Evaluation of a portable hand-held respirable dust monitor

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ABSTRACT: A program to evaluate a portable hand-held respirable dust monitor was conducted by the Dust Division, Pittsburgh Health Technology Center, Mine Safety and Health Administration. The instrument evaluated was the GCA Miniram which utilizes the principle of light-scattering to measure the mass concentration of dust in the environment. The instrument was evaluated by comparing measurements obtained with an actively operated Miniram and with a respirable coal mine dust sampler. Comparative measurements were obtained with four Miniram instruments in four underground coal mines located in different coalbeds. The effect of aerosol particle size distribution, material composition and dust concentration on Miniram measurements was also studied. Results indicate that a factor can be applied to the Miniram TWA (time weighted average) measurement to obtain an equivalent coal mine dust sampler measurement. Comparative field measurements showed that mass concentration measurements obtained with a Miniram were approximately 1.5 times (+20 percent) those obtained with a coal mine dust sampler. The effect of variations in particle size distribution and material composition on Miniram response could not be quantitated in this study.

1 INTRODUCTION

During the past several years, several manufacturers have developed and marketed instruments capable of providing an "instantaneous" assessment of the particulate mass concentration of an industrial environment. These instruments have been of interest to the Mine Safety and Health Administration and to the mining industry because they can provide the capability to determine from a short-term measurement when and where full-shift personal sampling should be conducted. In addition, these instruments could also be used to measure and define dust generating sources and evaluate the immediate effects of alterations to dust suppression and control systems.

Many of these instantaneous instruments use the principle of light scattering to measure the mass concentration of an aerosol. Measurements with a light-scattering instrument can be made in a relatively short period of time (often seconds), and the measurement is not dependent on the volume of air passed through the instrument. However, a major disadvantage of the light-scattering principle is that light scattered by an aerosol may be a function of factors such as the particle-size distribution, density, shape and surface properties of the aerosol being measured.

Since measurement by light scattering is not dependent upon a specified flow rate, light-scattering instruments have been developed which are of the passive type (no air mover). Shown in Figure 1 is an instrument developed under a NIOSH/BOM research contract (Lilienfeld & Stern 1982) by the GCA Corporation referred to as the Miniram Aerosol Monitor (reference to specific makes of equipment for identification purposes only and does not constitute endorsement by the Mine Safety and Health Administration. This instrument utilizes diffusion and ambient air movement to transport the aerosol through the instrument's sensing chamber. Passive samplers like the Miniram offer the advantage that they can be designed in smaller and lighter configurations than sampling devices requiring air movers. Since space and power are not required for a pump, the size and battery capacity can be substantially reduced. The instrument utilizes a light-emitting-diode operating in the near-infrared region as an illumination source. The illumination source has an emission spectrum which is centered on

