MEASUREMENT STRATEGIES IN U.S. UNDERGROUND COAL MINES

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ABSTRACT

The 1969 Federal Coal Mine Health and Safety Act (ACT) mandated standards for occupational exposures to respirable coal mine dust. For mine environments where the respirable dust contains less than 5 percent quartz the standard is 2.0 milligrams of dust per cubic meter of air (mg/m^3), where the respirable dust contains more than 5 percent quartz the standard is adjusted according to the quartz percentage. The Act also required mine operators to carry out a dust sampling program. This paper presents an overview of the current methods used in the United States of America to assess exposures to respirable dust in coal mines, the sampling strategies used to enforce the mandatory dust standard, the sampling requirements of coal mine operators and a description of the laboratory used to process the more than 100,000 samples per year collected by the coal mine operators.

ENFORCEMENT PROGRAMS (STRATEGIES)

Since December of 1969, the United States of America has had a Federally mandated respirable dust standard of 2.0 mg/m^3 for its underground coal mine environments. Respirable dust, for the purpose of this standard, is defined as the fraction of dust recommended by the British Medical Research Council (BMRC) and adopted by the Johannesburg Pneumoconiosis Conference in 1959. The sampling efficiency curve representative of the respirable dust criteria adopted at that conference is shown in Figure 1. Particle diameters in this figure refer to equivalent spherical diameters, which are defined as the diameter of spherical particles of unit density having the same falling velocity as the particles in question.

Because of the recognized increased health risk associated with exposure to quartz (crystalline silicon dioxide), the mandated exposure standard is to be adjusted (reduced) when the quartz content in the respirable dust exceeds 5 percent. The adjusted standard is determined by dividing the percent quartz in the respirable dust into the number 10 (i.e., 10/% SiO_2).

In the United States there are two programs to enforce the mandatory respirable dust standard, a program conducted by the mine operators in accordance with mandated regulatory requirements and a program conducted by the Federal government. Under the operator's program each operator is required to collect five respirable dust samples from a "designated occupation," the occupation on a coal getting operation that previous sampling has shown to have the highest dust exposure, in each coal getting operation every two months. The samples must be collected on consecutive production shifts or on production shifts on consecutive calendar days.

The collected samples are sent by mail, within 24 hours after collection, to a central laboratory in Pittsburgh, Pennsylvania, where the amount of dust collected is determined by weighing. A data card, shown in Figure 2, is submitted with each sample. The dust concentration is determined for each sample using the weight of dust collected, the time over which the sample was collected and the flow rate of the sampling device (in all cases this is 2.0 liters of air per minute). All samples are required to be collected for a full production shift (portal-to-portal).

The dust concentrations determined from these five samples are averaged. The average concentration is then compared to the 2.0 mg/m^3 dust standard (or adjusted standard) to establish compliance or noncompliance with regulatory requirements. In addition to the five samples collected bimonthly on the designated occupation, the mine operator is

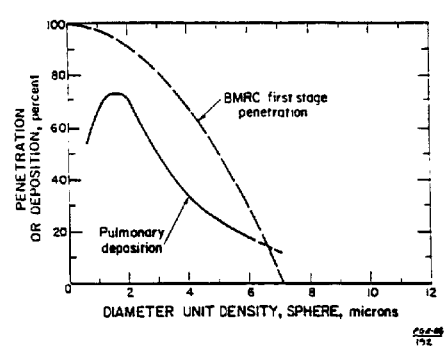

Figure 1. Comparison of BMRC respirable size criteria with pulmonary deposition curve.

also required to collect an additional sample bimonthly at specified locations throughout the mine. These locations are strategically selected so that the environment where miners normally work or travel is monitored for compliance with the respirable dust standard. If at any time it is determined from any of these samples that the respirable dust standard is exceeded, five additional samples are collected (either on consecutive days or consecutive production shifts) at the site where it was determined that the applicable standard may be exceeded. The dust concentrations determined from these samples are averaged and compliance is determined using the applicable standard for the area where the samples were collected. In accordance with regulatory requirements, the mine operator also submits to the Federal government a ventilation system and a methane and dust control plan which are to include: sources of dust generation in the outby areas of the mine, methods being used to control dust at these sources of dust generation and the specific location of places where samples will be collected to monitor the levels of dust in areas where miners normally work or travel. Also specified in the plan are the parameters characterizing the measures that are being used to control dust at the coal mining (getting) operation. The typical parameters specified include the quantity and velocity of air used to ventilate the face, the quantity and pressure of water and the number, type and location of nozzles used in the water spray system.

