HAZARD EVALUATION AND TECHNICAL ASSISTANCE

Report No. 79-103-108

Illinois Minerals Company
Elco, IL

Study requested by: Chief, Health Division for Metal and Non-metal Mine Safety and Health
Mine Safety and Health Administration

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Abstract

An environmental and medical survey of current and ex-workers was conducted on July 20, 25 and 26, 1979, at the Illinois Minerals Company, a silica mining and processing operation located in Elco, Illinois. The purposes of the study were to determine if workers were currently being exposed to hazardous levels of silica dust and to determine the prevalence of silicosis among current and ex-workers.

Health screening consisted of a chest radiograph, spirometry and a medical questionnaire detailing both occupational history and pulmonary symptomatology. Environmental measurements of respirable crystalline silica dust were obtained by sampling during three workshifts on July 20, 1979.

Analysis of the environmental data revealed the silica dust to be approximately 100% alpha quartz (free silica). Median particle size from air sampled in the plant ranged from 2.3 to 4.9 microns, well within the respirable range.

Forty-nine of the fifty-seven samples were above the NIOSH recommended standard of 0.05 milligrams per cubic meter. Several individual samples were several hundred times this recommended value.

Thirty (73%) of forty-one current workers and twenty-four (47%) of fifty-one eligible ex-workers participated. Participating ex-workers had more than one year of silica dust exposure over the past ten years. No radiographic evidence of silicosis was found in workers with less than one year exposure. Three (20%) of the fifteen current workers with one or more years of exposure and fourteen (58%) of the twenty-four eligible ex-workers had radiographic changes indicative of silicosis. Overall, in workers and ex-workers with one or more years of exposure, seventeen (44%) of thirty-nine had x-ray evidence of silicosis.

In conclusion, the very high prevalence of silicosis is due to the respirable size of the particles, the high free silica content of the dust, excessive respirable dust levels and ineffective respiratory protection. To insure protection of worker health, engineering controls should be implemented to reduce and maintain free silica dust levels to current acceptable exposure limits.

NIOSH considers the situation existing at the Illinois Minerals Company at the time this study was done to be of imminent danger status. There is a significant health hazard present and continued worker exposure to these conditions will cause irreversible harm to such a degree as to shorten life.

I. INTRODUCTION

Under Public Law 91-173, as amended by Public Law 95-164 (Federal Mine Safety and Health Act of 1977), the National Institute for Occupational Safety and Health has been delegated responsibility for evaluating, upon written request, the potential hazard of any substance in the concentrations normally used or found in the workplace or to determine whether any physical agents or equipment found or used in the workplace has potentially hazardous effects.

NIOSH received a request from the Mine Safety and Health Administration to investigate the health of employees exposed to silica-containing dust at Illinois Minerals Company, Elco, Illinois. This request was precipitated by the diagnosis of silicosis in an employee at a similar plant in the area (Tammsco, Inc.) and by previous Mine Safety and Health Administration reports of free silica levels above the permissible limits (Table I) (1).

II. EVALUATION

A. Process Description

The ore deposits in southern Illinois are unique because they are reported to contain approximately 99% silicon dioxide, SiO_2 (2). Mineralogically, the deposits are microcrystalline quartz. Other names for the material, such as amorphous silica, tripoli, or soft silica, are misnomers.

Silicon dioxide can be subdivided into two major categories: 1) free silica (SiO_2) and 2) combined silica (silicates). Category 1) can be divided into two sub-categories: 1a) amorphous silica and 1b) crystalline silica; with crystalline silica being further divided into three main categories; quartz (alpha and beta), cristobalite, and tridymite. The X-Ray Diffraction patterns of alpha-quartz and microcrystalline quartz are identical. The final product at Illinois Minerals Company's Elco Plant is commonly referred to as silica flour (2). It is used in paints as an extender, in the insecticide industry as a carrier, and in toothpaste and polishing compounds as an abrasive.

At Illinois Minerals, raw material is mined underground and hauled to the processing plant a few miles away. At the mill, the material is crushed, dried, and milled (Figure 1). It is then blended to yield the desired qualities of the products and stored in bins until ready for bagging. Fifty-pound capacity bags are filled at three locations. Most of the silica flour is bagged at the tandem bagger, where two bags can be filled simultaneously. Products milled in the A mill and B mill are bagged at the A mill bagger and the B mill bagger, respectively. The bags are then stored on pallets for shipment.

B. Evaluation Design and Methods

1. Environmental

To ascertain the levels of free silica and respirable dust the mill workers were exposed to on the sampling day (7-20-79), air was drawn through a personal dust cyclone pre-selector and a 37 mm filter cassette containing a pre-weighed FWS-B filter at 1.7 liters per minute. This procedure was also used for several general area samples placed in the mill. The samples were analyzed for quartz and cristobalite by X-Ray Diffraction. The Physical and Chemical Analytical Method (P & CAM) #109 as described in NIOSH's "Manual of Analytical Methods" was the method used with the following modifications: 1) The filters were dissolved in tetrahydrofuran rather than ashed in a furnace; 2) External quartz and cristobalite standards were gravimetrically prepared and used to construct calibration curves for the analyses; 3) Sample and standards were not washed after being deposited on silver membrane filters (3).

The Andersen 1 ACPM Particle Fractionating Sampler was stationed near the tandem bagger to measure the size distribution and total concentration levels of particulate matter. Each shift was sampled separately, then the samples were analyzed by gravimetric methods. Several bulk samples of the finished products were analyzed for quartz and cristobalite. The method for analysis of quartz and cristobalite was a modified version of NIOSH's P & CAM #109 as described above.

2. Medical

Health screening, done on July 20, 25, and 26, 1979, consisted of a chest radiograph, spirometry and a medical questionnaire detailing both occupational history and pulmonary symptomatology. Because of the high turnover rate of employees and the usual latent period between the beginning of exposure and development of radiographically detectable silicosis, we also studied the health of ex-workers with more than one year exposure to silica dust during the past ten years. A roster of present and ex-workers was supplied by the company. Ex-workers were notified via two letters mailed three weeks and one week before the study.

The present employees of a specialized milk processing plant located in a nearby town were examined as a control group. Health screening was identical to that performed at the Illinois Minerals Company.

A modified British Medical Research Council respiratory questionnaire with an additional question about personal respiratory protection while in the work environment was administered by trained personnel.

The weight and height of all workers was recorded.

Pulmonary function tests were performed on an Ohio 840 waterless spirometer under the supervision of trained technicians. The results of the tests on each worker were compared to predicted values from Knudson et. al. (4). The tests included the forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and the FEV_1/FVC ratio, expressed in percent.

Standard 14 by 17 inch posteroanterior and lateral chest radiographs were taken by registered radiology technicians. Chest radiographs were intially interpreted by an experienced clinical radiologist at the West Virginia University Hospital. Any worker or ex-worker whose chest radiograph showed an abnormality indicative of an acute process (infection, possible cancer, heart abnormalities, or any other potentially urgent finding noted by the consultant radiologist) was immediately informed of this by letter and advised to seek further medical attention. All radiographs were then independently interpreted by three "B" readers ("B" readers are physicians who have passed a proficiency examination in interpreting chest radiographs based on the 1971 ILO U/C classification (5)).

The company also supplied pre-employment radiographs on some employees. These were evaluated by two "B" readers and the author (D.B.).

C. Evaluation Criteria

1. Health Effects

Silica flour has been found to be more readily inhaled and retained than other silica dusts because of the small median aerodynamic diameter of its particles (6). Although there is a lack of information on silica flour, the substance may be more fibrogenic than other types of silica. Rapid onset of silicosis has been reported after brief exposure to silica flour (6). Health effects are further described in the Discussion section.

2. Environmental

NIOSH's recommended standard for crystalline silica states that no worker should be exposed to a time-weighted average (TWA) concentration of free silica greater than 50 micrograms (0.05 milligrams) per cubic meter of air as determined by a full shift sample (7). The standard is designed to protect the worker for up to a 10-hour workday, 40-hour workweek, over a working lifetime.

The values of the time-weighted average for free silica were computed by the following formula:

$$\text{TWA } (mg/m^3) \text{ free silica} = \frac{\text{milligrams of free silica per sample}}{\text{minutes sampled x flow rate x .001}}$$

For comparative purposes only, calculation of the MSHA free silica standard using NIOSH data is included in Table II. For each sample, MSHA calculates a threshold limit value (TLV) based on the amount of free silica in that sample. The time weighted average (TWA) for each sample is calculated, then compared to its TLV. The TWA must be below its TLV in order for the workplace to be in compliance. MSHA formulae used to compute these values are as follows:

$$\text{\% free silica} = \frac{\text{micrograms of free silica per sample}}{\text{10 x sample wt. (mg)}}$$

$$\text{TWA } (mg/m^3) = \frac{\text{sample weight (mg)}}{\text{480 (min.) x 1.7 (liters per min.) x .001}}$$

If the sample analysis indicates less than 1% free silica, TLV = 10 mg/m^3 (total dust sample) applies.

If the sample analysis indicates greater than 1% free silica, a respirable sample is taken and the TLV is calculated using the formula:

$$\frac{10}{\text{\% free silica + 2}} .$$

This value is multipled by 1.20, to incorporate sampling error factors (i.e. pump variation, analysis, etc.).