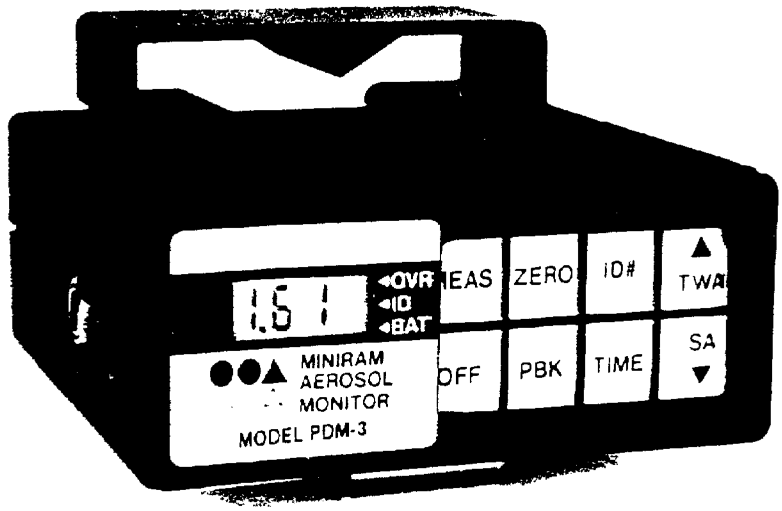

Figure 1. GCA Corporation's, Miniram Aerosol Monitor

880 nanometers (nm). Light scattered between the angles of 45° and 95° (Lilienfeld & Stern 1982) is measured by the instrument. The choice of light wavelength and angle of detection are such that the instrument's sensitivity to particle size approximates the respirable dust definition of the American Conference of Governmental Industrial Hygienists (Aerosol Technology Center Committee 1970). Therefore, respirable mass measurements are supposedly obtained without the need of classifying and separating particles before they enter the sensing chamber of the instrument.

While the Miniram does not require a particle classifier for operation, previous studies (Marple & Rubow 1984) have shown that measurements obtained with instruments employing the principle of light scattering can be affected by variation in the particle size distribution of the aerosol and by water droplets present in the airstream. To reduce variation in instrument response due to these factors the Miniram was equipped with an adapter that permitted the sampled air to be passed through a particle classifier before measurement. Figure 2 shows the optional adapter assembly.

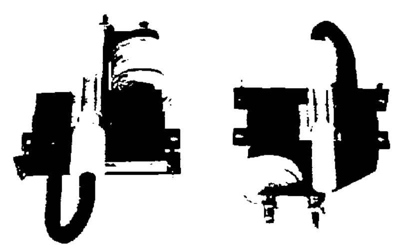

Figure 2. Personal Sampler Adapters used with Miniram for Sampling Coal or Metal/NonMetal Mining Operations

Sampled air is passed through the particle classifier (10 mm nylon cyclone) before entering the instrument's sensing chamber and through a 37 mm diameter membrane filter after exiting the chamber.

While the primary function of the filter is to protect the pump from dust, it also provides the opportunity, when pre-and post-weighed, to determine the gravimetric dust concentration of the dust passing through the sensing chamber. At a flow rate of 2.0 liters per minute (Lpm) the characteristics (mass concentration and size distribution) of the aerosol passing through the sensing chamber will be the same as that sampled with a respirable coal mine dust sampler.

In addition to eliminating the variation in instrument reading due to particle size distribution and water droplets in the aerosol, the adapter also blocks extraneous light from the instrument sensing chamber which could also affect a reading. When operated with a pump and cyclone adapter the instrument is considered to be operating in the "active" mode. Operating the instrument in the active mode reduces, or minimizes, the effect variations in aerosol size distribution has on the response of the Miniram; however, passing the aerosol through the cyclone removes the non-respirable fraction. Since the Miniram is designed to discriminate the respirable fraction from the total aerosol, removal of a portion of the aerosol by means of a cyclone causes the respirable mass concentration of the environment to be underestimated. Laboratory data obtained by Gero and Tomb (Gero & Tomb 1984) showed that Miniram measurements obtained actively are approximately 25 percent less than those obtained passively.

When operated in either the active or passive mode, instantaneous measurements are continuously displayed and updated every 10 seconds. In addition, the Miniram can be called upon to display the time weighted average (TWA) concentration and also has an analog output that can be used for continuous monitoring of the instrument's response using a data logger or strip chart recorder.

The purpose of this study was to determine the relationship between comparative measurements obtained simultaneously with the Miniram when operated actively and with a respirable coal mine dust sampler. Gravimetric measurements obtained with a respirable coal mine dust sampler would serve as the basis against which Miniram measurements would be compared. In addition, an attempt was made to determine the effect of mine aerosol particle-size distribution, material composition and dust concentration on the comparative measurements.

2 EXPERIMENTAL TECHNIQUES

To develop a relationship between the measurements obtained with a respirable coal mine dust sampler and the Miniram, a special sampling configuration was utilized. This configuration is shown in Figure 3. Essentially, a Miniram and a respirable coal mine dust sampler are connected so that both instruments sample the same dust atmosphere. The cyclone for the Miniram and the cyclone for the coal mine dust sampler were each connected to a leg of a "Y-connector". The third leg of the "Y-connector" was then interfaced with another "Y-connector" that was connected to the sampling pumps.

