MINIRAM Calibration Differences

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The MINIRAM (Miniature Real-time Aerosol Monitor), manufactured by MIE, Inc. (formerly the GCA Corporation), is a small aerosol monitor using the scattering of electromagnetic radiation to measure particulate aerosol concentrations. The manufacturer calibrates the response of the MINIRAM against a gravimetric reference using Arizona Road Dust (ARD). However, it has been observed that different MINIRAMs may not show the same concentration when simultaneously measuring the same aerosol.

This paper presents the results of comparative measurements obtained in the laboratory, under controlled conditions, with 46 actively operated MINIRAM instruments. Comparative measurements were obtained in ARD, silica dust, and limestone dust aerosols. Using one of the MINIRAMs as a reference, comparative measurements were obtained with each of the other instruments by sampling through an inlet manifold which allowed two instruments to be simultaneously exposed to the same aerosol.

Aerosol concentrations indicated by different MINIRAMs varied over a broad range, by a factor of two at the extremes. This study indicates that comparative measurements obtained with approximately 35 percent of the MINIRAMs would differ by more than 25 percent and that 8 percent of the MINIRAMS would disagree by more than 50 percent. Instrument response relative to gravimetrically determined concentrations was strongly affected by aerosol type, being approximately 60 percent higher in limestone than in Arizona Road Dust. Gero, A.J.; Tomb, T.F.: MINIRAM Calibration Differences. Appl. Ind. Hyg. 3:110–114; 1988.

Introduction

A recent development in instrumentation used to measure the concentration of a particulate aerosol has been the introduction of devices which provide a real-time measurement of aerosol concentration; that is, they indicate the aerosol concentration after a period of minutes or seconds and are capable of making a series of such measurements. Although several measurement principles have been used in the design of these instruments, probably the most popular approach is measurement of infrared radiation scattered by the aerosol. This technique has several advantages: a measurement can be made in a very short time period; the measurement is independent of the rate of air flow through the instrument, depending only on the quantity of aerosol present in the instrument's sensing volume; and the instrument can be designed so that its sensitivity is maximized for a given particle size range. However, instrument response is affected by changes in particle size distribution and composition of the aerosol and instrument calibration is dependent on the gain setting of the signal processing electronic circuitry.

One of the more recent light-scattering instruments to be made commercially available is the MINIRAM (Miniature Real-time Aerosol Monitor) shown in Figure 1. It was developed by the GCA Corporation under a joint Bureau of Mines/National Institute for Occupational Safety and Health contract. The MINIRAM, taking advantage of the fact that aerosol concentration measurement is independent of air flow rate, depends on diffusion and convection to transport the aerosol to its sensing chamber, eliminating the need for a pump. This design, since it does not require the space or battery power needed for a pump, allows the instrument to be much smaller and lighter than would otherwise be possible. The optical system is designed to be sensitive primarily to the respirable fraction of the aerosol as defined by the American Conference of Governmental Industrial Hygienists (ACGIH).[1] In addition to providing a real-time measurement, the MINIRAM integrates the measured signal and calculates a time-weighted average (TWA) measurement.

Although designed for use as a passive instrument, the MINIRAM can be modified to permit its use as an active sampler (pulling air through the sensing chamber) and is the mode in which the MINIRAMs were operated for the evaluation being reported. The modification consists of attaching an adapter which permits a pump to be used to pull air through the instrument's sensing chamber. The adapter also permits the sample to be passed through a 10-mm nylon cyclone and to be collected on a filter after passing through the MINIRAM, allowing the average aerosol concentration to also be measured by gravimetric means. The active mode was used for this evaluation because it had been previously shown[2] that sampling actively with the adapter minimizes the effect of differences in aerosol size distribution on instrument response, lessens measurement errors due to the presence of water droplets often found when used in underground coal mine environments, and provides a faster response time in highly variable dust concentrations. Use of the adapter also eliminates possible measurement errors which could be caused by ambient light reaching the detector. However, since some particles to which the instrument is sensitive are removed by the 10-mm nylon cyclone, the aerosol concentration reading of the MINIRAM is reduced by approximately 25 percent in a coal aerosol[3] when the adapter is used.

Several investigators have conducted studies of the MINIRAM, both in the laboratory[3,4] and under field conditions.[5,6] During some of these investigations,[3,4,6] it was noted that although the

Reference to specific brands, equipment or trade names in this paper is made to facilitate understanding and does not imply endorsement by the Mine Safety and Health Administration.

