

## TECHNICAL SESSION - III

## HEALTH HAZARDS

## "Dust Sampling Equipment and Instrumentation"

by

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ABSTRACT

A review is presented of the instruments that can be used or are under development for use in coal mines to measure concentrations of respirable dust. Both the advantages and limitations of the instruments are discussed. The review includes the work being done by the Bureau of Mines to develop instrumentation and improve techniques for dust measurements in mines for both determining compliance with dust standards and evaluating the effectiveness of dust control techniques.

INTRODUCTION

Three main categories of instruments being used in coal mines will be discussed in this review. These are (1) gravimetric dust samplers, (2) short-term dust monitors, and (3) instruments for particle size measurements. The overwhelming majority of mine dust measurements are made to determine compliance with coal mine dust standards and also to determine the effectiveness of dust control techniques in mines. Short-term dust monitors measure dust concentrations over a short time interval and give an immediate readout in the mine. They are especially useful for locating dust sources and for evaluating dust control techniques. There are also instruments available that are being used by the Bureau of Mines and Bureau contractors to sample dust in mines and later determine not only the dust concentration, but also the particle size distribution.

GRAVIMETRIC DUST SAMPLERS

The Federal Coal Mine Health and Safety Act of 1969 established a respirable dust standard for the active workings of coal mines, which is now  $2.0 \text{ mg/m}^3$  for the average concentration during each shift. Dust concentrations are to be measured with an MRE instrument or with another approved device that measures equivalent concentrations.

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The MRE instrument (1)<sup>2</sup> is the MRE gravimetric dust sampler type 113A, which was developed by the Mining Research Establishment of the British National Coal Board during the 1960's. The instrument is called "gravimetric" because the mass of respirable dust is determined by weighing the amount of dust collected on a filter. The sampler, shown in Figure 1, consists of a size selector, a filter holder and an electrically driven air pump. The size selector is a four-channel horizontal elutriator mounted on top of the instrument; the selector removes the larger airborne dust particles so that only respirable dust is deposited on the filter. The instrument, including the elutriator, must be operated in a horizontal position. The horizontal elutriator removes 50 pct of those particles with an aerodynamic diameter greater than 7.1 micrometers. The weight of the MRE instrument is about 9 pounds. Because it is larger and more expensive than the personal sampler, it is not used very much in U. S. coal mines.

The most commonly used dust samplers in U. S. mines are the MSA-Monitaire and Bendix Micronair<sup>3</sup> personal dust samplers shown in Figure 2. The personal sampler (2) consists of an air pump, filter cassette and a small nylon cyclone that acts as a size selector to remove nonrespirable dust particles.

The personal sampler is operated at 2.0 l/minute for coal mine dust measurements. The concentration measurements with the personal sampler are multiplied by a conversion factor of 1.38 to determine the equivalent MRE concentration. Unlike the MRE, the personal samplers are small enough to be worn by miners for better measurements of their personal exposure to respirable dust. Under normal conditions in coal mines, the personal samplers are operated for a full 8-hour shift.

The personal samplers are the instruments most commonly used by both operators and inspectors to determine whether coal mines are in compliance with dust standards. The samplers have been criticized in the past few years and, in particular, the accuracy of the dust measurements has been questioned. The National Bureau of Standards recently completed a study of the accuracy of coal mine dust measurements. Their report (3) mentioned the following factors as possibly affecting the accuracy of dust measurements with personal samplers:

1. Air flow is difficult to adjust and maintain during use.
2. The actual volume of air sampled is not indicated by the instrument.

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<sup>2</sup>Numbers in parentheses refer to items in the list of references.

<sup>3</sup>Reference to specific equipment (or trade names or manufacturers) does not imply endorsement by the Bureau of Mines.