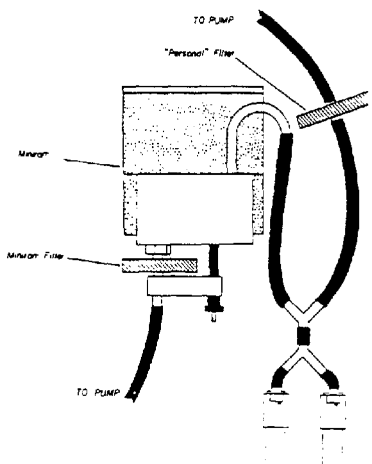

Figure 3. Special Sampling Configuration Utilized for Study

Two of these special sampling configurations along with a total dust sampler were assembled into a package. The Minirams were oriented in the package in a vertical position (i.e., display functions up or toward the top). Final assembly of the sampling package arrangement was done underground at each mine sampled. Two sampling packages were used for sampling each shift, providing four (4) sets of comparative test data. A total of 76 sets of test data were obtained for the entire study.

Filter samples (personal, Miniram, and total) were pre- and post-weighed to 0.01 mg on a ME-30 Mettler analytical balance. Filters were changed daily at the end of each shift sampled. Sampling flow rate through each pump was maintained at a rate of 2.0 Lpm. Constant flow pumps (Bendix Model BDX-60) and (MSA Model G) were used in the packages. Respirable dust concentrations determined gravimetrically from samples collected on the filters were multiplied by the constant 1.38 (Tomb 1973) to obtain an equivalent MRE concentration. Miniram TWA measurements were compared to the average of the equivalent MRE concentrations determined from the Miniram filter samples and the coal mine dust samples.

The total dust sample (no cyclone) collected in each sampling package was particle sized with a Model T Coulter Counter (Anderson & Tomb 1968). All Coulter Counter analyses were run using a 50-micrometer aperture tube to classify particles, ranging in size from 0.79 to 25.41 micrometers, into 15 intervals.

Sampling was conducted in four underground coal mines representative of three different coalbeds. Within each underground mine, sampling was conducted at various locations such as a section dump point or a belt transfer point. Sampling was conducted for periods of from 4 to 5 hours during each shift. Exact operating times on the instruments were recorded.

Comparative measurements were also obtained with the instruments used in the field study in a laboratory dust chamber using minus 200 mesh coal dust. For comparison of Miniram and gravimetric measurements, the Miniram TWA was compared to the MRE equivalent concentration obtained from the Miniram filter sample.

3 RESULTS AND DISCUSSION

Table 1 summarizes the test data obtained from sampling conducted at the various underground mines. Of the 76 sets of data points obtained for relating Miniram readings to personal gravimetric measurements, 60 sets were considered valid for data analysis. Thirteen of the 16 invalid data sets were due to apparent malfunctions in the Miniram the other 3 invalid data sets were due to inconsistency in the gravimetric samples. Valid Miniram TWA measurements ranged from 0.28 to 2.97 milligrams per cubic meter (mg/m^3). MRE equivalent gravimetric dust concentration measurements ranged from 0.19 to 1.65 mg/m^3.

A number of the malfunctions encountered with the Miniram during field tests had not been previously observed during laboratory testing and could not be duplicated when the instruments were removed from the mine environment. These malfunctions included disagreement between the TWA determined from successive instantaneous readings and from internal integration of the instrument's electronic signal. Additionally, malfunctions of various instrument functions (TWA, Shift Average, Time, Zero), erratic display when the function button was pressed, and instrument shutting off either automatically or when a function button was pressed, were observed during the field tests. Malfunctions occurred sporatically with all instruments, there was not one instrument that appeared to be more of a problem than others. Following a malfunction, the Miniram was removed from the mine, wiped clean and charged. A malfunctioning instrument generally operated satisfactorily on the following shift. However, this satisfactory operation could not be confirmed until gravimetric concentrations were determined and compared to the instrument's TWA reading.

