lamp Analysis. The fault lamps provide a good indication of the current status of the monitoring system operation and maintenance, particularly with reference to the optical beam intensity, optical system dust accumulation, or a zero/span malfunction. The monitor parameter indicated by a fault lamp is considered to be "out of specification" if the control unit lamp is illuminated. Of the 93 monitors audited, approximately 4 percent of the total were found to have one or more illuminated fault lamps. In addition, these same monitors had calibration errors in excess of 10 percent, thereby indicating a positive correlation between the fault lamp status and the reliability of measured opacity.

Automatic Gain Control (AGC) Circuit Analysis. The status of the AGC circuit (employed on the Lear Siegler monitor only) is indicative of the monitor's ability to compensate electronically for reductions in the optical beam intensity resulting from fluctuations in the lamp electrical

TABLE 1. OPACITY MONITOR AUDIT RESULTS[1]

AUDIT ANALYSES	LEAR SIEGLER Number Within Specs.	LEAR SIEGLER Number Out of Specs.	CONTRAVES GOERZ Number Within Specs.	CONTRAVES GOERZ Number Out of Specs.	DYNATRON Number Within Specs.	DYNATRON Number Out of Specs.	ESTERLINE ANGUS Number Within Specs.	ESTERLINE ANGUS Number Out of Specs.	% Total Number Monitors Tested Out of Specs.
Number of Monitors Audited	58		27		5		3		
MONITOR COMPONENT ANALYSIS									
Fault Lamps	56	2	27	0	3	2	3	0	4
AGC Circuit	57	1	NA[3]	NA	NA	NA	NA	NA	2
Monitor Alignment	55	0	26	0	3	2	2	1	3
Stack Exit Correlation Error	51	7	26	1	2	3	3	0	12
Panel Meter Status	0	55[4]	22	5	4	0	2	1	69
Reference Signal Error	54	1	NA	NA	NA	NA	NA	NA	2
Internal Span Error	44	11	22	5	3	1	3	0	19
Internal Zero Error	53	2	25	2	3	1	3	0	6
MONITOR MAINTENANCE ANALYSIS									
Zero Compensation Factor	47	8	NA	NA	NA	NA	NA	NA	15
Optical Dust Accumulation	41	12	22	3	3	1	3	0	19
Calibration Error Analysis:[2]									
Low Range (8.5% Opacity)	50	5	25	2	1	3	3	0	11
Midrange (18.5% Opacity)	49	7	22	5	1	3	3	0	17
High Range (42.5% Opacity)	46	9	19	8	0	4	2	1	25

[1] See Section II of this report for audit methodology, definition of terms, and audit criteria.

[2] The calibration error analysis for the Dynatron monitors utilized different neutral density filters: Low Range = 17.0% Opacity, Midrange = 56.5% Opacity, and High Range = 81.0% Opacity.

[3] Not Applicable

[4] Lear Siegler panel meter readings of opacity were generally accurate, but values for optical density and circuit current were typically erroneous.