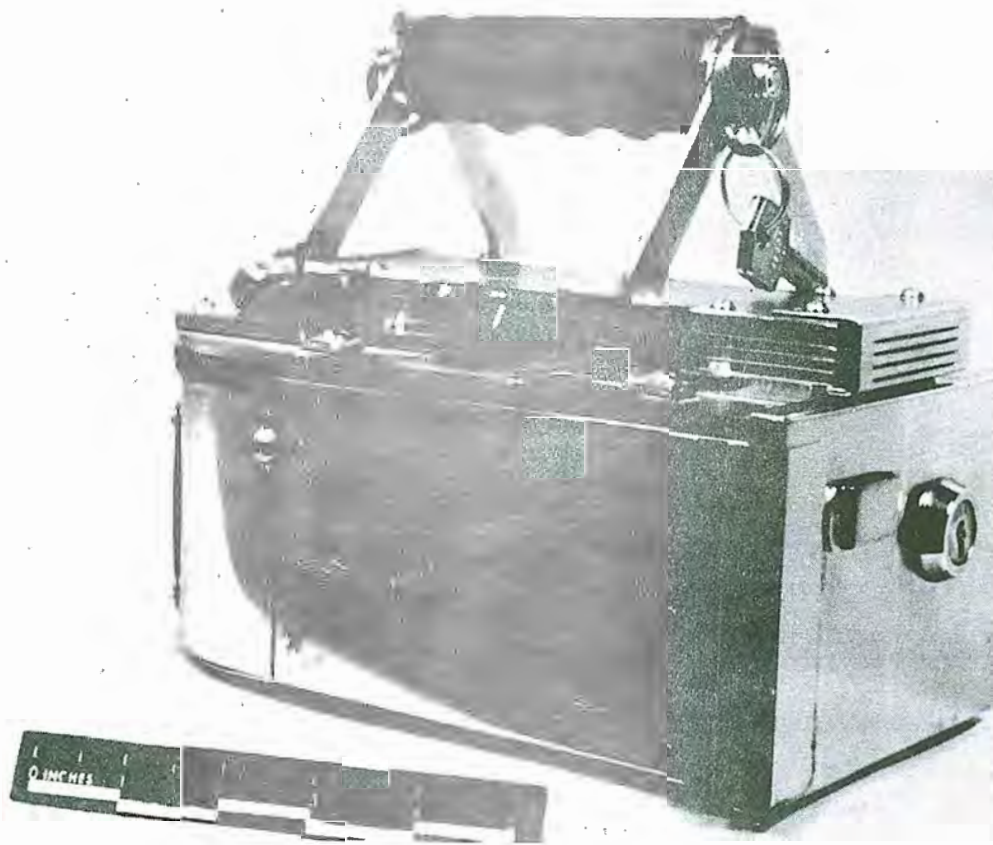


FIGURE 1. MRE Gravimetric Respirable Dust Sampler.