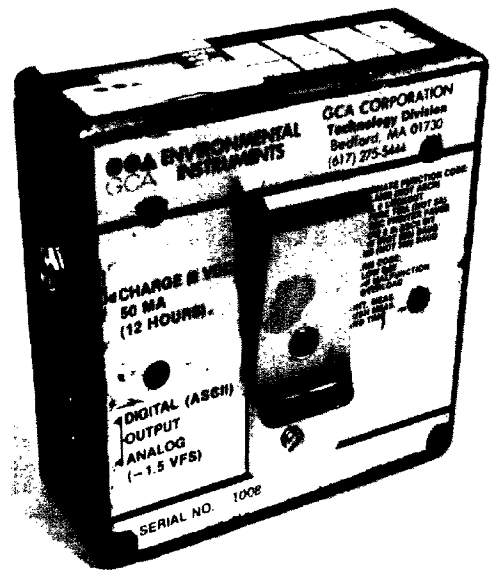

FIGURE 1. GCA MINIRAM.

manufacturer calibrates the MINIRAM against a gravimetric reference using Arizona Road Dust (ARD),[1] different instruments have been found to indicate different concentrations when exposed to the same aerosol. In 1984, the Mine Safety and Health Administration purchased 50 of these devices for their Metal and Nonmetal mine inspectors to use for making screening measurements. The objective of the work reported in this paper was to determine the precision of the calibration of the 50 actively operated MINIRAMs and to recommend procedures for use of the instrument when sampling particulate aerosols with different characteristics.

Procedures

To evaluate the variability associated with the calibration of the MINIRAM, one of the 50 MINIRAMs was randomly selected as a reference instrument and measurements obtained with it were compared to measurements obtained with each of the other instruments. In order to make certain that both the reference and the instrument being compared to it were being exposed to the same aerosol concentration, the sampling configuration shown in Figure 2 was used. The flow rate through each cyclone was maintained at 1.7 liters per minute (lpm) using DuPont P-2500 constant flow pumps. Prior to use, the sampling manifold was evaluated by replacing the MINIRAMs with two filters and collecting several comparative samples for 1.5 to 6 hours. The comparative measurements from these tests are shown in Table I. Analysis of the data using the paired t-test confirmed that the same quantity of aerosol was being delivered to both outlets of the sampling manifold.

TABLE I. Results of Test of Sampling Manifold

Sample Weight (mg)			
Branch 1	**Branch 2**	**Branch 1**	**Branch 2**
0.67	0.71	0.43	0.43
0.80	0.75	0.16	0.16
0.55	0.58	0.49	0.49

Before each comparison, both MINIRAMs were zeroed twice while pulling filtered air through the sensing chamber. If a MINIRAM's zero offset readings did not agree to within 0.02, the instrument was zeroed a third time.

The comparative MINIRAM measurements were obtained in a 0.3 cubic meter chamber. The aerosol, Arizona Road Dust (ARD), was introduced into the chamber using a TSI Model 3400 fluidized bed aerosol generator. To simulate aerosol concentration variations typically occurring in mine environments, aerosol concentrations in the chamber were varied between zero and 9 mg/m^3 during each comparison. The duration of each comparison was one hour. The average concentration during each comparison was typically between 1 and 2 mg/m^3. At the end of the hour, the time-weighted average (TWA) concentration indicated by each MINIRAM was noted. The filters in the adapters were pre- and post-weighed to 0.001 mg. Because two comparisons made with the same MINIRAM did not always agree, comparative measurements with each MINIRAM were repeated until the ratios of TWA's found during two comparisons were within 10 percent of each other. The average of these two results was used to define the relative response (with respect to the reference instrument) of the MINIRAM being tested. Four MINIRAMs failed before their relative responses could be determined.