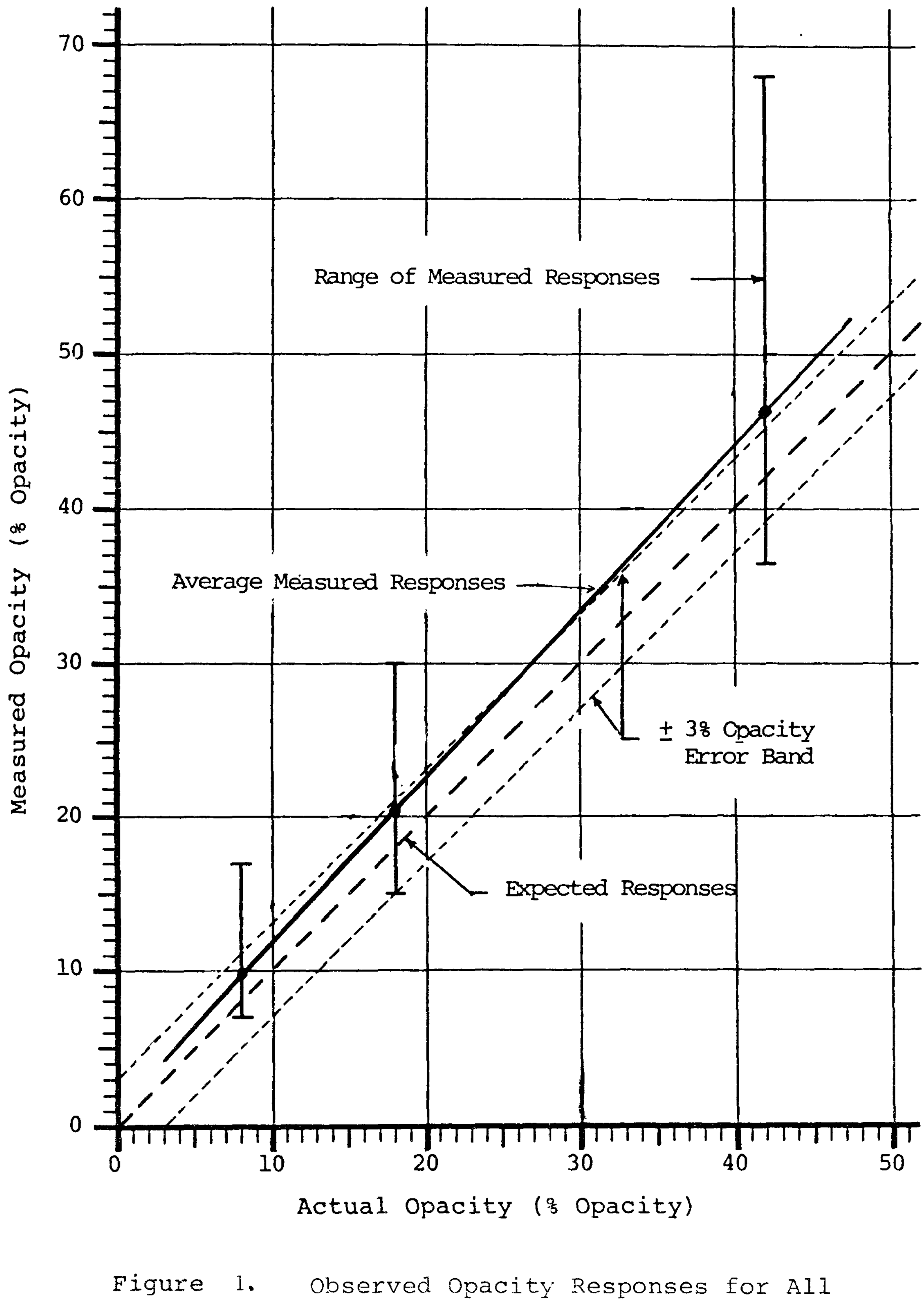

Figure 1. Observed Opacity Responses for All Audited Monitors: 89 Monitors

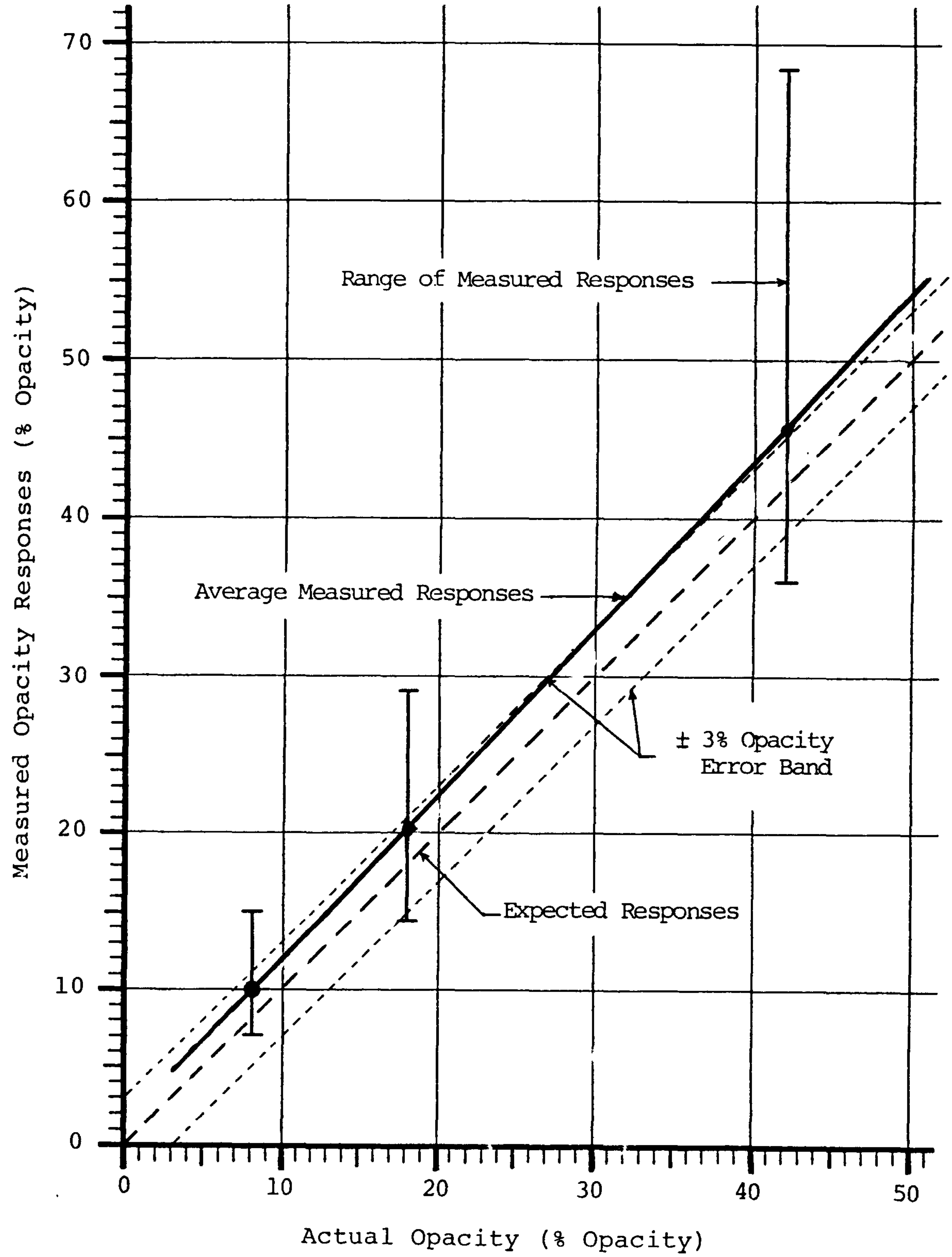

Figure 2. Observed Opacity Responses for 58 Lear Siegler Monitors

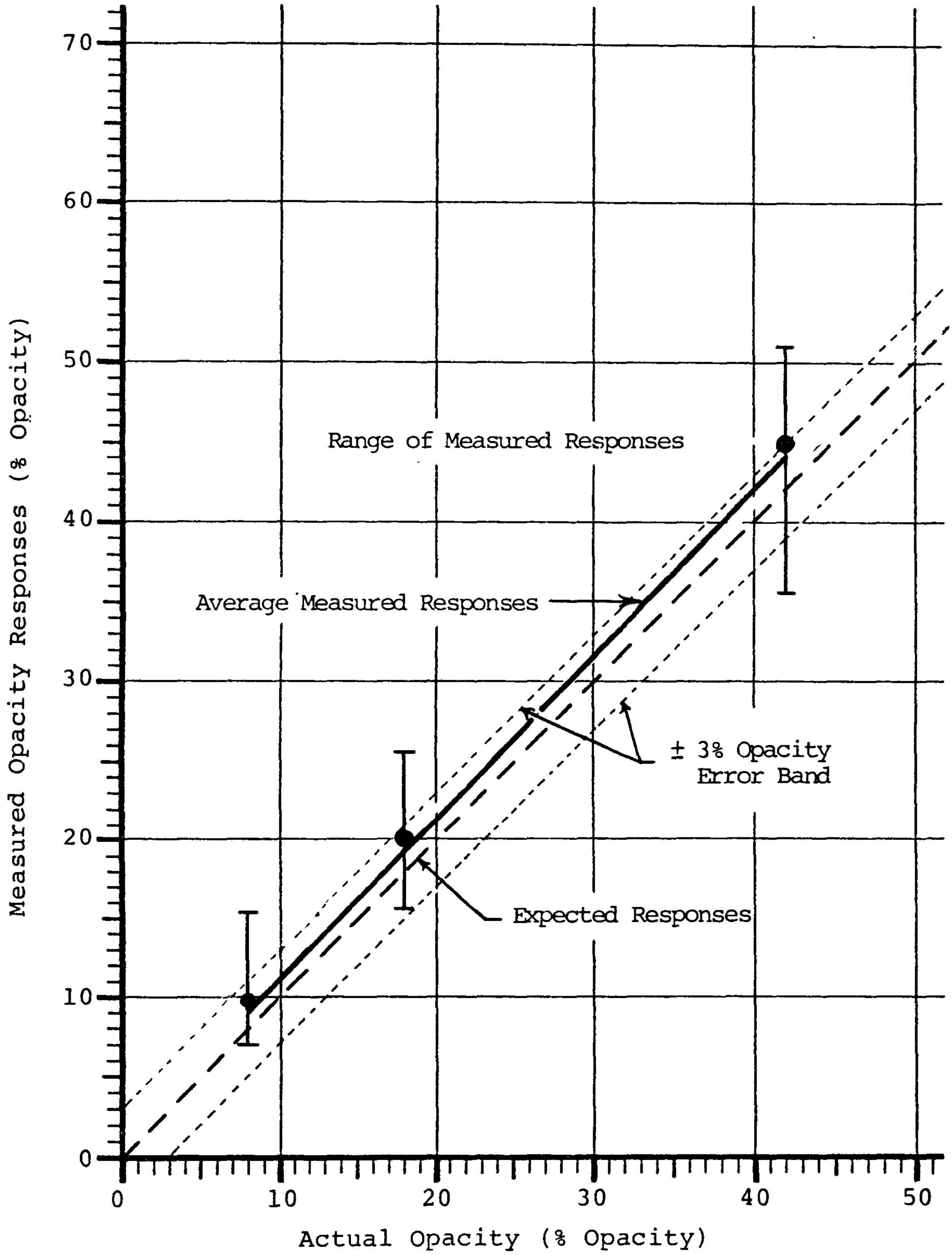

Figure 3. Observed Opacity Responses for 27 Contraves Goerz Monitors

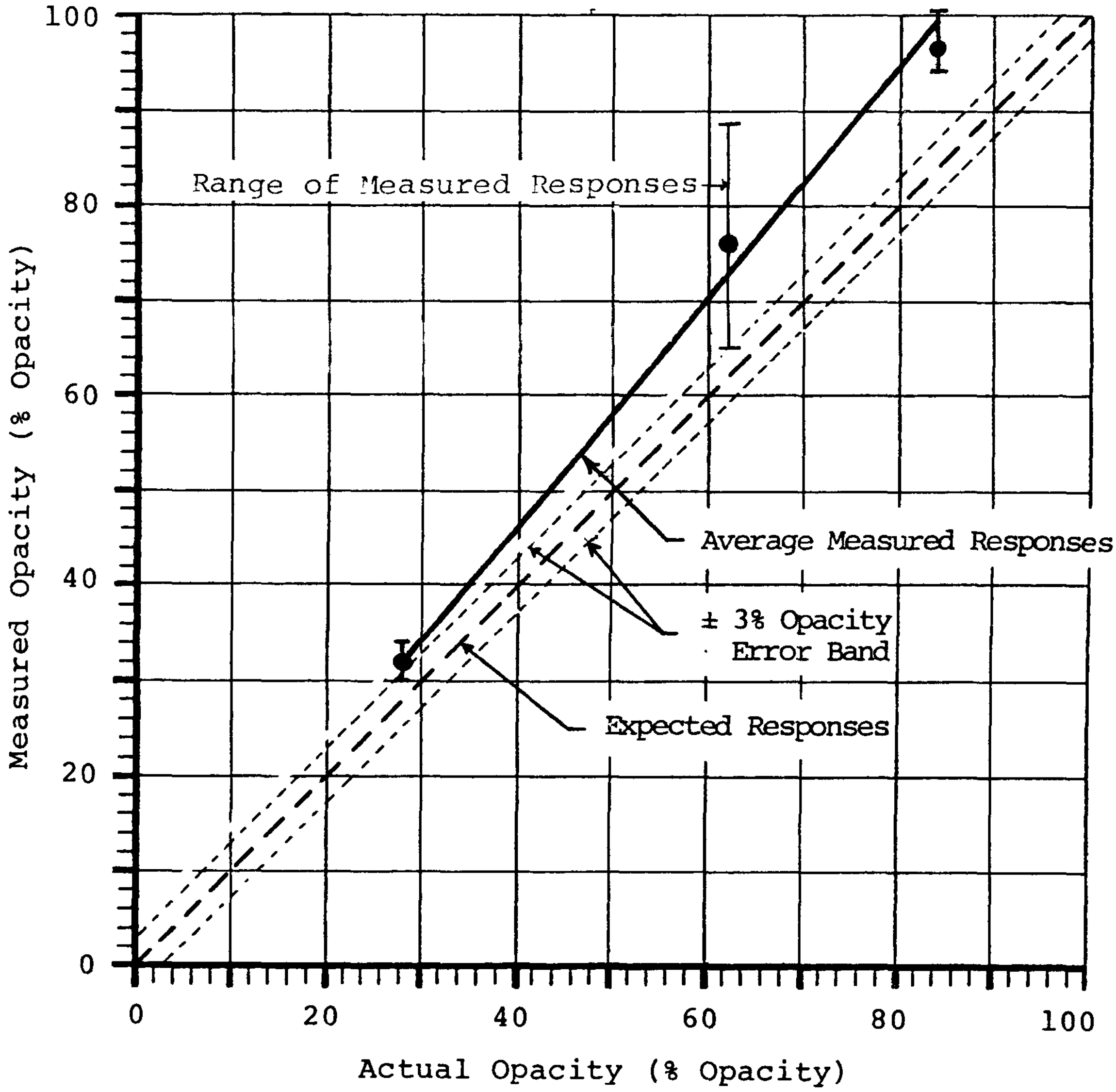

Figure 4. Observed Opacity Responses for 5 Dynatron Monitors