The Federal government's program to enforce the legislated respirable dust standard(s) consists of a mine inspector visiting each coal mining operation to approve, or check for compliance, that portion of the ventilation and dust control plan that describes the measures to be used by the mine operator to control respirable dust levels in the mine environment. To approve the "dust control" portion of the plan, an inspector will collect a personal sample on at least five miners working in the immediate area of the coal mining operation where the parameters described in the plan are being used to control the dust. If the type of mining is "room and pillar" employing continuous mining equipment, one sample must be collected from the environment of the continuous miner operator, one from the environment of the roof bolter operator and three from other occupations working in the immediate area. Typically these other three samples are representative of the environments of shuttle car operators, continuous miner operator helpers and laborers. If the mining operation is a longwall mining operation, the samples are representative of the shearer operators and shield (jack) setters.

The sampling equipment is normally mounted on the miners (referred to as personal sampling) prior to the start of the shift and removed after the shift is finished. After the samplers are removed from the miners, a mine data card is completed and the sample and data card taken to a local Federal enforcement laboratory for processing. The respirable dust samples collected are weighed to a tolerance of ± 0.1 mg which is the same as for those samples collected by the mine operators. After the samples are weighed and the net weight of the collected dust determined, the concentration of dust, in mg/m^3, is calculated using the weight of the dust collected and the volume of air sampled.

To determine if the parameters being used to control dust are effective in reducing the respirable dust level in the environment to the applicable standard, the dust concentrations determined from the five samples are averaged. For the plan to be considered adequate, the average dust concentration must be below 2.0 mg/m^3 and the concentration of no individual sample can be greater than 2.0 mg/m^3. If the average concentration determined from the five samples exceeds 2.0 mg/m^3, the work area is found to be in noncompliance and the mine operator must improve the practices being used to control dust and specify these changes in his dust control plan.

If the average concentration determined from the five samples is below 2.0 mg/m^3, but one or more of the individual samples is greater than 2.0 mg/m^3, then sampling continues on all five occupations on subsequent production shifts. Sampling is continued until the average concentration determined from the individual occupation samples collected on

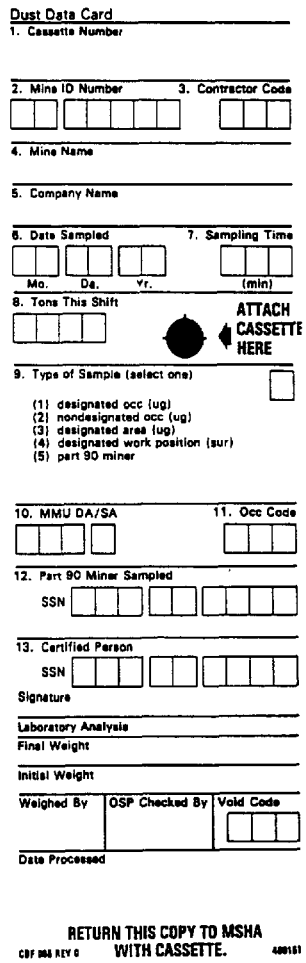
Dust Data Card
1. Cassette Number
2. Mine ID Number
3. Contractor Code
4. Mine Name
5. Company Name
6. Date Sampled
Mo. Da. Yr.
7. Sampling Time
(min)
8. Tons This Shift
ATTACH CASSETTE HERE
9. Type of Sample (select one)
(1) designated occ (ug)
(2) nondesignated occ (ug)
(3) designated area (ug)
(4) designated work position (sur)
(5) part 90 miner
10. MMU DA/SA
11. Occ Code
12. Part 90 Miner Sampled
SSN
13. Certified Person
SSN
Signature
Laboratory Analysis
Final Weight
Initial Weight
Weighed By
OSP Checked By
Void Code
Date Processed
RETURN THIS COPY TO MSHA WITH CASSETTE.

Figure 2. Mine data card.

consecutive production shifts and the average concentration determined from samples collected on the same shift are both equal to or less than 2.0 mg/m^3. No more than five production shifts are sampled.