3. Medical

Chest radiographs interpreted as category 1/0 profusion or greater based on the 1971 ILO U/C classification by at least two of the three "B" readers were considered positive for pneumoconiosis (5). Profusion refers to the number of opacities per unit area. The extent (number of zones) of the lung field affected as well as the size and shape of the opacities present on the radiograph is recorded.

The terms "obstructive and restrictive lung disease" are used as defined by the Intermountain Thoracic Society (8).

D. Results and Discussion

1. Environmental

The results of the respirable particulate and free silica analysis are listed in Table II. Levels of free silica measured in the plant on the day of the survey indicated nearly all workers were overexposed (based on NIOSH criteria) to dust containing free silica. Eight of the fifty-seven samples were below the 50 micrograms per cubic meter recommended standard. Figure 2 illustrates the distribution of the levels of exposure found on the sampling day.

X-Ray Diffraction on the bulk and respirable samples indicated there was no cristobalite present; only alpha-quartz was detected.

To quantitate the amount of free silica in the respirable dust samples, X-Ray Diffraction is the analytical method used. An important characteristic in terms of this analysis is the particle size of the free silica in the sample. The particle size of the external quartz standard used in constructing a calibration curve must be matched to the mean particle size of the sample material.

Particle size distributions were measured in the field by using the Andersen sampler. The instrument classifies particles according to aerodynamic dimensions, which is the true measure of lung penetrability (9).

From the results of sampling with the Andersen instrument, the mass median diameter of the dust sampled near the tandem bagger ranged from 2.3 to 4.9 micrometers (see Figure 3, 4, and 5).

Mine Safety and Health Administration data from fourteen dust inspections from 1973 to 1979 are reported in Table I. The MSHA method for computing the threshold limit value for free silica dust exposure is described above. In only one dust inspection was the mean exposure below the compliance limit. The maximum exposure was over ninety-two times the acceptable limit. The maximum mean dust concentration at that inspection was greater than twenty-four times the compliance limit. The mean silica dust concentration was approximately five times the threshold limit value. Seventy (84%) of the eighty-three samples measured during these inspections were above the threshold limit value.

2. Medical

a. Results

As reported in Table V, thirty (73%) of forty-one present workers participated in health screening. One present worker had previously been employed at Tammsco, Inc., a similar silica processing plant in the area, for more than one year. Twenty-four (47%) of fifty-one ex-workers with one or more years of exposure to silica dust participated. One of the fifty-one ex-workers is presently employed at Tammsco, Inc. Two other ex-workers also previously worked at Tammsco, Inc. for greater than one year. Seven of the fifty-one ex-workers could not be located. A total of fifty-four workers and ex-workers were tested.

The prevalence of pneumoconiosis, as determined by chest radiographs, is reported in Table VI. No worker with less than one year exposure to silica dust had roentgenographic evidence of silicosis. Of the fifteen present workers with more than one year exposure, two (13%) had simple pneumoconiosis and one (7%) had progressive massive fibrosis. The prevalence of pneumoconiosis in current workers with one or more years of exposure was 20%.

Twenty-four ex-workers with one or more years of silica dust exposure participated in the health screening. Ten (42%) had simple pneumoconiosis and four (17%) had progressive massive fibrosis, for a total prevalence of 58%.

Of the thirty-nine examined ex-workers and workers with more than one year exposure, twelve (31%) had simple pneumoconiosis and five (13%) had progressive massive fibrosis, for an overall prevalence of 44%.

Pre-employment radiographs were available on 28 workers examined in the current study. The median reading of 2 "B" readers and one of the authors (D.B.) was used for interpretation. Four pre-employment films were interpreted as showing category 1/0 opacities. Current radiographs of these four men were interpreted as category 0/0 (concensus of 3 "B" readers). This discrepancy of interpretation may be related to the poor technical quality of the pre-employment radiographs, seven of which were considered unreadable by 1 or more of the readers. Ten of the 24 men with negative pre-employment radiographs had evidence of pneumoconiosis on current radiographs. Three of these ten had progressive massive fibrosis.

Table VII summarizes the pulmonary function in those workers with pneumoconiosis. For the twelve subjects with simple pneumoconiosis, the mean silica dust exposure was 7.1 years with a range of 2-18 years. Eleven subjects (mean exposure 7.4 years) performed spirometry; three had obstructive lung disease and one had combined restrictive and obstructive disease. All with abnormal pulmonary function had at least a twenty-eight pack year cigarette smoking history.

For five men with progressive massive fibrosis, the mean silica dust exposure was 5.3 years with a range of 2 and 1/2 to 9 years. Four of these five had restrictive lung disease and one had combined restrictive and obstructive disease. Although all were smokers, one had a lifetime smoking history of only one-half pack year of cigarettes and three others had less than a ten pack year smoking history.

At the milk processing plant, sixty-six workers were notified and asked to participate. Forty-four (67%) employees participated. Only one of the forty-four workers studied had evidence of pneumoconiosis. He had worked at the milk processing plant for approximately one year, but had spend thirty-two years doing auto body work, both welding and repairing automobiles. Prior to that, he had worked seven years as an underground coal miner doing many jobs within the mine.

b. Discussion

As inhaled silica particles are deposited in the alveoli, certain physiologic events occur. Based on in vitro and cell culture studies, it has been shown that these particles are phagocytized by macrophages and act as a cellular poison resulting in cell death and liberation of cell contents. Once lung macrophages are injured or die, two events occur. First, other macrophages are attracted which ingest silica particles and die, also liberating cell contents. Second, the silica-induced death of macrophages stimulate fibroblasts to form collagen and become hyalinized. This process continues and the previously normal lung tissue is replaced by fibrotic tissue (10).

The physiologic results of these changes are ventilatory impairment, which may be minimal or incapacitating. In particular, restriction of lung volumes due to an increased lung stiffness is not unusual in advanced disease. In the lesser categories of simple silicosis, there may be little effect on ventilatory capacity (11). This is borne out in Table VII, where seven of the eleven workmen with simple pneumoconiosis tested had normal lung function. Other studies have shown those with early radiographic changes of silicosis have an increased prevalence of bronchitis and a greater decrement in ventilatory capacity with increasing age as compared to control groups (12).

As lesser categories of simple pneumoconiosis progress to advanced simple pneumoconiosis or progressive massive fibrosis, the ventilatory capacity declines significantly, as measured in terms of vital capacity and exercise tolerance (13). As nodules coalesce or mass lesions enlarge, the worker becomes progressively short of breath. Weight loss and hemoptysis (coughing up blood) may occur with heart failure and respiratory failure being terminal events. As well, silicotics have a much higher risk of developing tuberculosis than non-silicotics.

The radiographic changes in simple silicosis are primarily nodular. These are commonly 1.5 to 3.0 mm. in diameter, located in the lung interstitium and scattered throughout the lung fields.

Complicated silicosis or progressive massive fibrosis occurs when multiple nodules coalesce to form a mass lesion greater than 1 cm. in diameter on the chest radiograph. These areas are located primarily in mid and upper lung zones. On the chest radiograph, the result of this nodular coalescence is a conglomerate mass surrounded by residual air spaces, loss of functional lung volume, and retraction of the hilum toward the apex with compensatory bullous spaces located at the lung bases.

Physiologically, these changes correlate with restrictive lung disease due to the loss of functional lung parenchyma and obstructive lung disease due to distortion of airways and loss of normal airway support.

Both simple silicosis and progressive massive fibrosis have definite tendencies to progress, even after the worker is no longer exposed to silica dust (14). In this study, the young ages of the majority of men who developed progressive massive fibrosis (a twenty-four year old, a twenty-eight year old, two thirty-one year olds and a fifty-six year old worker), means a lifetime of respiratory impairment, as this disease is unresponsive to therapy. Two examples should be described:

The first of these developed progressive massive fibrosis with only two and one-half years of dust exposure. His latency period (time from first exposure to date of study) was four and one-half years. He had significant restriction by pulmonary function testing. He had symptoms of chronic bronchitis and breathlessness when hurrying on level ground or walking up a short hill. He denied any previous occupational respiratory exposure and his pre-employment chest radiograph was normal. He had smoked half a package of cigarettes daily for the past eight years.

Exposure to very high dust levels over short periods (several weeks to several years) may result in acute silicosis or silico-proteinosis (15). The physiologic response to large amounts of dust is an outpouring of protein rich exudate into the alveoli. This results in a hazy bilateral alveolar filling pattern on chest x-ray.

The chest radiograph of this worker is compatible with this description. Workers who develop silico-proteinosis have rapidly progressive dyspnea, cough and loss of weight. Unfortunately the disease is unresponsive to treatment and progression is inexorable.

A second man had combined obstructive and restrictive lung disease and progressive massive fibrosis. In a preliminary report, we had reported this worker as having a two year silica dust exposure. Further information has revealed his silica dust exposure to be four years and his latency period to be seven years. He also had a normal pre-employment chest radiograph and gave a lifetime smoking history of one-half pack year of cigarettes. He had complaints of breathlessness when walking at his own pace on level ground.