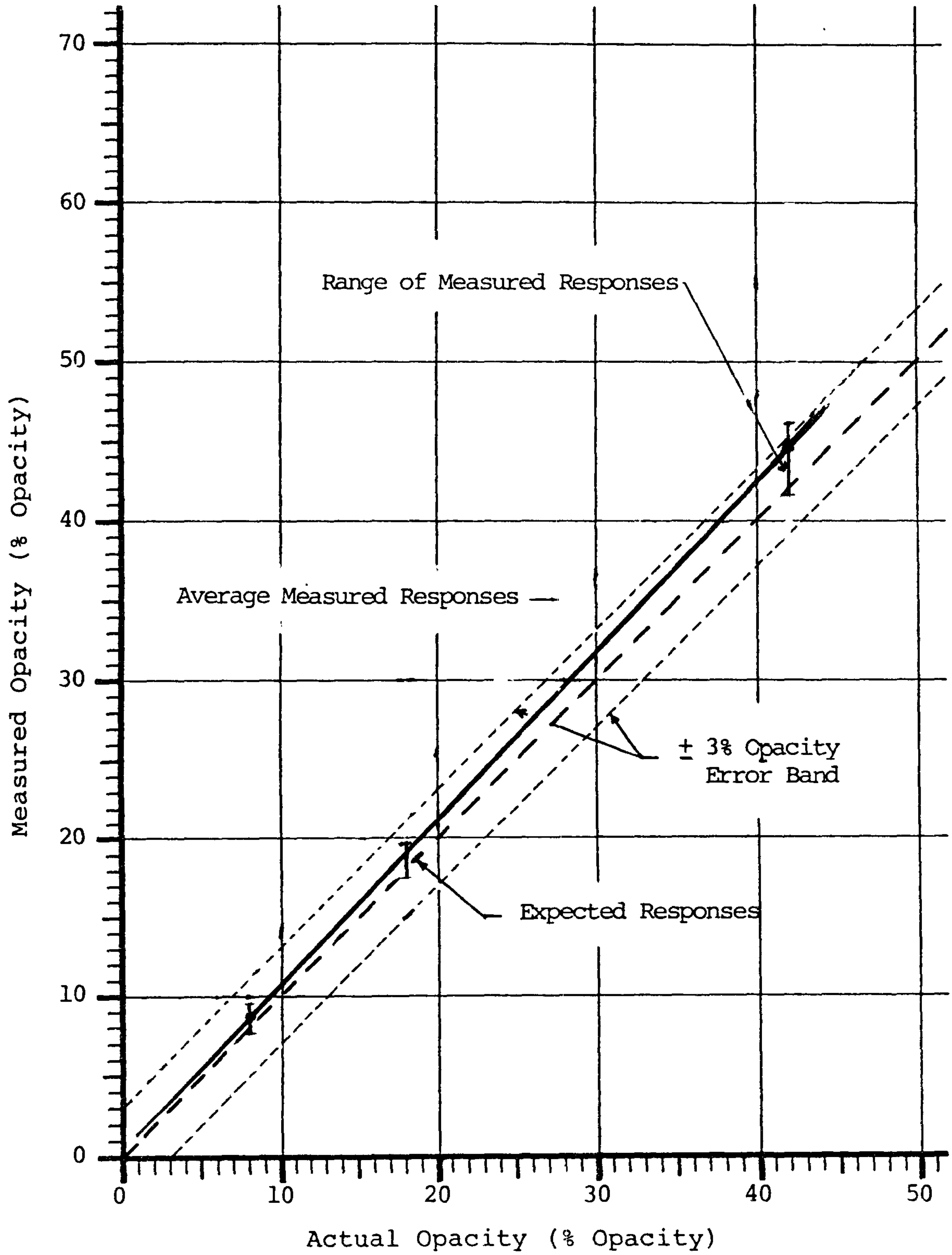

Figure 5. Observed Opacity Responses for 3 Esterline Angu
Monitors

supply and/or deterioration of the lamp bulb. The AGC circuit is considered to be "out of specification" if the circuit is not operating, as indicated by an LED on the Lear Siegler transceiver. Of the 58 monitors evaluated, only one monitor (approximately 2 percent of the total) was found to have an inoperative AGC circuit.

Monitor Alignment Analysis. The monitor alignment analysis indicates whether the optical beam path across the effluent stream is centered on the measurement retroreflector, with "out of specification" conditions being indicated by an off-center beam path. Improper alignment was found in three of 89 monitors audited, representing about 3 percent of the total. In addition, two of these monitors (Dynatron) were out-of-calibration, and the source indicated that attempts at proper alignment resulted in the loss of monitor zeroing capability. During off-stack calibration, however, an alternative alignment was devised, but this alignment failed to correct the zero calibration problem when the monitor was installed on the stack, thereby indicating that such problems may require the attention of a monitor service specialist. Finally, three Lear Siegler monitors had faulty alignment sights, and therefore, were not included in the tabulated audit results.