As previously discussed, the 2.0 mg/m^3 respirable dust standard is reduced whenever it is determined that the quartz content of the respirable dust exceeds 5 percent. Determination of the quartz percentage of the respirable dust is based on the analysis of a selected number of samples collected during the plan approval process. Those samples typically selected for analysis are the designated occupation sample, all roof bolter samples and any other sample that may be suspected of having a high quartz percentage.

After sampling has demonstrated that the procedures specified in the plan for controlling dust are adequate, subsequent inspections (up to three) during the year are limited to checking on conformance with the dust control plan; i.e., no dust samples are collected, only dust control procedures are evaluated.

RESPIRABLE DUST SAMPLING INSTRUMENTATION

To measure the respirable dust concentration of coal mine environments in the United States, a two-stage sampling instrument is used. The instrument, commonly referred to as a personal respirable coal mine dust sampler, is shown in Figure 3. The sampler was designed to be an instrument that was capable of sampling the environment to which a miner is exposed during his full work shift. Therefore, the instrument has the flexibility of either being mounted on a person (as shown in Figure 4) to obtain his exposure or of stationary mounting to obtain measurements of any general environment where it is located.

The sampler consists of a 10 mm diameter nylon cyclone, a filter and a pump. The 10 mm nylon cyclone, the first stage of the sampling system, separates the sampled aerosol into two fractions: a respirable fraction and a nonrespirable fraction. The particle selectivity curve that defines the separated fractions is shown on Figure 5.

The nonrespirable fraction is collected and retained in the cyclone (Figure 6) while the respirable fraction passes through the cyclone and is collected on a 37 mm diameter, 5 micrometer pore size, vinyl metricel membrane filter. The filter is preweighed by its manufacturer to a precision of ± 0.1 milligram. The cyclone and filter assembly, commonly referred to as the "sampling head," is designed to be mounted on the miner at his "breathing zone."

The pump, used to induce air into the sampling system, is

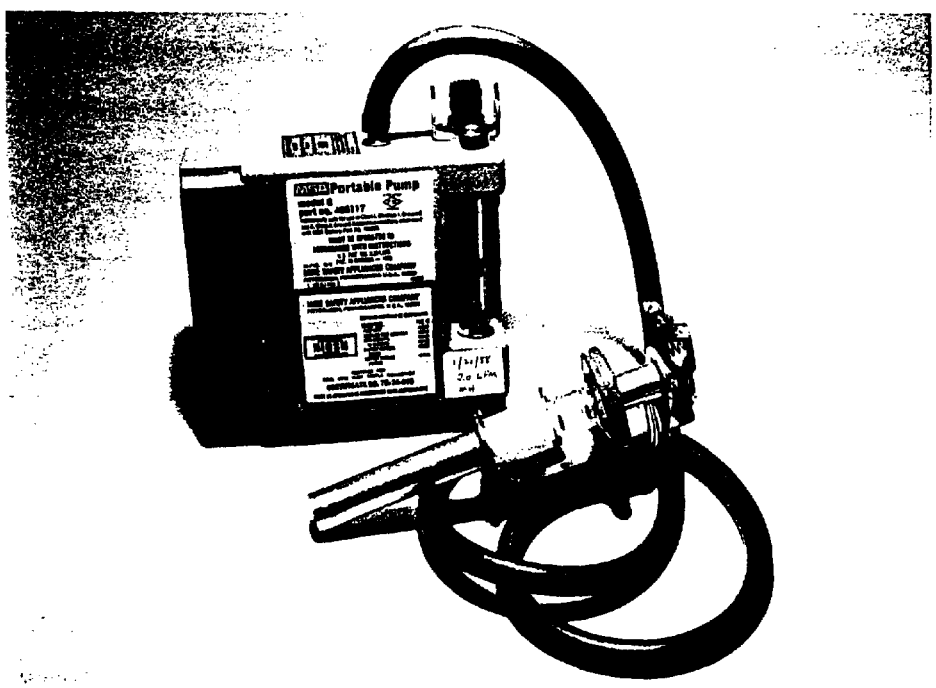

Figure 3. Personal respirable dust sampler.