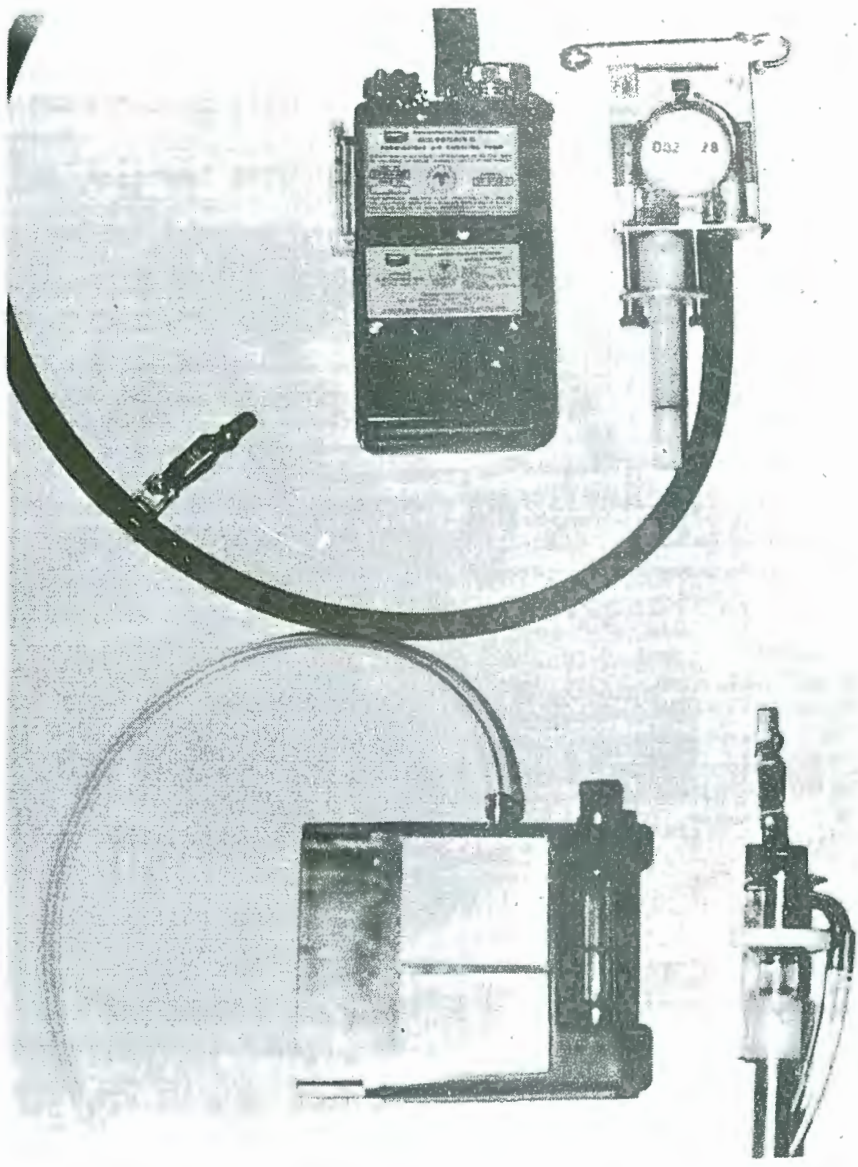


FIGURE 2. Bendix (top) and MSA (bottom) Personal Respirable Dust Samplers.

3. Simultaneous inversion and impact of the sampling head could contaminate the dust sample with non-respirable particles.
4. The sampling head is difficult to assemble and could be knocked out of alignment by physical impact.
5. The sample could be altered without detection.

The Bureau of Mines has investigated the precision of dust measurements with personal samplers over the past two years. Dust measurements have been made in coal and noncoal mines and processing mills with personal samplers operated side-by-side in packages such as that shown in Figure 3. Data collected by Bureau contractors both in the laboratory and in coal mines has also been evaluated.

The main results of these studies follow:

1. The coefficient of variation of measurements with the personal sampler in the laboratory is about 7 pct.
2. The coefficient of variation for dust measurements in coal mines with personal samplers can range from 7 pct to greater than 50 pct.
3. The true dust concentrations in coal mines vary from shift to shift with a coefficient of variation typically between 30 and 70 pct.

The laboratory measurements show that the personal sampler itself is a reasonably precise instrument when operated according to the proper procedures. The reasons for the greater variation in the dust measurements made in coal mines are not completely understood and are the subject of some controversy. The increased variation is probably due partly to the difficulty in operating the dust samplers under mine conditions and possibly also partly due to real variations in dust concentration between sampler locations. After reviewing all the available data on coal mine dust measurements, the National Bureau of Standards (3) concluded

"The uncertainty to be expected in the normal program operations, i. e. when the miners and mine operators perform and supervise the sampling and when the weighings are made in the normal manner, is estimated to be as large as 31 percent or  $0.63 \text{ mg/m}^3$ ."

This uncertainty of 31 pct (at a mean of  $2.0 \text{ mg/m}^3$ ) is the coefficient of variation for a single dust measurement. The uncertainty owing to measurement error can be reduced by taking an average of many dust measurements.

Even if the dust measurements were extremely precise, it would still be difficult to obtain a good estimate of an average dust concentration for a coal mine section. This is because of the large variation (30 to 70 pct) that usually occurs in the true dust concentrations at any location in a mine from shift to shift. Differences in dust concentration occur because