The occurrence of severe disease in these workers with such a short silica exposure without other explainable causes reflects the extremely high respirable dust levels within the mill, the high silica content of dust and the lack of adequate respiratory protective measures.

One half of the thirty current workers studied had one or more years of exposure to silica dust. In this group, silicosis was noted on chest radiograph in 20%. The large number of workers with less than one year exposure indicates a large turnover of the work force. This may be an important factor in minimizing the number of cases of pneumoconiosis in this environment.

Finally, it should be noted that the company labels this microcrystalline silica "amorphous silica" on its shipping bags. Amorphous silica is much less fibrogenic than microcrystalline silica and the consequences of this mislabeling may be exposure to hazardous levels of crystalline silica dust by workers unaware of the potential dangers to their health (16).

E. Conclusions

1. NIOSH considers the situation found at Illinois Minerals Co. to be of imminent danger status. There is a health hazard present and exposure to it will cause irreversible harm to such a degree as to shorten life.

2. Mine Safety and Health Administration data revealed the mean free silica dust measurements to be greater than

the threshold limit value in thirteen of fourteen dust inspections from 1973 to 1979. Thirteen of eighty-three acceptable samples were below the threshold limit value. On the day of this survey forty-nine of fifty-eight samples exceeded the NIOSH recommended standard of 50 micrograms of free silica per cubic meter. Thirty-six workers were found to be overexposed to free silica. Some workers in the bagging and housekeeping categories were grossly overexposed.

3. Forty-one percent of current workers and ex-workers with more than one year of silica dust exposure had radiographic evidence of silicosis. The very high prevalence of silicosis is due to the respirable size of the majority of the particles, the high free silica content of the dust, excessive dust levels and ineffective respiratory protection.

4. The seriousness of this hazard is best documented by the radiographic presence of progressive massive fibrosis in five men. Four of these five had six or less years of exposure, with one developing progressive massive fibrosis after only two and one-half years of exposure. All have significantly impaired lung function.

5. Mislabeling of microcrystalline silica poses a serious problem. Workers who handle this material in other industries may be exposed to potentially hazardous levels of this dust without adequate knowledge of its potential to cause pulmonary damage.

III. RECOMMENDATIONS

1. In the interest of worker health it is imperative that no worker be exposed to concentrations exceeding 0.05 mg/m^3 (7). Engineering controls should be instituted immediately in order to maintain free silica levels below the NIOSH permissible exposure limits (0.05 mg/m^3). These improvements should include at least the following:

a. Work clothes should be vacuumed before removal; this will require a high efficiency vacuum system.

b. General housekeeping duties should be intensified so that there is no dust accumulation on the machinery, beams, corners, etc. Such accumulation traps particles in the smaller size range which can become airborne when disturbed.

c. Avoid dry sweeping or blowing with compressed air; use dustless methods of cleaning such as vacuuming or washing down. A hose attachment to the riding sweeper to clean corners would aid in general housekeeping.

d. Emphasis shall be placed on cleanup of spills, preventive maintenance, and repair of equipment. Leaks in ductwork should be repaired.

e. Engineering controls to protect the bagger from free silica exposure could be a high priority. Refer to Appendix I for an article discussing improving the bagging operation.

2. Periodic environmental monitoring of the workers' level of exposure to free silica should be performed by the operator.

3. During operation of the processing plant while the effectiveness of the engineering controls are being evaluated, a comprehensive personal respiratory protection program must be in effect (Appendix II). Refer to Table IV for proper respirator selection. Note that respirator protection is not a substitute for engineering controls.

4. All current workers exposed to silica dust not examined in this NIOSH study should undergo a comprehensive medical examination. This should include a medical and occupational history, pulmonary function tests and 14 by 17 inch posteroanterior chest radiograph interpreted by a "B" reader using the 1971 ILO U/C classification (1980 ILO classification when available).

5. Current workers with radiographic evidence of silicosis should be given the opportunity to transfer to jobs without silica exposure (defined by exposure to less than half of the NIOSH recommended environmental level in the workplace (7)).

6. Current workers with impairment of pulmonary function should be evaluated by a physician qualified to advise the worker whether he should continue to work in a dusty trade.

7. Medical examinations should be performed at first exposure to silica dust and at yearly intervals. This should consist of:

a. medical and occupational history to evaluate exposure and signs and symptoms of respiratory disease

b. a posteranterior chest radiograph, 14 x 17 inches, categorized by a "B" reader using the 1971 ILO U/C classification (1980 ILO classification when available)

c. pulmonary function tests including forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and the FEV_1/FVC ratio.

Workers with pulmonary impairment or abnormal chest radiographs should be evaluated by a physician qualified to advise the worker whether he should continue to work in a dusty trade.

8. The bagged silica flour should be labeled correctly and appropriate health warnings placed on each bag.

9. Enforcement of regulations is mandatory to assure compliance with the standard and protection of the worker's health.

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TABLE I

MSHA Dust Inspections
Illinois Minerals Company

Date	# Samples	(Mean Concentration/TLV)	Range	# Samples ≤ TLV
11-27-73	8	8.26	6.30-11.70	0
4-24-74	7	2.26	0.30- 5.21	3
6-17-75	4	2.21	1.03- 3.40	0
12-9-75	4	7.63	3.05-14.79	0
5-12-76	4	5.34	2.26- 8.57	0
11-17-76	5	1.45	0.33- 2.14	2
5-19-77	4	2.00	1.00- 2.77	1
8-11-77	3	0.78	0.38- 1.26	2
8-23-77	6	1.83	1.00- 2.83	1
1-24-78	6	2.53	1.65- 4.60	0
5-16-78	9	24.24	2.43-92.10	0
5-24-78	8*	1.35	0.21- 3.44	4
2-7-79	4	3.70	3.00- 5.00	0
9-24-79	12	6.86	1.32-25.39	0
	84	5.03		13(15%)

* includes one sample declared void therefore not used in analysis

The values (referenced in Table I) do not include the 20% error factor MSHA allows in its computations.

TABLE II

PERSONAL AND AREA SAMPLES FOR RESPIRABLE PARTICULATE AND FREE SILICA
Illinois Minerals Company
July 20, 1979

JOB DESCRIPTION	SAMPLE NO.	FREE SILICA TWA (mg/m^3)	RESPIRABLE PARTICULATE** TWA (mg/m^3)	% FREE SILICA	MSHA TWA (mg/m^3)	MSHA TLV (mg/m^3)
<u>Bagger</u>:						
two spout bagger	4464	0.70	0.96	73	0.81	0.16
two spout bagger	4389	30.93*	38.49	80	39.38	0.15
two spout bagger	4411	3.35	3.43	98	3.47	0.12
two spout bagger	4408	5.18*	6.45	80	6.41	0.15
A mill bagger	4469	0.28	0.53	54	0.45	0.21
A mill bagger	4479	2.31	2.10	>100	2.11	0.12
A mill bagger	4393	0.28	0.41	68	0.42	0.17
area, two spout bagger	4409	11.00*	14.97	73	13.66	0.16
area, two spout bagger	4445	3.27	3.13	>100	2.79	0.12
area, two spout bagger	4465	0.86	0.95	90	0.77	0.13
area, A mill bagger	4394	0.20	0.80	25	0.67	0.44
<u>Boiler Operator</u>:						
boiler operator	4376	0.33	0.55	61	0.47	0.19
boiler operator	4366	0.20	0.57	36	0.48	0.32
boiler operator	4395	0.40	0.66	60	0.65	0.19
boiler operator	4401	0.20	0.36	55	0.36	0.21
area, boiler room	4335	LLD	0.24	--	--	--
area, boiler room	4399	0.13	0.25	53	0.21	0.22
area, boiler room	4403	LLD	0.09	--	--	--

TABLE II
(continued)

JOB DESCRIPTION	SAMPLE NO.	FREE SILICA TWA (mg/m^3)	RESPIRABLE PARTICULATE** TWA (mg/m^3)	% FREE SILICA	MSHA TWA (mg/m^3)	MSHA TLV (mg/m^3)
Control Room:						
mill operator, control rm.	4387	0.10	0.60	17	0.51	0.64
mill operator, control rm.	4407	0.53	0.59	90	0.59	0.13
mill operator, control rm.	4406	0.09	0.28	30	0.28	0.37
area, control rm.	4368	LLD	0.23	--	--	--
area, control rm.	4412	LLD	0.09	--	--	--
area, control rm.	4410	LLD	0.06	--	--	--
Housekeeping:						
clean up crew	4463	15.04*	19.96	75	17.67	0.16
Clean up crew	4331	0.78	1.04	76	0.91	0.15
clean up crew	4473	0.33	0.56	59	0.48	0.20
clean up crew	4475	0.65	0.90	73	0.72	0.16
clean up crew	4478	0.63	1.33	47	1.12	0.24
clean up crew	4391	0.61	0.72	84	0.75	0.14
clean up crew	4324	1.28	1.25	>100	1.14	0.12
clean up crew	4398	0.70	0.76	92	0.78	0.13
clean up crew	4405	0.28	0.41	70	0.40	0.17
clean up crew	4390	0.80	0.88	92	0.87	0.13
clean up and bag printer	4467	0.46	0.77	60	0.64	0.19
area, outside	4468	0.13	0.20	63	0.20	0.19
Mechanic:						
maintenance	4471	0.58	0.99	59	0.83	0.20
maintenance	4466	1.19	1.76	68	1.48	0.17