Gravimetric determinations obtained from the Miniram filters ranged from 0.44 to 1.50 times those obtained with the respirable coal mine dust sampler. The average ratio between gravimetric determinations was 0.96 with a standard deviation of ± 0.15. This agreement showed that the aerosol passing through the Miniram's sensing chamber was the same as that sampled by the coal mine dust sampler. These results indicate that gravimetric determinations obtained from the Miniram filter can be used to determine the gravimetric concentration of respirable dust to which the Miniram was exposed.

The ratio of TWA obtained from the Miniram to the average of the two gravimetric concentration measurements (Miniram filter and coal mine dust sampler filter) as shown in Table 1 ranged from 0.99 to 2.44. The average ratio of Miniram TWA to MRE equivalent gravimetric concentration was 1.52 with a standard deviation of ± 0.34. In computing the ratio, the gravimetric determination was considered the independent variable. Based on the ratios established, a Miniram TWA can be converted to an equivalent gravimetric concentration, to within ± 20 percent, by either dividing the Miniram measurement by 1.52 or multiplying the Miniram measurement by 0.66.

In addition to computing the ratios between the Miniram TWA and the gravimetric determinations, the ratio and gravimetric concentration data were analyzed using regression analysis to determine if there was a dependency of the ratio on dust concentration. The regression analysis showed that the ratio was not dependent on the magnitude of the dust concentration.

Table [illegible]. Miniram and Gravimetric Data Results and Ratios of Gravimetric Data and Miniram TWA to Gravimetric Data (MRE Equivalent Concentrations)

Miniram No	Miniram TWA Conc mg/m³	Miniram Cassette Conc mg/m³	Personal Cassette Conc mg/m³	Ratio Miniram Cassette/Personal Cassette	Ratio Miniram TWA/Average Cassette
[illegible]	[illegible]	[illegible]	0.26	0.85	[illegible]
[illegible]	[illegible]	[illegible]	0.4	1.09	[illegible]
[illegible]	0.42	0.38	0.34	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.28	1.50	[illegible]
[illegible]	[illegible]	0.40	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.26	[illegible]	[illegible]
[illegible]	[illegible]	0.93	0.96	0.95	[illegible]
[illegible]	0.95	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	3.02	[illegible]	1.26	1.12	2.26
[illegible]	[illegible]	[illegible]	1.65	[illegible]	[illegible]
[illegible]	2.49	0.96	[illegible]	0.82	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.85	1.04	0.8	[illegible]
[illegible]	[illegible]	[illegible]	0.93	0.88	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.38	0.89	[illegible]
[illegible]	[illegible]	[illegible]	0.48	[illegible]	[illegible]
[illegible]	[illegible]	0.48	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.40	0.42	[illegible]	[illegible]
[illegible]	[illegible]	0.40	[illegible]	[illegible]	[illegible]
[illegible]	0.59	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.44	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.22	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	0.86	[illegible]
[illegible]	[illegible]	0.95	0.88	[illegible]	[illegible]
[illegible]	[illegible]	0.84	[illegible]	0.98	[illegible]
[illegible]	[illegible]	[illegible]	0.52	0.86	[illegible]
[illegible]	[illegible]	0.45	0.45	1.00	[illegible]
[illegible]	[illegible]	0.62	0.62	[illegible]	[illegible]
[illegible]	[illegible]	0.95	0.89	1.06	[illegible]
[illegible]	[illegible]	0.93	0.84	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.54	[illegible]	0.99
[illegible]	[illegible]	0.48	0.48	[illegible]	[illegible]
[illegible]	[illegible]	0.70	0.86	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.89	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.8	[illegible]	[illegible]
[illegible]	[illegible]	0.60	[illegible]	[illegible]	[illegible]
[illegible]	0.96	[illegible]	0.56	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.86	[illegible]	1.02	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.38	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.49	[illegible]	[illegible]
[illegible]	[illegible]	0.70	0.70	1.00	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.40	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.26	[illegible]	0.96	[illegible]
[illegible]	[illegible]	0.28	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1.08	[illegible]
[illegible]	[illegible]	0.69	0.62	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.71	[illegible]	[illegible]
[illegible]	[illegible]	0.77	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	0.92	[illegible]
Average				0.96	[illegible]
Standard Deviation				[illegible]	[illegible]