Stack Exit Correlation Analysis. The stack exit correlation analysis evaluates the pathlength correction factor which has an exponential impact on the monitor opacity reading. The audit results indicate that the most common error in computing the monitor optical pathlength was the use of the flange-to-flange distance, rather than the stack/duct inside diameter. Approximately 12 percent of the monitors audited had incorrect pathlength correction factors. However, the data obtained for these monitors can be used, provided that the erroneous opacity readings are mathematically corrected by using the proper pathlength correction factor.

Panel Meter Analysis. The panel meter analysis serves to evaluate the accuracy of the panel meter readings of opacity, optical density, and (on Lear Siegler monitors only) reference circuit current values. The panel meter is considered to be "out of specification" if any of the meter readings vary by more than 2 percent of the true value. Although 61 of the monitors audited (about 69 percent of the total) exhibited faulty panel meter readings, 55 of these units were Lear Siegler monitors which accuractely indicated opacity, but were inaccurate in their readings of optical density and/or monitor circuit current. In addition, zero and span function adjustments were made on five monitors using inaccurate panel meter readings. In general, the audit results indicated that chart recorder readings of opacity, optical density, and monitor circuit current should be used in monitor calibration and adjustment. However, seven monitors (8 percent of the total) were found to have incorrect chart recorder readings.

Reference Signal Analysis. The reference signal analysis for the Lear Siegler monitor serves as an internal verification of the beam intensity as well as an indication of the status of the photo detector and its associated electronics. The reference signal is considered to be "out of specification" when it varies by more than $\pm$10 percent beyond the value specified by the monitor manufacturer. Based on the audit data, all of the

Lear Siegler monitors had reference signals within the recommended range, with the exception of one unit. This monitor had an incorrectly calibrated panel meter, and correction of this miscalibration resulted in a reference signal reading within the manufacturer's recommended range.

Internal Zero and Span Analysis. The internal zero and span analysis evaluates the monitor's ability to maintain calibration by automatically adjusting its internal electronics to compensate for dust accumulation on monitor optics. The zero and span are considered to be "out of specification" when either of their errors exceed ±2 percent opacity. The audit results indicated no direct correlation between zero/span errors and monitor miscalibration. Although 72 monitors had accurate zero/span responses, 12 of these had calibration errors outside the specifications. Likewise, of 17 monitors having zero/span errors exceeding the specifications, only 10 had excessive calibration errors.

Procedural error was identified at two sources having seven monitors in which the zero and span were adjusted without cleaning the monitor optics. Because the zero mode is designed to simulate the amount of light returned to the transceiver under clear stack conditions, any dust accumulation on the transceiver window during the zero adjustment causes a lesser amount of light to be returned to the detector, and thus, an improper zero adjustment. However, the Lear Siegler monitor's zero compensation circuit is automatically reset during the zero adjustment, and the circuit will respond to the dirty optics as if they were clean. Thus, the adverse impact of making zero adjustments without cleaning the monitor optics depends on whether the monitor has a zero compensation function and on its effectiveness, and may or may not bias the recorded opacity.

Zero Compensation Analysis. The zero compensation analysis evaluates the extent to which the zero compensation circuitry of the Lear Siegler monitor electronically nullifies the adverse effects of dust accumulation on monitor optics. The zero compensation is considered to be "out of specification" if the indicated value exceeds ±0.018 optical density (4 percent opacity). The audit results indicated that the zero compensation circuit values are an accurate measure of the amount of dust on the transceiver optics, but give no indication of the dust accumulation on the retroreflector. Eight (15 percent) of the 55 Lear Siegler monitors had zero compensation values exceeding 4 percent opacity, and eleven monitors incorrectly used the zero compensation value as an indication of dust accumulation on the entire system optics. Thus, the Lear Siegler zero compensation circuitry generally fulfills its intended purpose of accounting for dirt on the transceiver optics.

Optical Dust Accumulation Analysis. The optical dust accumulation analysis is a quantitative determination of the dust deposition on a monitor's exposed optical surfaces. An "out of specification" dust accumulation is indicated by a value in excess of 4 percent opacity. Of 85 monitors audited, 16 (19 percent of the total) had excessive dust on the optical surfaces. The audit results indicated that dust deposition on monitor optics is both site- and monitor-specific, with deposition occurring at dissimilar, non-linear rates for transceiver and retroreflector optics.