TABLE II
(continued)

JOB DESCRIPTION	SAMPLE NO.	FREE SILICA TWA (mg/m^3)	RESPIRABLE PARTICULATE** TWA (mg/m^3)	% FREE SILICA	MSHA TWA (mg/m^3)	MSHA TLV (mg/m^3)
Mill Area:						
bag printer	4367	0.38	0.71	53	0.58	0.22
area, at ball mill	4477	0.07	0.10	71	0.09	0.16
area, 20' from ball mill	4396	0.06	0.11	57	0.09	0.20
area, at ball mill	4402	LLD	0.06	--	--	--
Shipping:						
loading crew	4474	1.32	1.38	96	1.22	0.12
loading crew	4472	21.20*	24.58	86*	21.30	0.14
loading crew	4413	1.65	1.58	>100	1.47	0.12
forklift operator	4330	0.61	0.89	69	0.86	0.17
forklift operator	4392	0.54	0.71	75	0.70	0.15
area, pallitizer	4470	LLD	0.62	--	--	--
area, pallitizer	4400	2.55	2.29	>100	1.96	0.12
area, pallitizer	4444	1.22	1.25	98	1.09	0.12
area, on forklift	4388	LLD	0.28	--	--	--
area, on forklift	4374	0.32	0.46	69	0.36	0.17
area, inside boxcar	4462	0.60	0.68	88	0.53	0.13
area, whse./storage	4438	0.26	0.38	68	0.31	0.17
Supervisor:						
clean up boss	4375	0.11	0.52	22	0.45	0.51
maintenance foreman	4476	0.08	1.11	8	0.97	1.25
foreman	4404	0.49	0.67	74	0.65	0.16

TABLE II
(continued)

JOB DESCRIPTION	SAMPLE NO.	FREE SILICA TWA (mg/m^3)	RESPIRABLE PARTICULATE** TWA (mg/m^3)	% FREE SILICA	MSHA TWA (mg/m^3)	MSHA TLV (mg/m^3)
Blank	4416	LLD	-0.01			
Blank	4297	LLD	-0.03			
Blank	4298	LLD	-0.02			
Blank	4417	LLD	-0.01			
Blank	4310	LLD	-0.03			
Blank	4303	LLD	-0.01			
Blank	4304	LLD	-0.02			
Blank	4299	LLD	-0.03			

NIOSH Recommended Standard = 0.05 mg/m^3 free silica

LLD = Lower Limit of Detection = 0.02 mg

(*) represents approximated values of free silica content because some filters were grossly overloaded. The laboratory method used destroyed most of the free silica in these samples. Approximated values were obtained by calculating the mean of "% Free Silica" values of other related samples (i.e. personal or area samples from the same job category), then using this mean value and the amount of respirable particulate of the sample in question to attain an approximate value for the free silica time-weighted average.

(**) Respirable particulate refers to that fraction of dust passing a size-selector meeting the criteria of the AIHA Aerosol Technology Committee, AIHA J. 31:2, 1970 p. 133.

TABLE III

SUMMARY OF FREE SILICA ANALYSIS
(from TABLE II)

Job Category	Number of Samples Personal	Area	Geometric Mean (mg/m^3)	Range (mg/m^3)
Bagger	7	4	1.73	0.20-30.93*
Boiler Operator	4	3	0.12	LLD- 0.40
Control Room	3	3	0.07	LLD- 0.53
Housekeeping	11	1	0.69	0.13-15.04*
Mechanic	2	0	0.83	0.58- 1.19
Mill Area	1	3	0.08	LLD- 0.38
Shipping	6	6	0.56	LLD-21.20*
Supervisor	3	0	0.16	0.08- 0.49

LLD = Lower Limit of Detection = 0.02 mg

(*) represents approximated values of free silica content because some filters were grossly overloaded. The laboratory method used destroyed most of the free silica in these samples. Approximated values were obtained by calculating the mean of "% Free Silica" values of other related samples (i.e. personal or area samples from the same job category), then using this mean value and the amount of respirable particulate of the sample in question to attain an approximate value for the free silica time-weighted average.

TABLE IV

RECOMMENDED REQUIREMENTS FOR RESPIRATOR USAGE AT CONCENTRATIONS ABOVE THE STANDARD (7)

Concentrations of Free Silica in Multiples of the Standard	Respiratory Type*
Less than or equal to 5x	Single use (valveless type) dust respirator
Less than or equal to 10X	Quarter or half mask respirator with replaceable dust filter or single use (with valve) dust respirator
	Type C, demand type (negative pressure), with quarter or half mask facepiece
Less than or equal to 100X	Full facepiece respirator with replaceable dust filter
	Type C, supplied air respirator, demand type (negative pressure), with full facepiece
Less than or equal to 200X	Powered air-purifying (positive pressure) respirator, with replaceable applicable filter**
Greater than 200X	Type C, supplied air respirator, continuous flow type (positive pressure), with full facepiece, hood, or helmet

*Where a variance has been obtained for abrasive blasting with silica sand, use only Type C continous flow, supplied air respirator with hood or helmet.

**An alternative is to select the standard high efficiency filter which must be at least 99.97% efficient against 0.3 um dioctyl phthalate (DOP).

TABLE V

SUMMARY OF WORKERS STUDIED
Illinois Minerals Company

Current production workers	41
Current workers studied (includes 1 worker previously employed for more than 1 year at Tammsco, Inc.)	30
Percent participation	73%
Ex-workers with 1 or more years exposure in the last 10 years	51
Ex-workers studied (includes 1 ex-worker previously employed at Illinois Minerals for more than 1 year and presently employed at Tammsco, Inc. and 2 ex-workers also previously employed at Tammsco, Inc. for more than 1 year)	24
Percent participation	47%

TABLE VI

PREVALENCE OF PNEUMOCONIOSIS*
Illinois Minerals Company

	#	Simple	P.M.F.**	Total
1. Current workers (less than 1 year exposure)	15	0(0%)	0(0%)	0(0%)
2. Current workers (1 or more years exposure)	15	2(13%)	1(7%)	3(20%)
3. Ex-workers (1 or more years exposure)	24	10(42%)	4(17%)	14(58%)
4. Total ex-workers and workers (1 or more years exposure)	39	12(31%)	5(13%)	17(44%)

*Pneumoconiosis is considered present if two of the three "B" readers described the radiograph as category 1/0 greater using the ILO U/C 1971 classification.

**Progressive massive fibrosis

TABLE VII

PNEUMOCONIOSIS AND PULMONARY FUNCTION

Simple	
Number performing spirometry*	11
Years exposure	
Mean	7.4
Range	2-18
Obstructed	3
Restricted	0
Combined	1
Total with abnormal pulmonary function	4
Progressive Massive Fibrosis	
Number	5
Years exposure	
Mean	5.3
Range	2.5-9
Obstructed	0
Restricted	4
Combined	1
Total with abnormal pulmonary function	5

Obstructed[8]: $\frac{FEV_1}{FVC}$ < 70%

Restricted[8]: FVC < 80% predicted

*One of 12 workers with simple pneumoconiosis refused spirometry.