The relationship between a MINIRAM's response and gravimetrically determined aerosol concentrations was determined from the measurements obtained with the reference MINIRAM. Only reference instrument measurements were used because the reference MINIRAM was the only instrument for which a large amount of data was collected. The relationship was determined by averaging the individual ratios established from comparing the reference instrument's TWA and the concentration deter-

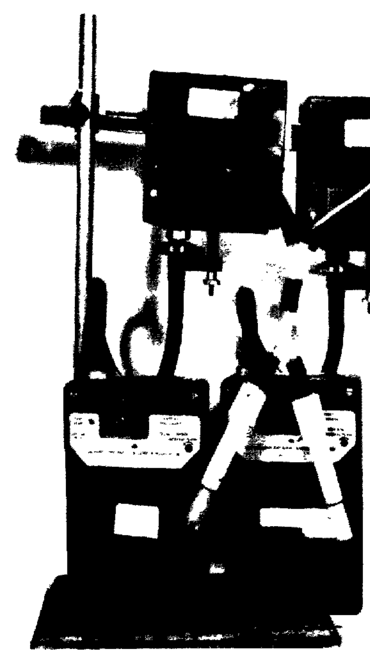

FIGURE 2. Sampling configuration for comparative measurements.

mined from the weight gain of its filter. The relative response of each of the other MINIRAMs was then used to establish the relationship between its readings and gravimetrically determined concentrations.

Comparisons were also made between the reference instrument and six of the MINIRAMs in silica and limestone aerosols to see whether between-instrument relationships remained constant in different aerosols and to obtain information regarding instrument response relative to gravimetrically determined respirable aerosol concentrations in different aerosols. Aerosol size distribution parameters are given in Table II.

TABLE II. Aerosol Size Distribution Parameters

	ARD	Silica	Limestone
Count Median Diameter	0.81 μm	0.52 μm	0.69 μm
Surface Median Diameter	2.08 μm	2.04 μm	1.80 μm
Mass Median Diameter	3.34 μm	4.02 μm	2.91 μm
Geometric Standard Deviation	1.99	2.28	2.00

Results and Discussion

Initially, two comparison measurements were obtained for each MINIRAM. Figure 3 shows the cumulative distribution of differences between these pairs of comparative measurements. For only 17 of the instruments (39%) did the two measurements agree within 10 percent, while for five (11%), they were found to disagree by more than 25 percent. These results illustrate the degree of variability associated with comparative measurements with the same two MINIRAMs.

The data plotted in Figure 4 illustrate the large differences obtained in relative responses. The relative responses shown are for those 17 MINIRAMs whose two comparative measurements were within 10 percent of each other. As the data show, there is the potential for measurements made by two instruments in the same environment being different by approximately 2 to 1 because of differences in instrument calibration.

To illustrate the effect of the calibration differences and measurement variability on an aerosol measurement, the ratios established from each of the first two comparative measurements made with each MINIRAM were randomly selected, two at a time, 25,000 times by computer simulation and the second ratio compared to the first. The first two ratios were used because only two comparative measurements were necessary with some instruments to determine a relative response, and it was desired to have each instrument equally represented in the simulation. Each ratio represents a MINIRAM's response during one measurement, normalized to the response of the reference MINIRAM. For example, if during one comparison a MINIRAM's TWA was 90 percent of the TWA of the reference, while in the second comparison its TWA was 70 percent of the reference's TWA, the ratios 0.90 and 0.70 would be included in the simulation among the two ratios from each instrument. If the first ratio (0.90) was paired by the computer simulation with a ratio of 1.25 obtained from a different MINIRAM, the difference between the two readings would be either 28 percent or 39 percent, depending on which ratio was the first selected. The results of this simulation, shown in Figure 5, show that readings from two MINIRAMs have the probability of differing by more than 25 percent, when measuring the same aerosol concentration, 37 percent of the time. Readings would differ by more than 50 percent, 8 percent of the time.

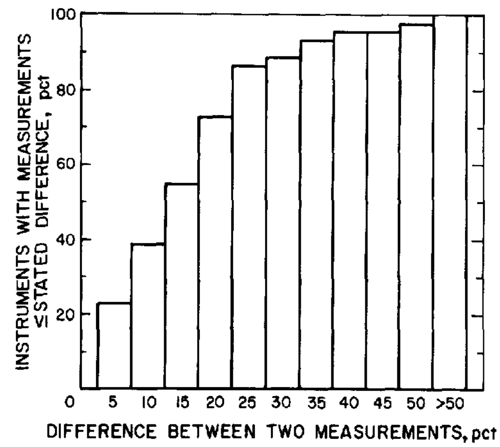

FIGURE 3. Cumulative distribution of differences between the first two comparative measurements.