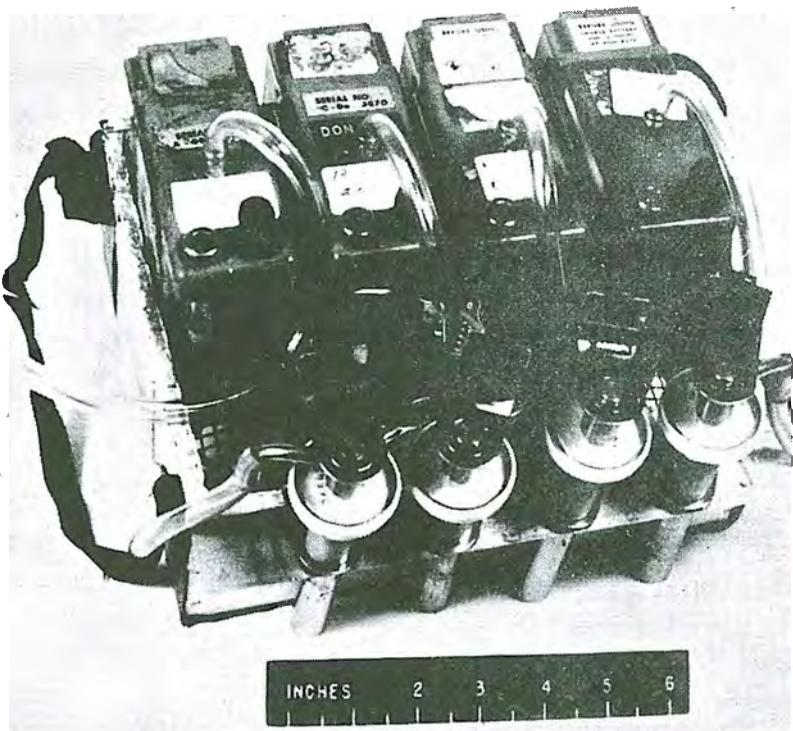


FIGURE 3. Sampler packages used to determine dust measurement precision.

of variations in the amount of coal mined, changes in the coal from place to place and variations in the ventilation and other dust control parameters such as water sprays. Under normal production conditions, the dust concentration near a continuous mining machine operator in a mine can have a coefficient of variation of 70 pct. The variation is usually smaller for dust concentrations in return airways, but even then it is usually greater than 30 pct.

This variation in dust concentrations from shift to shift makes it very difficult to determine the real effectiveness of dust control techniques in coal mines when using personal samplers for dust measurements. Figure 4 shows the number of tests required under each condition to be 90 pct confident that there is a reduction when using a new dust control technique. For example, if a 20-pct reduction were observed under a normal production situation where the coefficient of variation is about 70 pct, then about 42 measurements are required before and 42 after the dust control technique is introduced. Since a full shift is normally required for a single personal sampler measurement, an impractically large number of 84 shifts would be required to achieve 90 pct confidence that the new technique is effective. The number of shifts required can be greatly reduced if the observed dust reduction is much larger, or if the coefficient of variation of the measurements is reduced by maintaining as constant as possible the parameters that affect dust levels. A dust reduction of 40 pct or greater is not too difficult to demonstrate after about 20 shifts. However, one should be very skeptical about claims for the effectiveness of any control technique that has been tested for only a few shifts.

### SHORT-TERM MONITORS

The problem of evaluating dust control techniques in coal mines can be simplified by using an instrument that can measure dust concentrations after a much shorter time interval than that required by the personal sampler. Instruments are available that can measure the dust concentration after one minute or less and also give an immediate readout in the mine. These instruments are useful for locating and determining the magnitude of dust sources in mines and are especially useful for evaluating some dust control methods such as dust collectors, which can be quickly and repeatedly turned on and off in a mine. With a short-term dust monitor, many dust measurements can be made during one shift, and thus it is possible to determine the effectiveness of the collector in one shift instead of the dozens required using personal samplers.

Instruments that use the principle of light-scattering to measure dust concentrations have been available for many years. However, none were suitable for use in coal mines. Under a Bureau of Mines contract, Stanford Research Institute developed an intrinsically safe, portable, light-scattering dust monitor for use in coal mines.<sup>4</sup> This SRI dust monitor (Figure 5) is used in conjunction with an MSA personal sampler. It consists of three sections. The back section contains an incandescent bulb,