Figure 1

Illinois Minerals Company
Plant Diagram

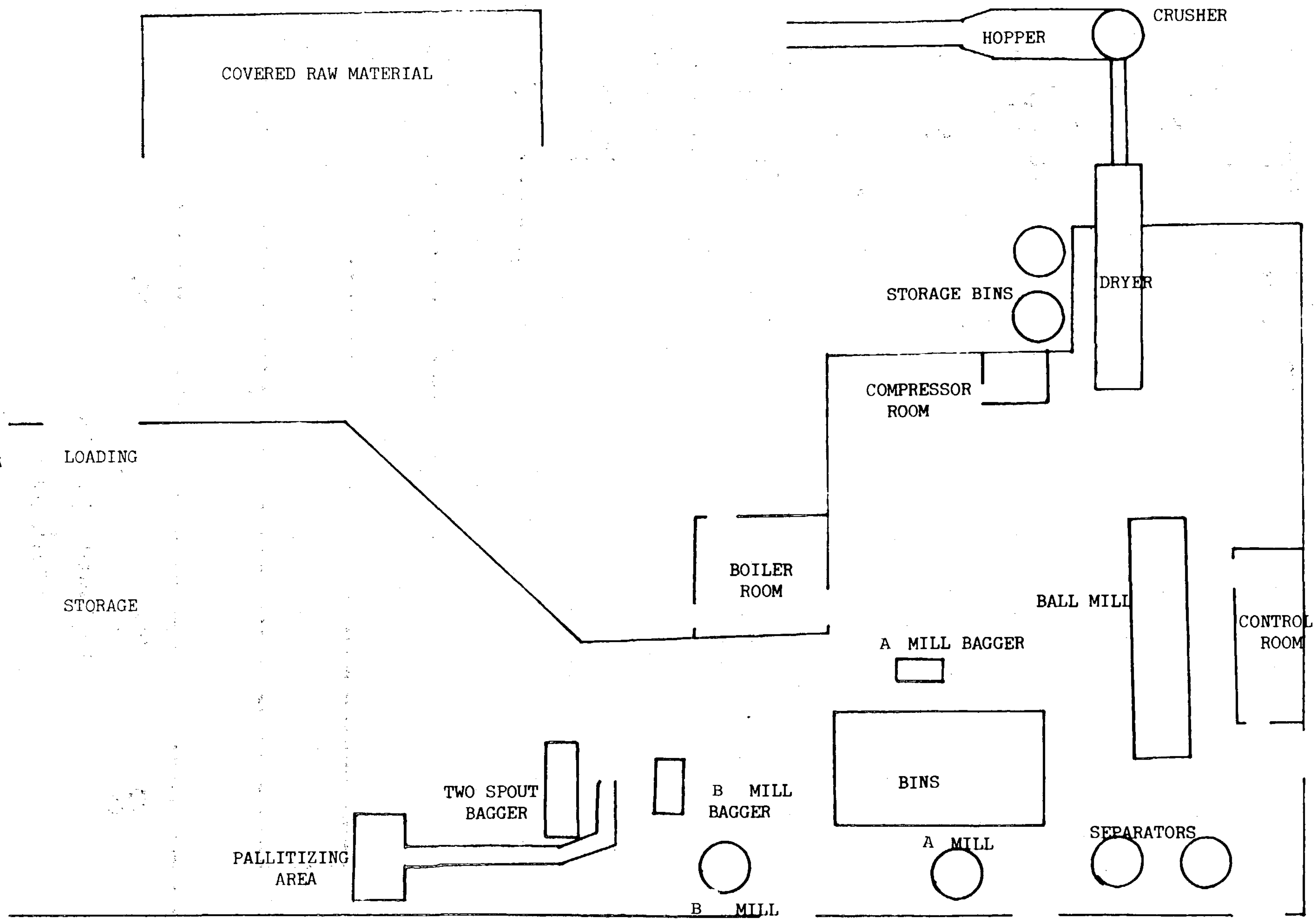
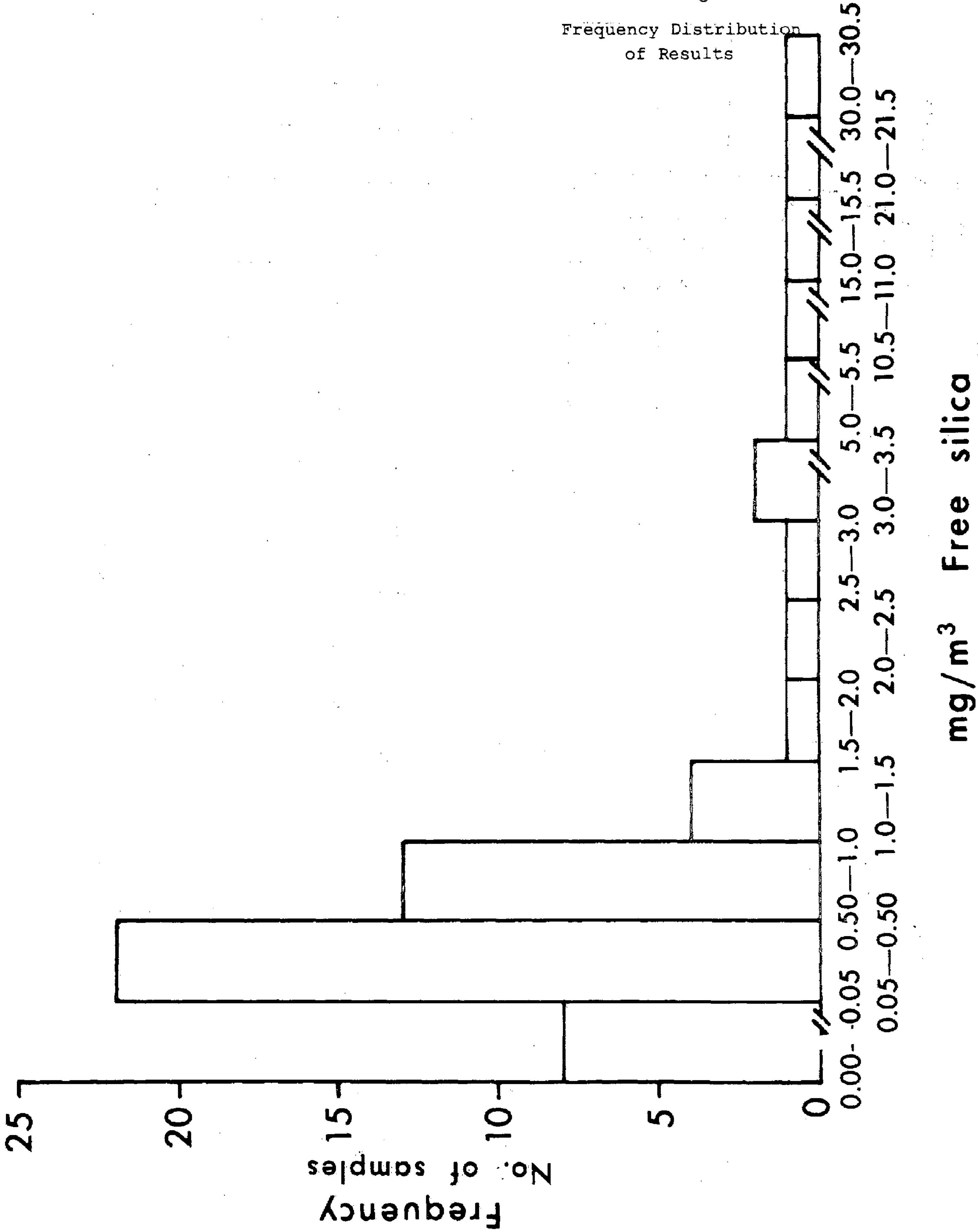
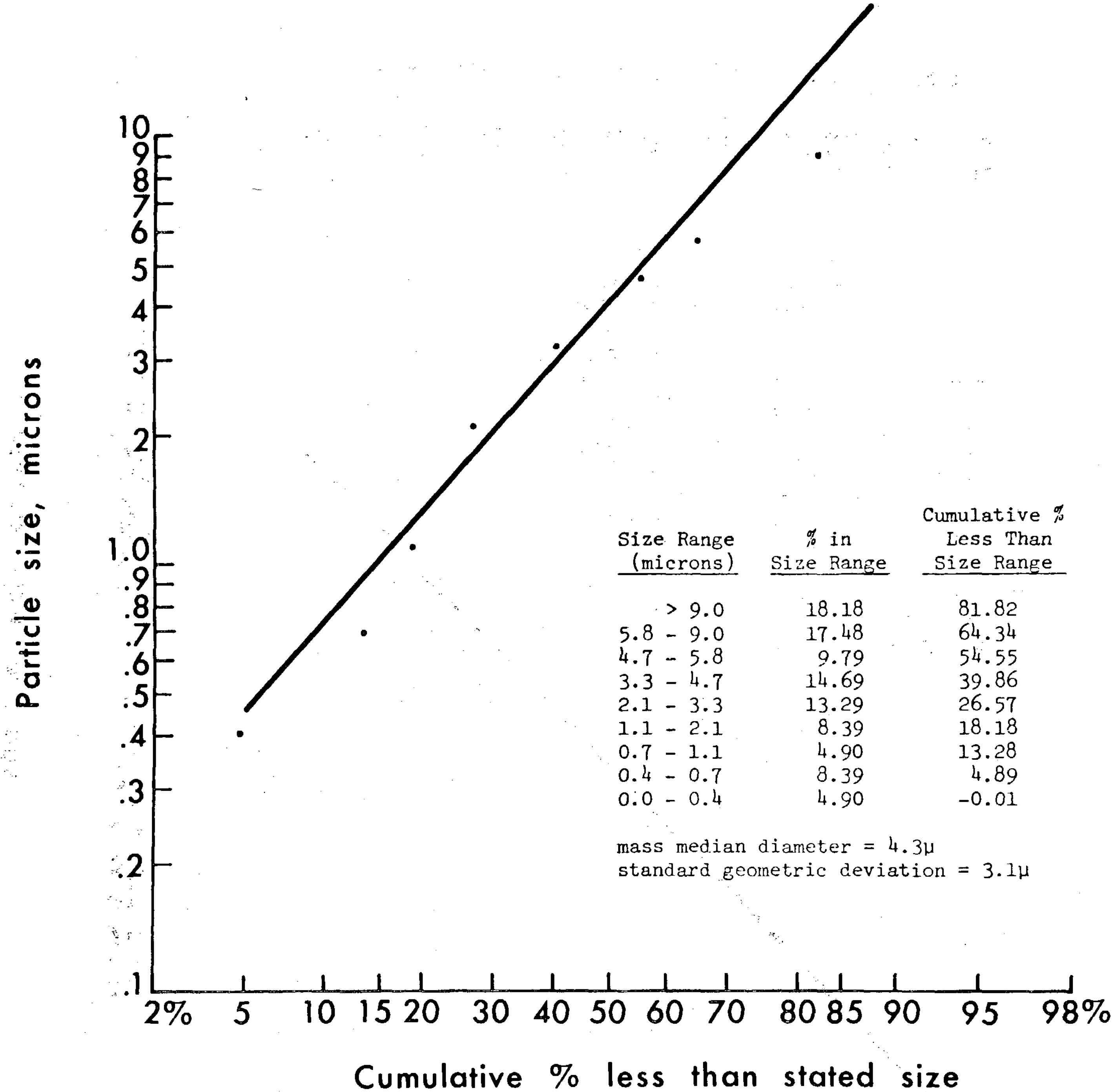