Table 2 contains a matrix showing the average and standard deviation of the Miniram TWA versus average gravimetric determinations for each instrument at each mine. Also shown in the table are the average values for each mine and for each instrument. Considering the averages, standard deviation and the number of data points available, it appears that the difference between the overall average and the averages by instrument and mine are insignificant. While other investigations have shown that changes in the particle size distribution of the aerosol effects instrument response, this result was not observed in this study. Either variations in the particle size distribution of the total dust were insignificant or more likely the range of particle size distribution of the dust passing through the cyclone was not great enough to cause a measurable variation of instrument response. The mass median diameter of the total dust ranged from 4.00 to 6.00 micrometers with a standard geometric deviation of approximately 2.3 micrometers. The mass median diameter of the dust passing through the cyclone ranged from 2.35 to 4.30 micrometers with a standard geometric deviation of approximately 2.2 micrometers. The coal dusts used by other investigators to determine that the response for passively operated instruments was affected by particle size had mass median diameters ranging from 2.0 to 5.0 micrometers.

It should be pointed out again that the maximum gravimetric respirable dust concentration (MRE equivalent) obtained during the field study was 1.65 mg/m^3. While higher dust concentrations were not obtained during field testing, they were obtained during the laboratory testing of each instrument. Table 3 shows the laboratory results of Miniram TWA and cassette filter data for each of the four instruments used during the field study.

A comparison of the overall average of the Miniram TWA to gravimetric concentration from field and laboratory testing of the instruments shows similar results (1.52 $\pm$0.34 versus 1.47 $\pm$0.35). However, while field tests did not quantify a difference in instrument to instrument response, laboratory results have shown some difference among the response of individual instruments. Therefore, to use the instrument TWA to estimate the gravimetric concentration, a factor should be determined for each instrument to convert the instrument TWA to an equivalent gravimetric concentration. The concentration determined gravimetrically from the Miniram filter can be used for this determination.

An additional observation made during this study is that instantaneous respirable dust concentrations at a location can vary greatly and rapidly. As a result, in order to use the Miniram to evaluate a dust generation source, the averaging capability of the instrument (TWA) should be used. During the field tests it was observed that a consistent comparison of TWA readings from instruments operated in the package was obtained after approximately 1 hour of operation. Comparative TWA measurements for operation times less than 1 hour were not made during this study.

Table 2. Ratio of Miniram TWA to Average Cassette Concentration For Each Mine and Instrument

	Instrument				
Mine	No. 1	No. 2	No. 3	No. 4	Mine Average
A	1.66 ±0.18	1.85 ±0.83	1.99 ±0.56	1.38 ±0.29	1.71 ±0.50
B	1.42 ±0.28	1.34 ±0.20	1.37 ±0.12	1.40 ±0.16	1.38 ±0.18
C	1.72 ±0.33	1.75 ±0.51	-- --	1.46 ±0.34	1.64 ±0.39
D	1.49 ±0.27	1.47 ±0.27	1.36 ±0.26	1.47 ±0.12	1.45 ±0.22
Instrument Average	1.56 ±0.28	1.56 ±0.41	1.56 ±0.41	1.42 ±0.44	1.52 ±0.34

Table 3. Laboratory Comparison of Miniram Time-Weighted Average to Gravimetrically Determined Aerosol Concentration (MRE equivalent) Showing Ratio of Time-Weighted Average to MRE Equivalent Concentration