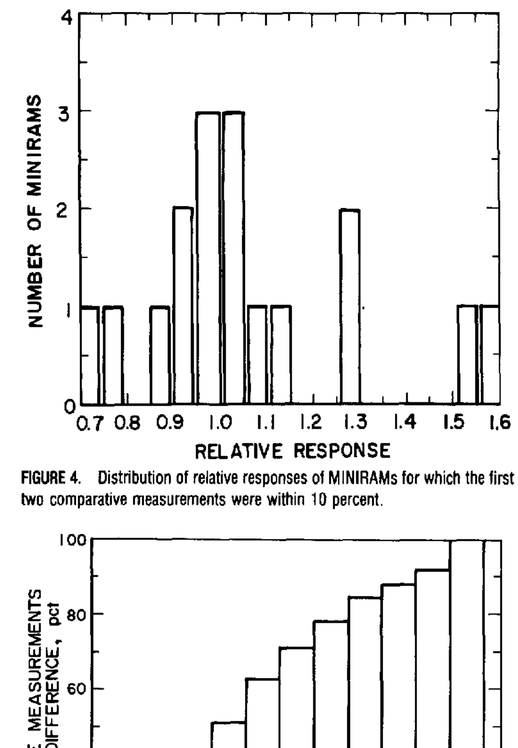

FIGURE 4. Distribution of relative responses of MINIRAMs for which the first two comparative measurements were within 10 percent.

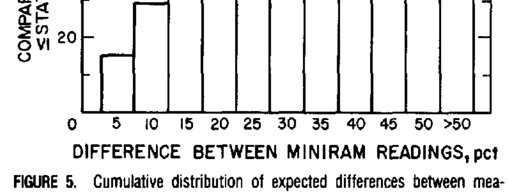

FIGURE 5. Cumulative distribution of expected differences between measurements obtained with two randomly selected MINIRAMs.

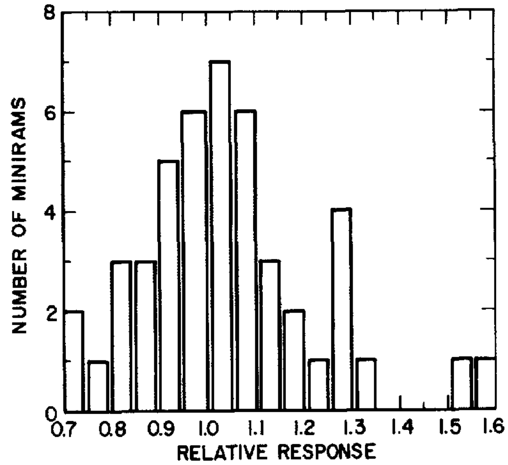

FIGURE 6. Distribution of relative responses of all MINIRAMs, obtained from two comparative measurements within 10 percent.

To reduce the uncertainty associated with the relative response estimates of those MINIRAMs that had their two comparative measurement ratios differing by more than 10 percent, comparative measurements were repeated with each MINIRAM until the results of two comparisons were within 10 percent of each other. The average of these two comparisons was used as the relative response estimate. For all but three of the instruments, two ratios within 10 percent were obtained with no more than three comparisons. The distribution of the relative responses (based on two comparative measurements within 10%) for all of the MINIRAMs is shown in Figure 6. These data show that the most probable relative responses established for these 46 instruments will yield comparative measurements that could differ by 1.7 to 1.

The effect of differences in MINIRAM calibration, as evidenced by the varying relative responses, can be minimized either by adjusting the amplifier gain of each instrument or by deriving a factor (the reciprocal of the relative response) by which to multiply readings obtained from each instrument so that they would be equivalent to readings obtained with the reference MINIRAM. The effects of such an adjustment to instrument calibration were investigated by computer simulation. The first two ratios determined for each instrument were divided by the relative response established for that instrument. Pairs of the "corrected" ratios were compared using computer simulation. If, in a third comparison, the TWA ratio of the first MINIRAM (in the previous example) and the reference instrument is 0.84, then its relative response is 0.87 (the average of 0.90 and 0.84). The "corrected" ratios used in the simulation would be 1.03 (0.90/0.87) and 0.80 (0.70/0.87). If the second MINIRAM had a relative response of 1.25, the "corrected" ratio would be 1.00 and the two "corrected" measurements would differ by three percent. The results of this simulation are shown by the solid bars in Figure 7 (the dashed line bars represent the same data presented on Figure 5). The number of pairs differing by more than 25 percent decreases from 37 to 15 percent, while the number of pairs differing by more than 50 percent decreases from 8 to 2 percent.