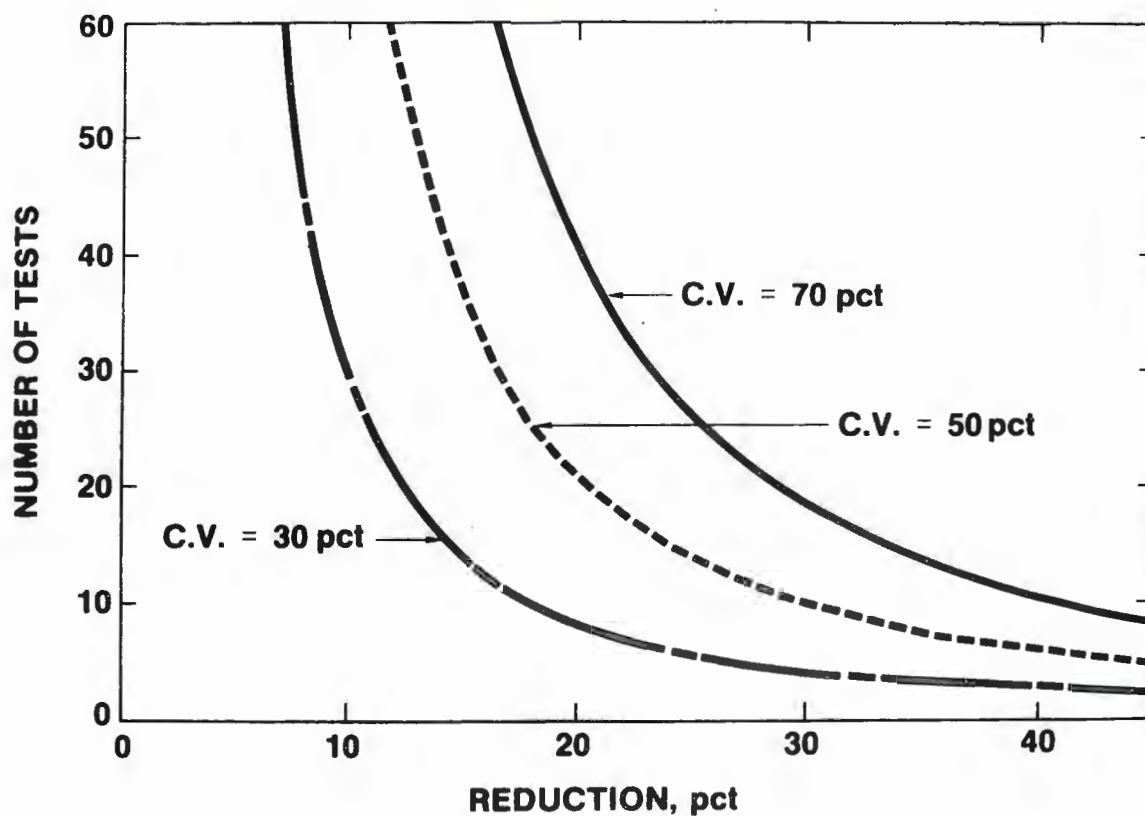


FIGURE 4. Number of tests at each condition required to detect a reduction in dust levels with 90 pct. confidence. C.V. is the coefficient of variation of dust concentrations.

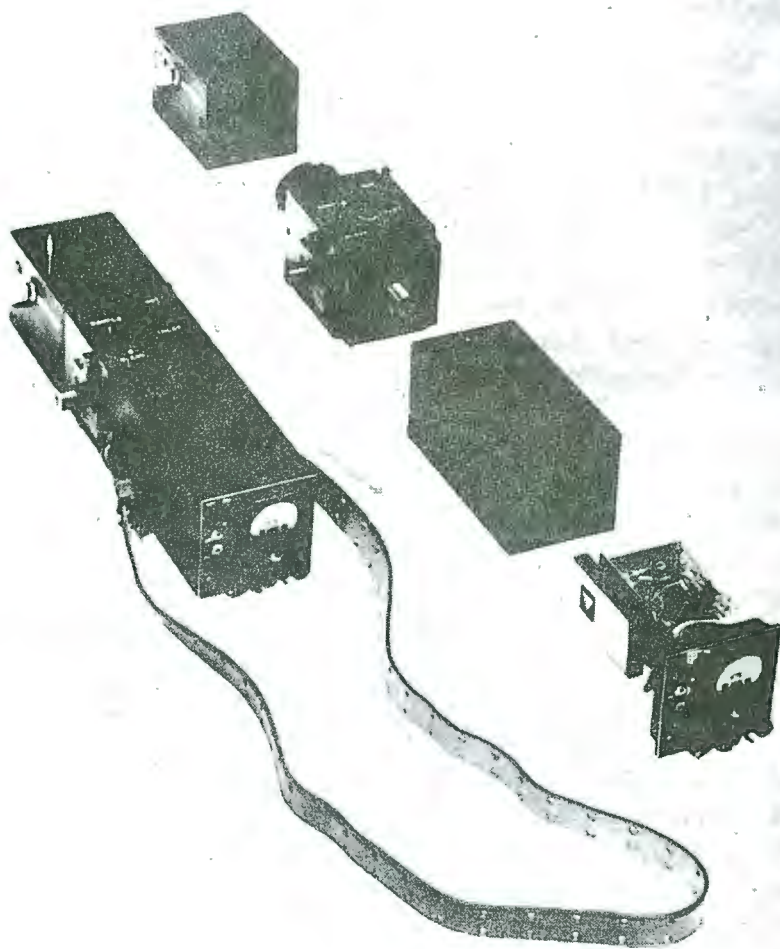


FIGURE 5. SRI light scattering dust monitor.

which is powered by the battery of the MSA pump. The middle section contains the optics and a chamber through which respirable dust is drawn by the MSA pump. Light scattered from the dust in the forward direction by a photodiode in the front section of the instrument. The signal from the photodiode is amplified and displayed on a meter on the front panel. The meter reading is proportional to the concentration of respirable dust that enters the instrument.