Figure 2

Frequency Distribution of Results

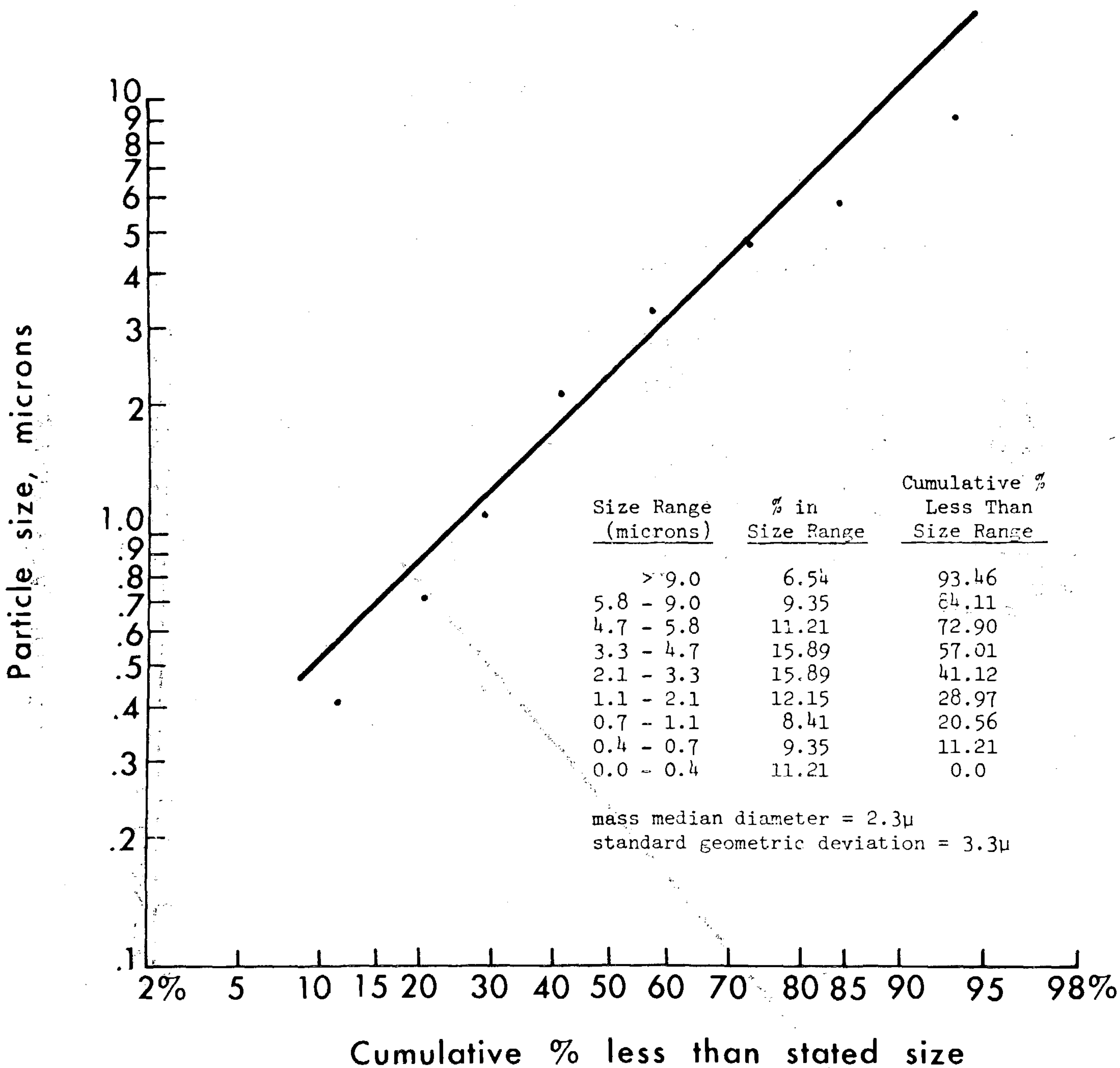




Size Range (microns)	% in Size Range	Cumulative % Less Than Size Range
> 9.0	18.18	81.82
5.8 - 9.0	17.48	64.34
4.7 - 5.8	9.79	54.55
3.3 - 4.7	14.69	39.86
2.1 - 3.3	13.29	26.57
1.1 - 2.1	8.39	18.18
0.7 - 1.1	4.90	13.28
0.4 - 0.7	8.39	4.89
0.0 - 0.4	4.90	-0.01

mass median diameter = 4.3μ
standard geometric deviation = 3.1μ

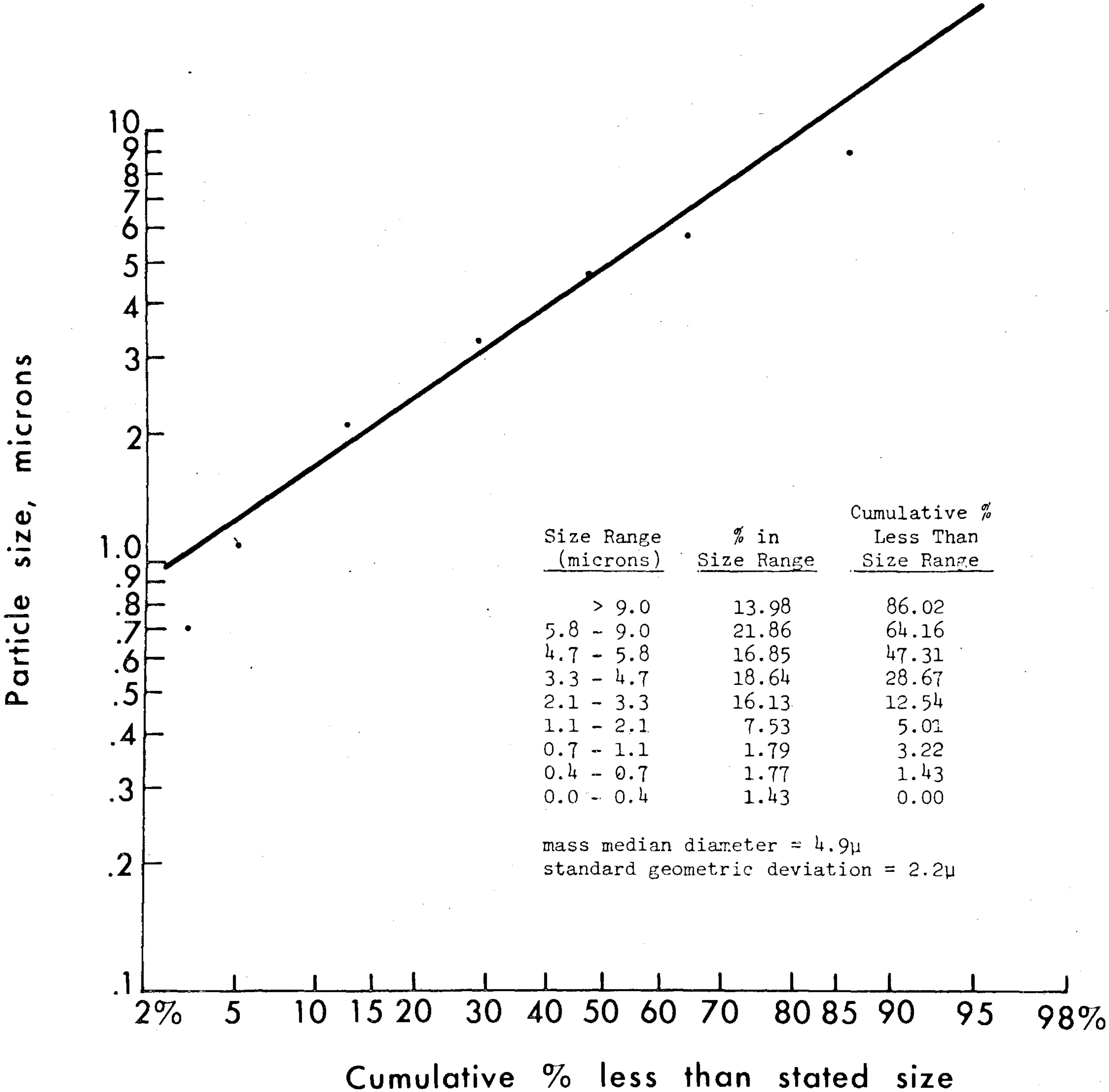
Figure 3
Andersen Sampler Data
1st Shift



Size Range (microns)	% in Size Range	Cumulative % Less Than Size Range
> 9.0	6.54	93.46
5.8 - 9.0	9.35	84.11
4.7 - 5.8	11.21	72.90
3.3 - 4.7	15.89	57.01
2.1 - 3.3	15.89	41.12
1.1 - 2.1	12.15	28.97
0.7 - 1.1	8.41	20.56
0.4 - 0.7	9.35	11.21
0.0 - 0.4	11.21	0.0

mass median diameter = 2.3μ
standard geometric deviation = 3.3μ

Figure 4
Andersen Sampler Data
2nd Shift



Size Range (microns)	% in Size Range	Cumulative % Less Than Size Range
> 9.0	13.98	86.02
5.8 - 9.0	21.86	64.16
4.7 - 5.8	16.85	47.31
3.3 - 4.7	18.64	28.67
2.1 - 3.3	16.13	12.54
1.1 - 2.1	7.53	5.01
0.7 - 1.1	1.79	3.22
0.4 - 0.7	1.77	1.43
0.0 - 0.4	1.43	0.00

mass median diameter = 4.9μ
standard geometric deviation = 2.2μ

Figure 5
Andersen Sampler Data
3rd Shift

Dust Control in Bagging Operations

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A survey of silica sand processing mills conducted by the Bureau of Mines found that better techniques were needed to control dust around the bag-filling operations. In cooperation with member companies of the National Industrial Sand Association, the following specific dust sources of fluidized valve packing machines were identified: (1) leakage around the nozzle, (2) spillage of material from nozzle, (3) dust from bag surface, leaky seams, broken bags, and poorly sealed bag sleeves, and (4) background dust from other sources.