Calibration Error Analysis. The calibration error analysis determines the accuracy and linearity of the entire opacity monitoring system, excluding retroreflector optics and monitor alignment. The calibration error is considered to be "out of specification" if the difference between the indicated opacity and that of the NBS neutral density filter employed exceeds 3 percent opacity. In order to optimize the accuracy of the calibration error analysis, all exposed monitor optics were cleaned prior to calibration, and the optical pathlength correction factor preset by the manufacturer was used to correct the audit filters for stack exit conditions.

For all four types of monitors evaluated, the high range calibration error was the most prevalent with 25 percent of the monitors having opacity readings in excess of the specifications. Furthermore, the mid and low range error analyses indicated corresponding reductions in calibration error, with these values being determined as 17 percent and 11 percent, respectively. Thus, a linear relationship between the magnitude of the opacity and that of the calibration error was indicated wherein monitors with lower range errors would not only have high range errors, but these errors would be of a greater magnitude (see Figure 1). In general, the monitors audited with calibration errors in excess of 3 percent opacity were biased high. Poorly performing monitors tended to give falsely high opacity readings, and, therefore, it is in the source's best interest to calibrate and maintain opacity monitors properly.

Results of Monitor-Specific Analyses

Lear Siegler. The component analysis of 58 Lear Siegler opacity monitors indicated significant problems with panel meter and internal span errors. Although none of the monitors' panel meters were within specifications, the erroneous readings were limited to values of optical density and circuit current, with opacity readings of panel meters being generally accurate. Internal span errors were present in 11 monitors (19 percent of the total) thereby, indicating either the presence of significant quantities of dust on the transceiver system optics, miscalibration of the monitor, or an incorrectly labeled internal span filter.

An analysis of monitor maintenance indicated that dust accumulation on system optics was a significant factor, with approximately 30 percent of the Lear Siegler monitors having excessive dust accumulations. As a further consequence of this dust accumulation, 17 percent of the monitors had zero compensation values in excess of the specified value. In addition, several of the sources indicated that they were unaware of the specifications for the zero compensation value, thereby indicating their lack of understanding of the role of the zero compensation as an indicator of dust accumulation on the transceiver optics.

Monitor calibration was found to be generally accurate and linear, with the greatest number of "out of specification" monitors resulting from the high range calibration error analysis (9 monitors, or 16 percent of the total). As Figure 2 illustrates, the Lear Siegler monitors tended to give elevated opacity measurements, but typically not in excess of the 3 percent opacity error band based on average measured responses. However, the range of measured opacities increased disproportionately with increases in the actual opacity, thereby indicating that monitor accuracy deteriorated with higher actual opacity.

Contraves Goerz. An analysis of the performance of 27 Contraves Goerz monitors indicated that panel meter and internal span errors occurred in about 20 percent of the monitors audited. Monitor maintenance, as indicated by the optical dust accumulation, was generally satisfactory, with only 3 units (about 12 percent of the total) having excessive dust accumulations. Monitor calibration, as illustrated in Figure 3, was adequate, with average low, medium, and high opacity values falling within the ±3 percent opacity error band. Contraves Goerz monitor opacity measurements were typically higher than actual opacity values, and this bias increased with higher actual opacity values.

Dynatron. Audits of 5 Dynatron opacity monitors yielded problems with stack exit correlation factors in 60 percent of the monitors (3 units). Also, monitor alignment errors were found in 2 units, and these alignment problems were not corrected. Fault lamp errors were encountered in 2 monitors, and were not previously repaired by the source because the monitor control unit partially obscured view of the lamps.

Maintenance of Dynatron monitors, as indicated by dust accumulation on monitor optics, was satisfactory, with only one monitor having excessive dust on system optics. Figure 4 illustrates the very high bias found in the calibration analysis, indicating severe inaccuracies in measured opacity, particularly in the higher range of actual opacity values. In fact, only 25 percent of the Dynatron units were found to be within the acceptable range of accuracy for low and mid-range opacity values. Moreover, monitor linearity was found to be deficient, with average mid-range opacity values having less accuracy than either low or high range opacity values.

Esterline Angus. Of 3 Esterline Angus monitors audited, one unit had problems with monitor alignment and panel meter errors. Optical dust accumulations were found to be minimal, thereby indicating adequate monitor maintenance. Furthermore, only one unit was found to have excessive calibration error (high range). Monitor accuracy and linearity, as illustrated in Figure 5, were satisfactory, with both low and mid-range calibration errors falling well within the ±3 percent error band.

IV. CONCLUSIONS AND RECOMMENDATIONS

General Conclusions

1. Opacity monitoring systems installed at stationary sources typically achieve high levels of availability (approximately 95 percent)

2. Contemporary opacity monitoring instrumentation is capable of providing accurate emissions monitoring data.

3. Problems impacting opacity monitoring data quality are generally limited to monitor miscalibration and/or adjustment, as well as improper or inadequate operation and maintenance practices.