Figure 4. Personal sampler worn by miner.

battery powered and can be easily worn by a miner during the performance of his duties. It weighs less than one kilogram and has overall dimensions of approximately 5 cm × 10 cm × 13 cm.

Air is sampled at the rate of 2.0 liters per minute (±0.1 liters per minute). Because the 2.0 mg/m^3 dust standard is based on measurement data obtained with an instrument that sampled with respect to the BMRC selectivity curve shown in Figure 1, respirable dust concentrations determined from measurements obtained with the personal coal mine dust sampler must be multiplied by a factor of 1.38 before the measurements can be used to determine compliance with the mandatory dust standard.

PROCESSING COAL MINE OPERATOR DUST SAMPLES

As a result of the Federally mandated regulatory program, approximately 110,000 dust samples are collected by mine operators each year. These samples and associated data are mailed to the Federal government's central processing laboratory located at Pittsburgh, Pennsylvania.

At the central processing laboratory, samples are processed in a "clean room" environment. The laboratory is maintained

at a slight positive pressure to limit the entry of extraneous dust from surrounding work areas. The environment in the room where samples are weighed is maintained at 23° ± 1°C and 50 percent ±5 percent relative humidity.

Prior to weighing, samples are vacuum desiccated to remove moisture that may be present on the sample. The internal pressure of the desiccator chamber is reduced to 5 mm Hg and held at that pressure for 15 minutes.

Since January, 1985, respirable dust samples have been processed using the Automated Weighing System (AWS) shown in Figure 7. The AWS is a robotic system which has been designed for unattended weighing of filter capsules on a Mettler AE163 analytical balance.

The robotic arm (Figure 8) has the ability to rotate 360° around its central vertical axis, move up and down its vertical axis as well as in and out from the horizontal axis. At one end of the robotic arm is a "hand" with a pair of fingers which may be made to open and close as well as rotate 180° in wrist-like movements around the arm's horizontal axis. The system is designed so that the robot can sequentially process up to 200 samples from five trays without manual intervention. Processing time for 200 samples is approximately four hours.

Performed tasks are programmed into a power and event controller. The power and event controller zero's the balances before weighing each sample, switches a relay to select either of two balances, activates a solenoid to open and close a balance door and to sound an alarm buzzer when manual intervention with the AWS is required. Upon completion of a weighing, the controller activates a printer which prints the weight of each filter capsule and a sequence number on a 1 cm x 5 cm pressure sensitive label. The label is subsequently affixed to the data card.

The Mettler Model AE163 analytical balance used with the AWS is shown in Figure 9. This state-of-the-art analytical balance has a weighing precision of ±0.02 mg. Each balance is calibrated twice daily and checked with a Class M certified calibration weight. A radioactive deionizing unit is used to eliminate the presence of static charge on filter capsules. To isolate vibrations, the balances are positioned on a marble table weighing approximately 320 kg.

The AWS has been programmed to systematically weigh a sample twice on two different Mettler AE163 balances. One in eight of each filter capsule weighed is reweighed on the second balance. If the weight difference obtained between the two balances is within ±0.1 mg, the weighings are considered to be within tolerance and weighings are continued. If the weights are out of tolerance, an alarm sounds and both balances are recalibrated. The system then reweighs the last seven filters, performs another quality control check weighing and continues processing additional samples if the check weights are within the established tolerance.

As previously discussed, each respirable dust sample is

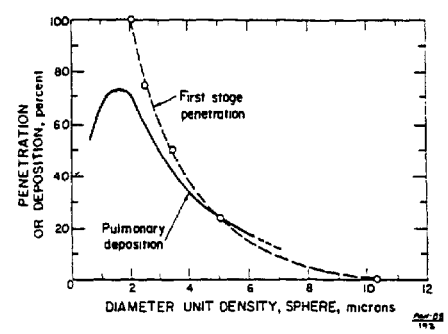

Figure 5. Comparison of the 10 mm diameter cyclone selectivity curve with pulmonary deposition curve.