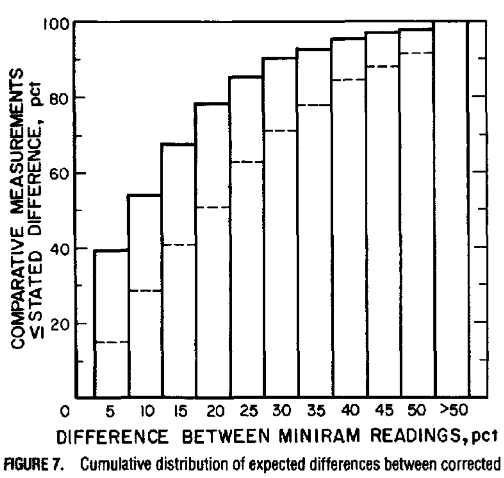

FIGURE 7. Cumulative distribution of expected differences between corrected measurements obtained with two randomly selected MINIRAMs (dashed line same data as presented in Figure 5).

TABLE III. Ratio of Instrument Reading to Gravimetrically Determined Aerosol Concentration

	ARD	Silica	Limestone
	1.16	1.20	1.93
	1.04	1.18	1.49
	1.01	1.30	1.69
	1.04	1.53	1.63
	0.99	1.28	1.56
	0.94	1.22	2.01
	0.98	1.27	1.49
	1.17	1.28	
	1.08	1.54	
	1.13	1.12	
	1.19	1.18	
	1.26	1.38	
	0.97	1.28	
	1.04		
Average Ratio	1.07	1.29	1.69
Standard Deviation	0.096	0.128	0.208

The data for comparative measurements in the ARD, silica, and limestone aerosol are shown in Table III. Because of the large amount of data obtained in the ARD aerosol, only a representative portion is shown. As can be seen, the relationship between instrument response determined from the TWA readings and the gravimetrically determined respirable aerosol concentration varied considerably with different aerosols. Statistical analysis, using the t-test for independent samples, confirms the significance of the differences. The average ratio of the TWA of the reference MINIRAM to the gravimetric concentration was 1.07 in ARD, 1.29 in silica, and 1.69 in limestone. It does not appear that the differences in MINIRAM response can be attributed to particle size differences among the materials. The differences in size distribution are not large and were, as noted earlier, further decreased by active sampling through the cyclone preselectors. These results, which are in agreement with previous referenced investigatory work, clearly demonstrate the necessity of calibrating a MINIRAM in the aerosol of interest if accurate mass concentration measurements of that aerosol are desired.

Conclusion/Recommendation

This paper describes a study to evaluate the variability associated with the calibration of the MINIRAM aerosol monitor. Comparative measurements were obtained in the laboratory, under controlled conditions, with 46 MINIRAM instruments. One of the MINIRAMs was randomly selected as a reference instrument and measurements obtained with it were compared to measurements obtained with each of the other instruments. A special sampling configuration was used to ensure that both the reference and the MINIRAM being compared to it were being exposed to the same aerosol concentration. Comparative measurements were obtained in ARD, limestone, and silica aerosols.

The results of this study show that there is a high degree of variability in the calibration of MINIRAMs as received from the manufacturer, indicating that the manufacturer's procedure for calibrating the MINIRAM should be improved. As received, different instruments exhibit considerable variation in concentration readings when exposed to the same aerosol concentration; at the extremes, one could indicate a concentration more than twice that shown by another in the same environment. Also, aerosol composition was again demonstrated to have a substantial effect on instrument response. Readings obtained with the MINIRAM in a limestone aerosol were 59 percent higher (relative to gravimetrically determined concentration) than those obtained in an aerosol of ARD.

The results clearly indicate the need to check the calibration of each MINIRAM in the aerosol of interest by comparing its response to a gravimetric determination if it is desired to have the MINIRAM reading relate to a gravimetrically determined aerosol concentration. Separate determinations are needed for different aerosols. If more than one instrument is used, their responses should be compared to determine how readings obtained with the different MINIRAMs relate to each other.

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