Miniram #1 (mg/m^3)			Miniram #2 (mg/m^3)			Miniram #3 (mg/m^3)			Miniram #4 (mg/m^3)		
TWA (mg/m^3)	Gravimetric (mg/m^3)	Ratio	TWA (mg/m^3)	Gravimetric (mg/m^3)	Ratio	TWA (mg/m^3)	Gravimetric (mg/m^3)	Ratio	TWA (mg/m^3)	Gravimetric (mg/m^3)	Rati[illegible]
3.93	3.01	1.31	3.11	1.97	1.58	2.58	1.41	1.83	1.76	2.08	0.8[illegible]
5.07	2.91	1.74	18.00	10.57	1.70	14.50	15.59	0.93	11.10	9.11	1.2[illegible]
4.48	3.11	1.44	6.89	3.34	2.06	10.40	9.15	1.14	11.40	9.00	1.2[illegible]
3.35	2.48	1.35	3.96	1.97	2.01	4.66	2.94	1.59	4.39	2.70	1.70
3.73	3.45	1.08	3.24	2.04	1.59	3.56	1.90	1.87	4.76	4.50	1.0[illegible]
15.40	11.90	1.29	5.49	3.59	1.53	2.59	1.96	1.32	2.39	2.76	1.0[illegible]
5.71	2.82	2.02				14.10	7.77	1.81			
Mean		1.46			1.75			1.50			1.1[illegible]
Standard Deviation		0.316			0.232			0.373			0.29[illegible]

Overall Mean Ratio = 1.47
Standard Deviation = 0.349

4 SUMMARY

A study was conducted to determine the relationship between respirable dust measurements obtained with an actively operated Miniram and a coal mine dust sampler. Comparative measurements were obtained with four Miniram instruments in four underground coal mines representing three coalbeds. Results of the study indicate that gravimetric measurements (obtained with a coal mine dust sampler) can be estimated to within 20 percent by multiplying the Miniram TWA reading by 0.66. From the limited results of this study, the effect of variations in the size distribution or material composition of the aerosols typically found in underground coal mine environments on the relationship derived between Miniram and gravimetric measurements could not be quantified.

Comparison measurements made in the laboratory although not a part of this study have shown that instruments received from the manufacturer are not uniformly calibrated and that individual instrument response can vary. Therefore, it is important that the calibration of each instrument be checked (or established) using an aerosol typical of the type on which measurements are to be made.

While this study did demonstrate the potential of the Miniram for assessing particulate concentrations in underground coal mines, numerous intermittent operational and reliability problems were encountered with the four Miniram instruments used during the field testing. These problems should be resolved and additional testing should be conducted to establish the integrity and reliability of the Miniram when used in underground coal mine environments.

5 REFERENCES

Lilienfeld, P. & R. Stern. Personal Dust Monitor-Light Scattering. Final Report, U.S. BuMines Contract H0308132, GCA Corporation, Bedford, MA (1982).

Aerosol Technology Committee, American Industrial Hygiene Association. Guide for Respirable Mass Sampling, Am. Ind. Hyg. Assoc. J., v. 31, p. 33 (1970).

Marple, V.A. & K.L. Rubow. Respirable Dust Measurement. Draft Final Report, U.S. BuMines Contract J0113042, University of Minnesota, Minneapolis, MN (1984).

Gero, A.J. & T.F. Tomb. Comparison of Measurements Obtained Actively and Passively with a GCA Miniram. Proceedings of the Dust Control Conference, Morgantown, WV, October 1984.

Tomb, T.F., et al. Comparison of Respirable Dust Concentrations Measured with MRE and Modified Personal Gravimetric Sampling Equipment. U. S. BuMines RI 7772, 1973, 29 p.

Anderson, F.G., T.F. Tomb, & M. Jacobson. Analyzing Midget Impinger Samples with an Electric Counter. U.S. BuMines RI 7104, 1968.