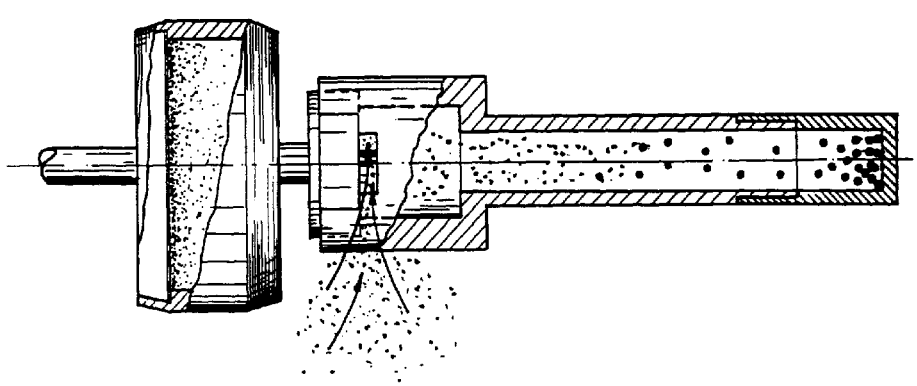

Figure 6. 10 mm cyclone with filter.

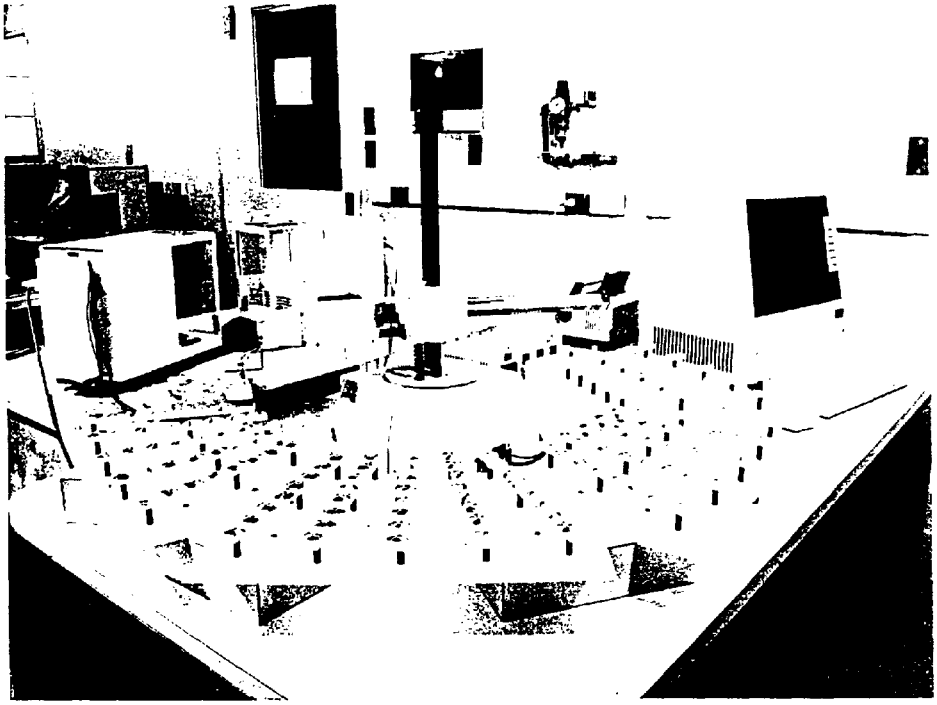

Figure 7. Automated weighing system.

accompanied by a mine data card (Figure 2). The data on each card is manually transcribed (Figure 10), in numeric notation, onto magnetic discs. Each card contains 62 keystrokes or digits. Data transcription is verified using a double entry system. Data retranscribed by a second operator is compared to that originally transcribed. The verifying operator is alerted to resolve errors or mismatched data. All disks generated during the day are then machine edited for completeness and accuracy. After editing, all data is accumulated and telecommunicated to an Information Systems Center in Denver, Colorado.

The information telecommunicated to the Information Systems Center is compiled and the respirable dust concentration for each sample calculated. A copy of all the data and sample results are mailed directly to the mine operators. The results are also telecommunicated to local enforcement offices which have interactive access to all dust data file information.

SUMMARY

The promulgation of a respirable dust standard for underground coal mine environments and the programs instituted to enforce that standard have resulted in a more healthful working environment for U.S. coal miners. As shown in Figure 11, occupational exposures have steadily decreased since promulgation of the respirable dust standard. However, as the data on this graph also depicts, the reduction of dust levels on longwall mining operations has not been as great as on the other types of mining operations. Work still needs to be done to develop methods to control dust on longwall mining operations.