Introduction

In 1974, the Bureau of Mines initiated a project to examine the dust control needs of the silica mining and milling industry. Early quarry and plant dust surveys revealed several problem areas in the milling of silica products, which have a low respirable dust threshold limit value (TLV). The most notable of these dust sources was the bagging and handling of dried silica sand products. Subsequently detailed respirable dust surveys of bagging operations of silica sand plants were conducted throughout the United States. Most plants sampled belong to the National Industrial Sand Association; members of the Association account for over 80 percent of the industrial silica mined in this country. These surveys found need for new and improved dust control techniques in the whole-grain sand and flour bagging areas. As a result, the Bureau of Mines entered into a series of agreements with member companies of the National Industrial Sand Association to further investigate and develop solutions for dust control problems associated with fluidized-type baggers, which are the machines most widely used by the industry. These cooperative agreements have resulted in the development of improved engineering dust control techniques for bagging machines. Field sampling of dust using emission-rate technique* was developed by the Bureau of Mines and provided increased awareness of the role played by background dust levels in personal dust exposure.

Engineering dust control for baggers

Systematic observation of fluidized-type bag-filling machines defined several emission sources: (1) Dust emitted while filling the bag, (2) spillage of material from nozzle and bag

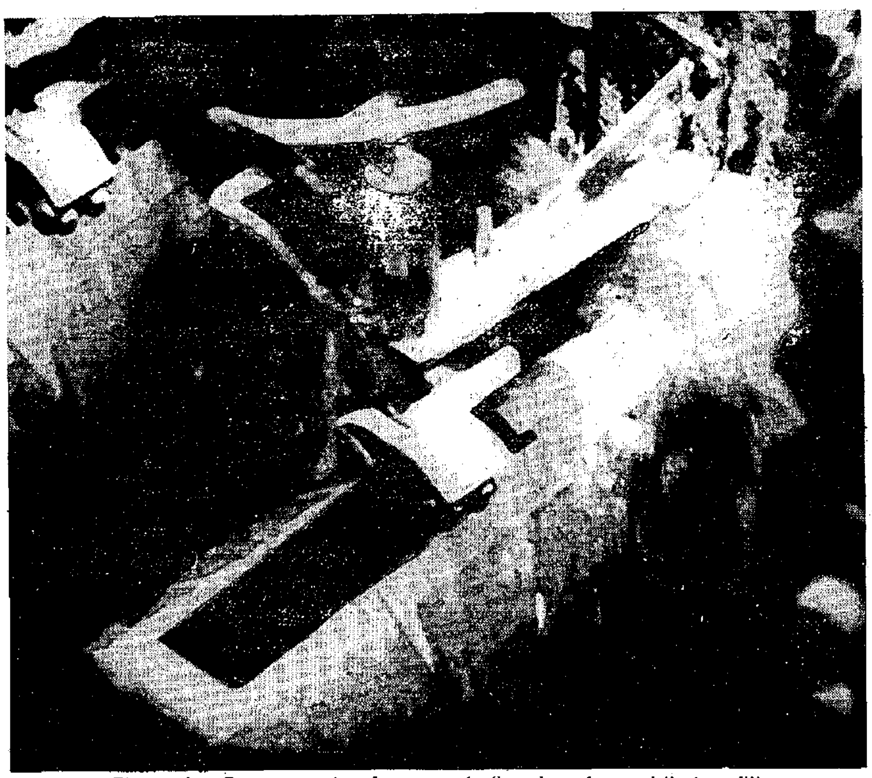

Figure 1 — Dust escaping from nozzle/bag interface while bag fills.

*A discussion of this technique is appended.

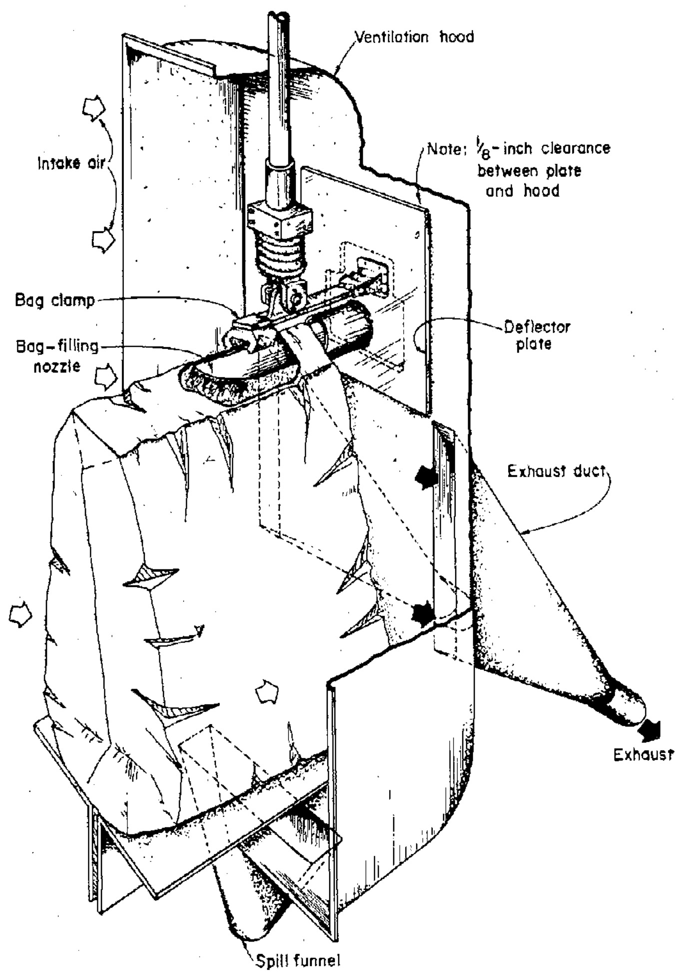

Figure 2 — Dust ventilation hood for bag filling machines.

sleeve as bag leaves the machine, (3) dust adhering to the surface of the bag, and (4) poor bag quality, resulting in inadequate closure, broken bags and leaky seams.

Dust emission during filling

Fluidized-type filling machines use air to fluidize the product material, causing it to flow through the machine and into the bag. This fluidizing air pressurizes the bag. The faster the air pressure is released the more quickly the bag fills with material. One technique to allow the air to escape is to provide perforations directly through all layers of the bag under the nozzle. Much material can escape through these holes punched in the bag, resulting in a large amount of airborne dust. Another area where fine product and dust escape while the bag fills is the nozzle and bag interface, which is seldom tightly sealed. (Figure 1) The above problems are very common both in whole-grain and flour bagging operations.

It was established that fluidizing air can be vented by using bags with perforations staggered through the layers of bag paper. This avoids a direct path for product and dust spillage while still maintaining adequate air relief through the bag. Moreover, the porosity of the paper further aids air relief while providing a filtering effect.

Dust escaping around the nozzle is difficult to control. Commercial devices such as inflatable valve seals and tapered sleeves can help to seal the nozzle/bag interface, but they require constant maintenance or are not 100 percent effective. Therefore, dust must be collected around the filling tube of the bag to prevent it from escaping into the workroom. The best solution is to hood the nozzle area and the bag, so that escaping dust is caught and directed to the exhaust ventilation source.