The SRI dust monitor is about 3 inches high x 3 inches wide x 14 inches long and weighs 6.9 pounds exclusive of the MSA sampler. It is a continuous monitor; i.e., the meter continuously responds to changes in dust concentration. The response time for the instrument to reach 90 pct of its final reading is 6 seconds after any sudden change in dust concentration.

The response of any light scattering dust monitor depends on the index of refraction and size distribution of the dust measured. Thus, the SRI dust monitor cannot read out directly a mass concentration ( $\text{mg}/\text{m}^3$ ) of dust, although it can be calibrated to give an approximate mass concentration to within  $\pm 50$  pct in coal mines. It is of great value in conducting mine surveys to determine the relative magnitude of dust sources and for any other purposes in coal mines where differences in dust levels rather than absolute mass concentration measurements are needed.

Figure 6 shows the response of an SRI dust monitor to mass concentration of respirable coal dust measured in a Bureau of Mines laboratory. The data show that as long as the size distribution and type of dust is kept the same, the response of the SRI monitor is linear up to at least 40  $\text{mg}/\text{m}^3$ . Theoretically, the response should be linear up to hundreds of milligrams per cubic meter, which is well beyond the range required for dust measurements in coal mines.

Another instrument used for dust measurements in coal mines is the GCA model RDM-101 respirable dust monitor (Figure 7).<sup>(5)</sup> Respirable dust is collected inside this instrument by impaction on a thin, grease-coated plastic disk. The mass of dust collected over a short time period (e.g., one minute) is measured by the change in attenuation of beta radiation caused by the buildup of dust on the impaction disk. The instrument weighs 6.6 pounds and is intrinsically safe for use in coal mines. It is battery powered and completely self-contained. At dust concentrations normally encountered in coal mines, about one minute is required for a measurement. At the end of the one minute sampling period, the average dust concentration over that period is read out on a digital display.

The great advantage of this instrument over light-scattering dust monitors is that, within certain limits, the instrument measures the mass concentration independent of the type of dust and particle size distribution. Since impaction is used to collect the dust, only dust particles larger than about 0.7 micrometers in diameter will be collected and measured