The program requiring coal mine operators to sample their mine environments and to submit the samples to the Federal government for analysis has been effective in reducing underground respirable dust levels, and has provided the impetus for them to institute procedures to control dust.

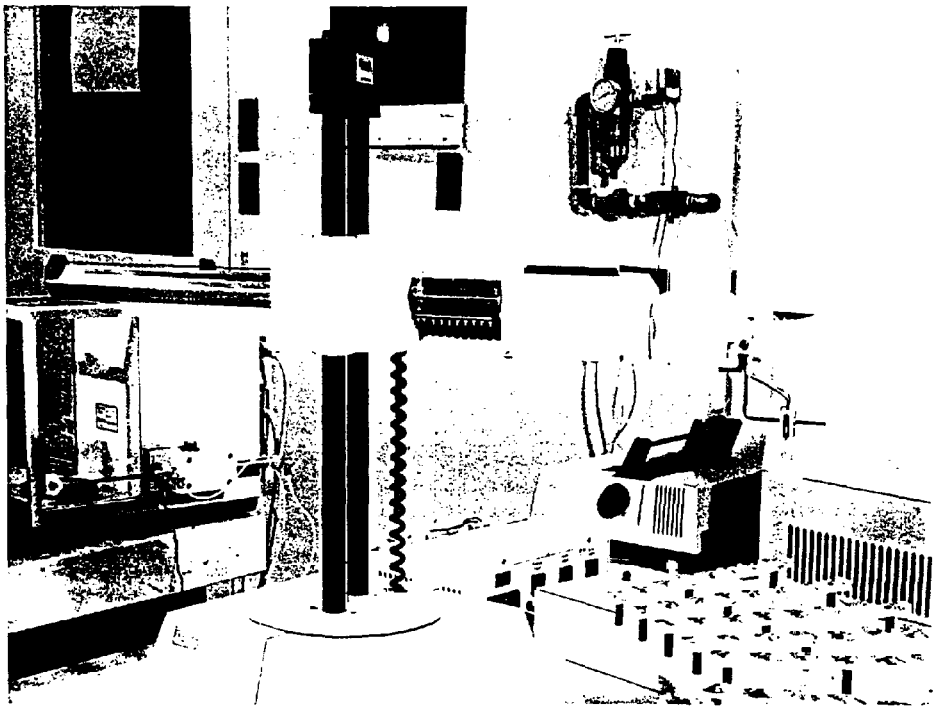

Figure 8. Robotic arm.

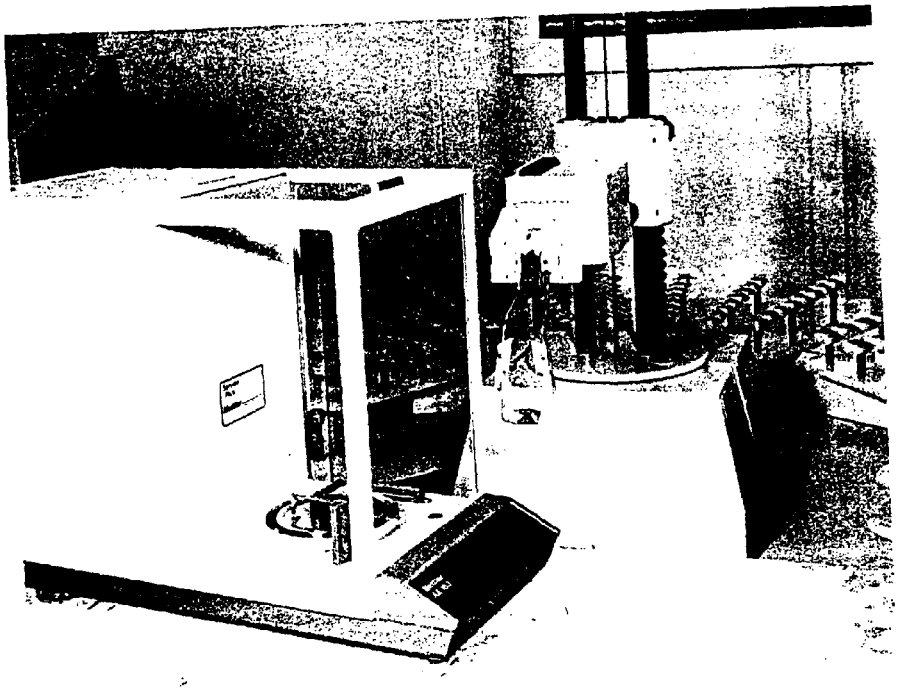

Figure 9. Analytical balance used with automated weighing system.