4. The opacity monitor performance audit procedures which have been evaluated provide a reliable indication of the accuracy of opacity monitoring data and the adequacy of monitor operation and maintenance practices.

Specific Conclusions

1. Monitors which were properly operated and maintained demonstrated acceptable performance relative to audit test criteria and provided accurate opacity monitoring data.

2. Most installed opacity monitors are not affected by optical alignment problems. However, opacity monitoring systems provided by one manufacturer may be more susceptible to alignment problems than other monitoring systems.

3. Incorrect stack exit correction factors for opacity monitoring systems are often encountered.

4. Inappropriate methods are frequently used for determining stack-exit opacity where multiple opacity monitors are installed in separate ducts which are exhausted through a common stack.

5. Measurement values displayed on monitor panel meters are often inaccurate and are generally less reliable than strip chart readings.

6. Monitor responses to internal zero and span checks are in excess of acceptable limits in many cases; however, a direct correlation between zero and span check results and calibration error test results has not been observed.

7. Automatic zero compensation circuits generally provide a reliable indication of dust accumulation on the transceiver optics; however, some monitor operators are not aware of the 4 percent opacity zero compensation limit and/or incorrectly interpret the zero compensation value.

8. Dust accumulation on exposed optical surfaces is both site- and monitor-specific and may occur at different rates for the transceiver and reflector components. Excess dust accumulation on optical surfaces was observed for approximately 19 percent of the audited monitors.

9. Calibration error test results in excess of the acceptable limits occurred most frequently at high opacity levels; the magnitude of calibration errors was found to increase as the measured opacity increased. Poorly performing monitors tended to provide measurements which were biased high relative to the correct value.

Recommendations

The following recommendations are offered for those source operators where installed opacity monitoring systems failed to demonstrate acceptable performance during audits.

1. The personnel who perform the required daily zero and span checks should receive adequate training to allow them to perform routine adjustments, as necessary, to eliminate excessive zero drift, span drift, and discrepancies between the control panel display values and the permanent data recording system. This training should be monitor-specific and should include adequate explanation, as applicable, of automatic zero compensation functions, stack exit correction factors, and procedures for determining equivalent calibration filter values corrected for stack exit conditions.

2. After all calibration/adjustment problems observed during audits are corrected, monitor operators should institute a well defined operation and maintenance program for the opacity monitoring systems. Such a program must address monitor-specific and site-specific considerations, and should at least include the following activities:

   a. daily checks, and as necessary, adjustment of: fault lamp indications, zero drift, span drift, panel meter accuracy, data recorder adjustment, and available monitor-specific operational indicators,

   b. periodic evaluation and, as necessary, corrective actions for dust accumulation on exposed optical surfaces, optical alignment, reference voltages/currents, etc.

   c. routine maintenance as specified by the manufacturer and including: replacement of measurement lamps, fault lamp bulbs, purge air filters, dessicant, etc.

   The appropriate frequency for performing periodic evaluations and routine maintenance should be established through a trial and error procedure. Such a procedure involves: (1) selecting an initial frequency for these activities, (2) performing periodic evaluations and routine maintenance and documenting results of these activities over a sufficient period of time to evaluate their impact on monitor performance, and (3) modifying the initially selected frequency in view of the results obtained in order to minimize the expenditure of resources while consistently monitoring instrument performance within acceptable limits.

3. Monitor operators should institute a self auditing program which includes a calibration error determination at three points over the measurement range of the instrument. At a minimum, this procedure should be performed concurrently with the required annual optical and zero alignments of Performance Specification 1, Appendix B, 40 CFR 60. The frequency of self-audits should be adjusted as necessary, to maintain instrument performance within acceptable limits.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

Opacity monitor performance audit procedures and devices have been developed and field tested on 93 opacity monitors. The results of this test program indicate that opacity monitoring systems achieve high levels of availability, and are capable of providing accurate emissions data. The results also show that problems impacting data quality are generally limited to monitor miscalibration and/or misadjustment, as well as improper or inadequate operating and maintenance practices. It is believed that improved monitor performance and data reliability can be achieved with additional training of monitor operators and more frequent performance audits. This document describes the audit program for continuous emission monitors (CEMs) of effluent opacity. Detailed explanations of the audit methodology, monitor analyses, and analytical criteria are included, and both criteria- and monitor-specific results of installed opacity monitor audits are delineated. Finally, conclusions are drawn as to the adequacy of monitor performance and data reliability, and recommendations are offered that can optimize opacity monitoring system performance.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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