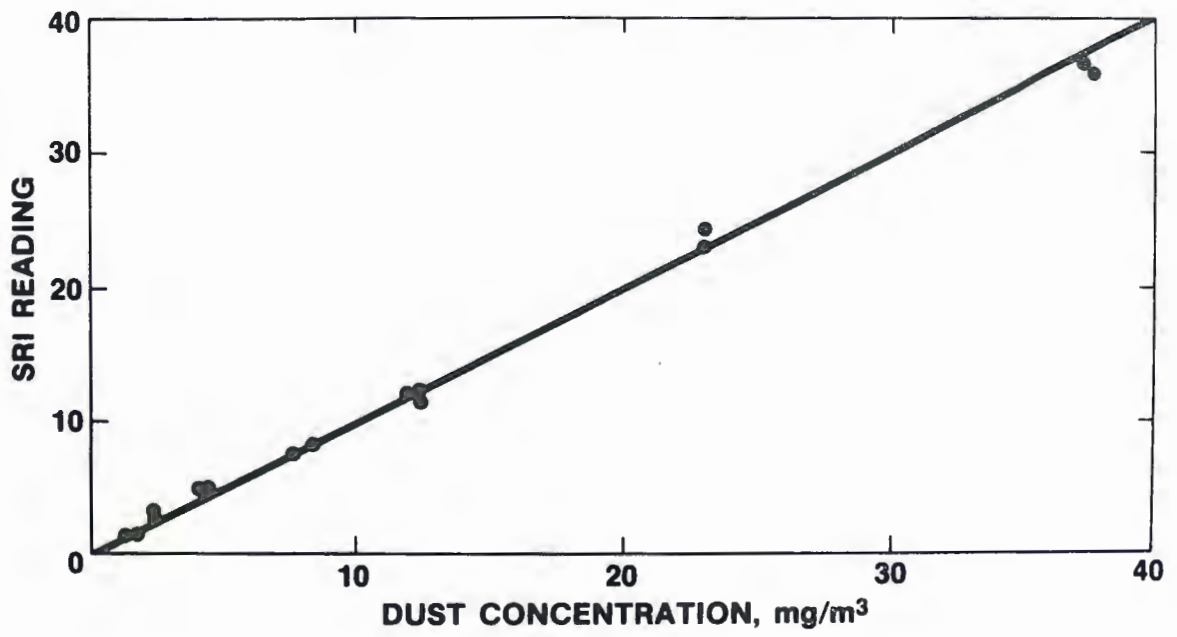


FIGURE 6. SRI reading vs gravimetric dust concentration.

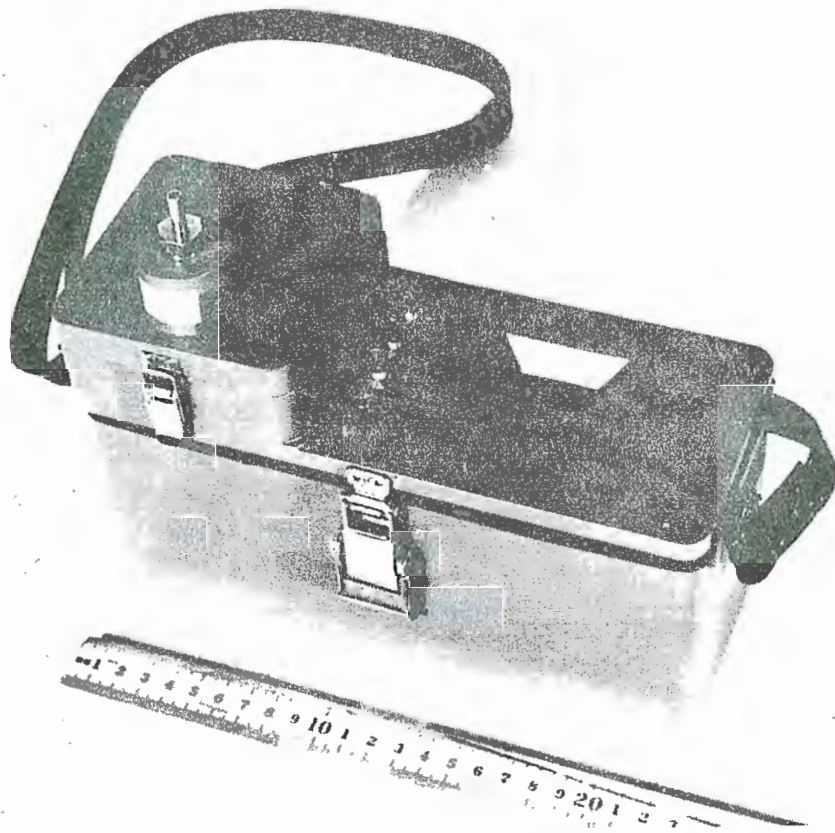


FIGURE 7. GCA respirable dust monitor model RDM-101.

accurately. Normally most of the mass of respirable dust in coal mines will be in particles larger than this size.

Laboratory tests by the Bureau of Mines have shown the GCA RDM-101 dust monitor to give low measurements at high coal dust concentrations. This defect was brought to the attention of GCA, and the company has since changed the recommended coating material for the impaction disks, and this has partially corrected the problem. The University of Minnesota under a Bureau of Mines contract has recently completed an evaluation of the GCA RDM-101. (6) They also found that the response tended to fall off at higher concentrations although the newer instruments using the revised coating gave reasonably accurate measurements for respirable coal dust concentrations up to about  $10 \text{ mg/m}^3$ . The accuracy of the instrument can be improved at high concentrations by using a shorter sampling time than one minute.

GCA Corporation, under a Bureau of Mines contract, developed a respirable dust recording mass monitor. (7) This instrument uses the same particle-impaction and beta-attenuation system as the RDM-101. In addition, the instrument will automatically take up to 450 one-minute measurements of respirable dust and print the individual mass concentration measurements on paper tape. This instrument allows automatic unattended operation for up to eight hours on battery power.

GCA has now produced a modified version of the respirable dust recording mass monitor called the GCA RDM-301 (Figure 8). It is 18 inches long x 13 inches wide x 11 inches high and weighs 42 pounds, including the battery. It is intrinsically safe for mine use.