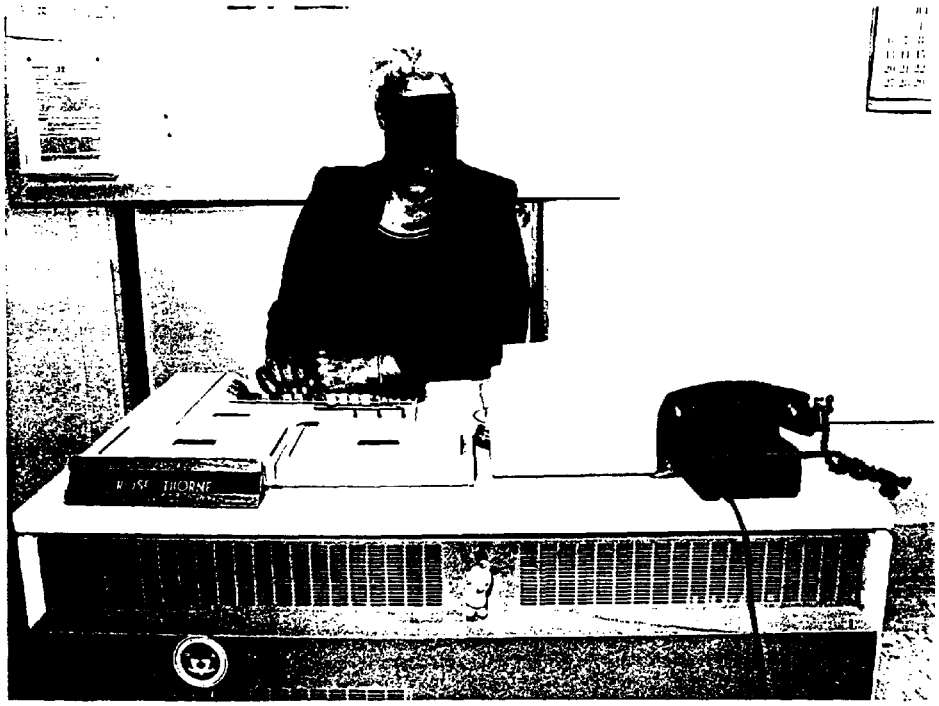

Figure 10. Data processing station.

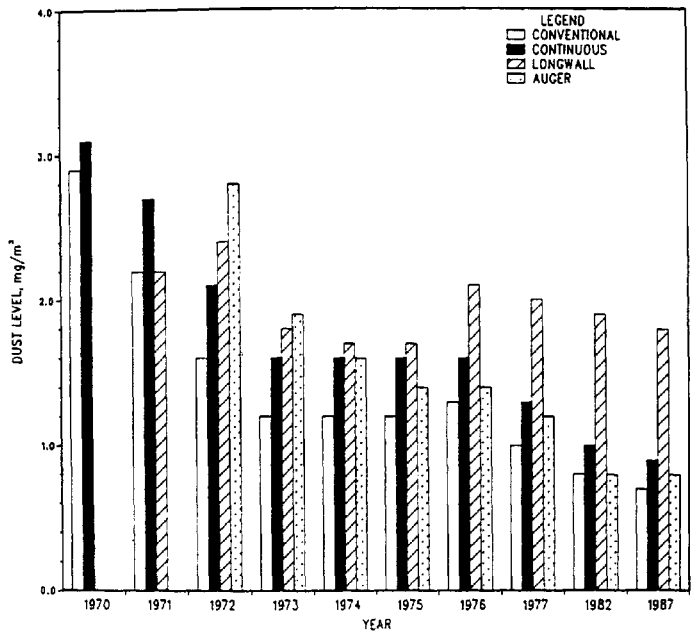

Figure 11. A yearly comparison of dust levels for four types of mining.