This instrument has the same disadvantage as the RDM-101 in that the accuracy of coal dust measurements is questionable at high dust concentrations. However, it does have application particularly for research purposes where a quasi-continuous record of mass concentration of dust is needed. This type of instrument may eventually evolve into a dust monitor that could be used in the face area of a coal mine to warn mine personnel that dust levels are too high. The Bureau of Mines is pursuing the development of this type of respirable dust instrumentation.

## PARTICLE SIZE MEASUREMENT

Prior to the late 1960's, the midget impinger was the most commonly used instrument for measuring airborne dust in mines. It can still be useful for short-term dust-concentration measurements when it is not necessary to have an immediate readout in the mine. The Bureau of Mines uses the Coulter Counter (8) to measure the dust concentration and particle size distribution of samples collected with midget impingers. The Coulter Counter can also be used to count and size particles collected on a suitable filter (e. g. Nuclepore) if all the particles can be washed from the filter with alcohol without significant deterioration of the filter.



FIGURE 8. GCA respirable dust monitor model RDM-301.

The Coulter Counter counts and sizes dust particles according to the volume diameter of the dust particles. It can be used to size particles slightly below one micrometer in diameter. The major disadvantage of measuring coal mine dust size distributions with the Coulter Counter is that the dust must be suspended in a liquid, usually isopropyl alcohol. Any coal dust particles existing as part of agglomerates while airborne will separate in the alcohol. Thus, the particle sizes measured with the Coulter Counter may be somewhat smaller than the particle sizes of the original airborne dust.

The Bureau of Mines has also made use of a scanning electron microscope (SEM) for measuring the particle size of coal mine dust. The SEM can produce useful photographs of dust particles less than 0.1 micrometer across. Examination of dust samples with the SEM shows that agglomerates occur but are relatively rare.

### IMPROVING MINE DUST MEASUREMENTS

The Bureau of Mines is now involved in or planning various projects to improve the measurement of respirable coal mine dust. The studies of the precision of mine dust measurements will be extended in cooperation with MESA, NIOSH and the National Bureau of Standards. The purpose of the new study is to determine quantitatively the precision of the dust measurements made with the current sampling equipment by coal miners in underground mines.

Eastern Associated Coal Corporation has recently completed a study of the feasibility of area sampling in the face area of coal mines. Dust measurements from samplers on miners correlated well with measurements from samplers located at fixed points near the miners. The Bureau has also awarded a contract to MSA Research Corporation for a study of area dust sampling at points located outby the face. The advantage of area sampling is that it removes the burden of wearing the samplers from the miner. It also may allow larger and better instruments to be used eventually.

Two contracts are already underway for improving the filter cassettes of the personal samplers. Bendix and MSA have Bureau contracts to develop tamperproof cassettes. The contracts call for filter cassettes with the following features:

1. One-way flow valves to prevent the filter from being back-flushed with air.
2. A case designed to prevent the cassette from being opened and reassembled.
3. Traps to prevent dust from being shaken from the filters.

Both contractors have already delivered prototype cassettes. We know that the improved features may add to the cost of the cassettes if

they are adopted. The advantages of the improved features will be balanced against any increased cost of the cassettes before the new cassettes would be required by any new regulations. The Bureau is also considering a similar project for improvements in the sampling pumps.

The long-range goal of the Bureau in the area of coal mine dust measurement is the development of a dust monitor that could be mounted on face machines in coal mines and would continuously monitor respirable dust concentrations during every shift. The respirable dust recording mass monitor developed for the Bureau by GCA is one possible type of instrument for this purpose. The Bureau has recently awarded contracts to GCA and Bendix for developing machine-mounted dust monitors using the principle of beta attenuation to measure the mass of dust collected on a filter. We are probably at least five years away from having a machine-mounted dust monitor ready for regular use in coal mines. However, once it is available, it will be possible to automatically monitor respirable dust levels in the face areas of coal mines. If dust levels become excessive, an alarm can be set off so that the situation can be corrected immediately.

## CONCLUSION

The state-of-art of coal mine dust measurements has been reviewed. There is no perfect instrument for the measurement of respirable dust in mines. The personal samplers are the most commonly used and are the best available instruments for measuring the exposure of miners to respirable dust. Short-term dust monitors are available that give a readout of dust concentration in the mine. These can be very useful for locating dust sources and evaluating dust control techniques. All the available instruments have some limitations of which the user should be aware.

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