The concept of an improved ventilation hood that encloses the bag and exhausts the dusty air to an appropriately sized dust collector was developed by the Bureau of Mines and refined by industry. Hoods of this type are being used successfully on whole-grain filling machines. Their use does not significantly interfere with the normal operations or maintenance of the machine. (Figure 2) The hood captures dust generated during bag filling, and the exhaust ventilation carries the dusty air through ducts at the back of the hood to an exhaust fan and dust collector. The hood is mounted on the machine frame and is suspended in front of the weighing arm. It encloses about two-thirds of the bag, allowing relatively easy bag placement by the operator. Negative pressure in the hood makes tight seals between the weighing arm and hood assembly unnecessary. However, a special deflector plate mounted on the nozzle inside the hood prevents the escape of blowback material through the back of the hood. Approximately one-eighth inch clearance should be maintained between the deflector plate and hood to prevent interference with the weighing mechanism. The deflected dust is captured by intake air and carried into the duct at the back of the hood.[1]

Effectiveness of the hood was demonstrated on one of two side-by-side silica-flour-bagging machines. Respirable dust samples were taken from the worker's breathing zone, and relative dust concentrations were determined qualitatively using light-scattering dust monitor developed by Stanford

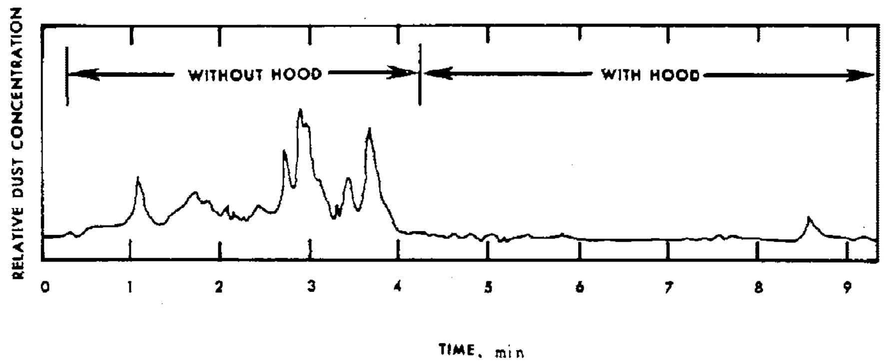

Figure 3 — Effectiveness of hood measured with light-scattering dust monitor.

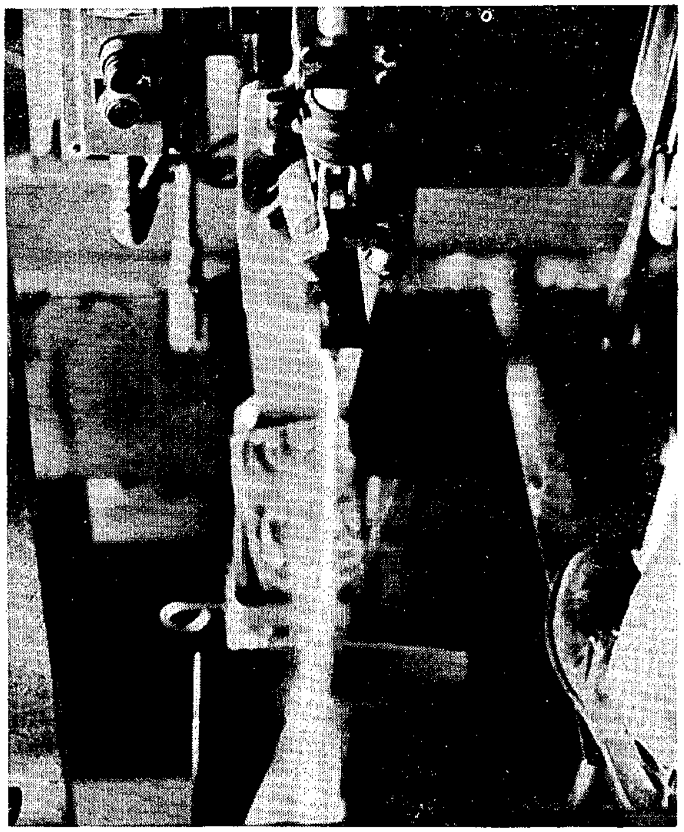

Figure 4 — Fluidic flow of whole-grain sand from nozzle as bag leaves machine.

Research Institute under Bureau of Mines contract.[2] A strip chart recording (Figure 3) shows the change in monitor dust exposure as the worker moved from the nonhooded machine to the hooded machine. The small peak near the end of the trace corresponds to a leak in the rear seam of the bag for which dust was not captured by the exhaust ventilation system. Qualitatively, this represents 89 percent reduction in the worker's exposure to respirable dust exclusive of background dust levels. Similar recordings with the dust monitor located at a fixed position between machines indicated qualitatively 85- and 95 percent reduction in respirable dust.

Spillage from nozzles

Spillage of material from the nozzle as the bag leaves the machine is another major source of dust. The bag is usually discharged from the machine immediately after the flow of product into the bag is stopped. However, material remaining in the nozzle area is still fluidized with air. Figure 4 shows the still-fluidized whole-grain sand flowing from the nozzle much like water, and dust is sprayed into the air (Figure 5). The same phenomenon exists in flour bagging. This spillage can also prevent the bag sleeve from sealing properly (Figure 6), thus creating a continuous dust source as the bag moves along the conveyor system.

For whole-grain products, the spillage problem was remedied by cleaning the nozzle prior to releasing the bag from the machine. This involved a modification to the control circuitry which delayed the release of the bag from the machine and injected a short high-velocity, low-volume blast of compressed air at the rear of the nozzle. This defluidized the material remaining in the nozzle and forced it into the bag. A whole-grain bagging machine equipped with the nozzle cleanout substantially reduced spillage. Bag sleeves were observed to seal more effectively, and cleanup time around the machine was reduced.

Cleaning flour materials from the nozzle was more difficult because the light fluffy nature of the material caused it to retain fluidizing air for long periods. The simple airblast at the rear of the nozzle was not sufficient to clean it: However,

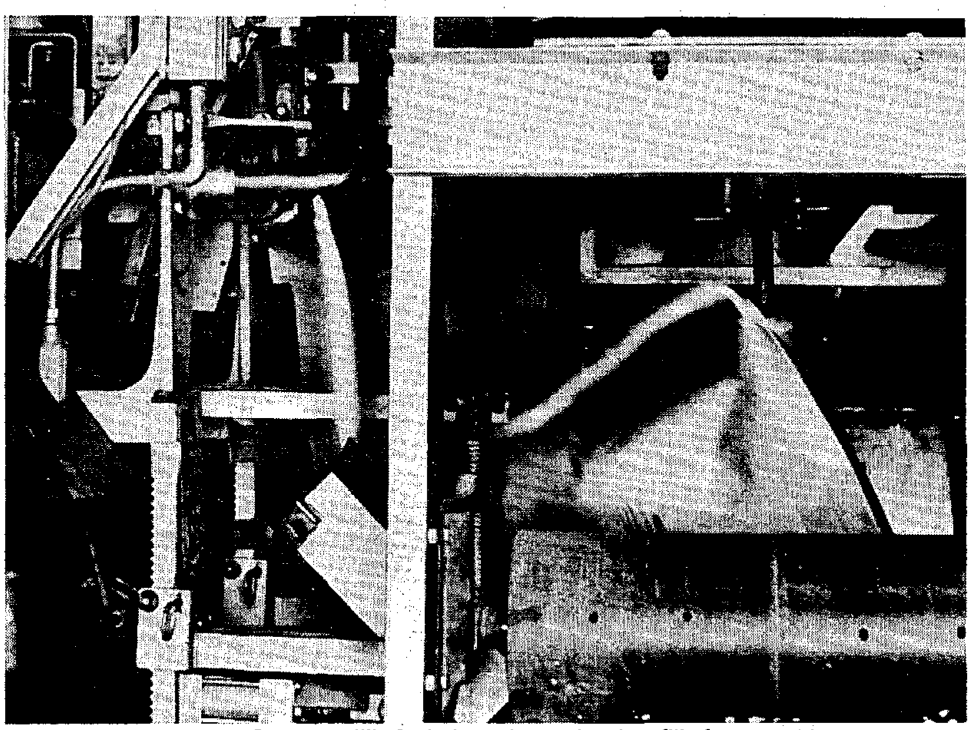

Figure 5 — "Rooster tail" of whole-grain sand as bag fills from machine.

TABLE I
Area Background Respirable Alpha-quartz (RAQ) Levels versus Area Samplers at Work Station

	Day 1	Day 2	Day 3
Intake RAQ mg/m^3	0.073	0.313	0.246
Worker Station RAQ mg/m^3	0.118	0.607	0.399

preliminary experiments indicate that the nozzle may be cleaned by venting, while simultaneously introducing a clean-out blast near the front of the nozzle (Figure 7). The air from the bag is vented through the nozzle as shown in the figure. This system shows promise but does not have a satisfactory life for abrasive products. A bagging machine manufacturer is developing a venting circuit for abrasive use.

Bag surface dust

Flour-type products present an additional dust control problem by adhering to the outer surface of the bag. Bag surface dust results from leakage around the nozzle as the bag fills and falls. Dust on the bag surface can become airborne during the conveying and loading operations. Attempts to clean the bags by air brushing thus far have been unsuccessful. Further experimentation is required.

Bag quality

Broken bags, leaky valve inserts and seams are other dust sources attributable to quality or improperly stored bags. Leaks from the nozzle insert and poorly glued seams constitute a continuous dust source as the bag is conveyed from the machine to the loading point. While an individual leak may seem trivial, a large number of such defects can conctribute significantly to the overall dust level. Proper bag specification, elimination of sharp obstructions in bag handling and proper filling pressures can significantly reduce the number of broken bags. Bags should be stored at recommended temperature and humidity to prevent drying

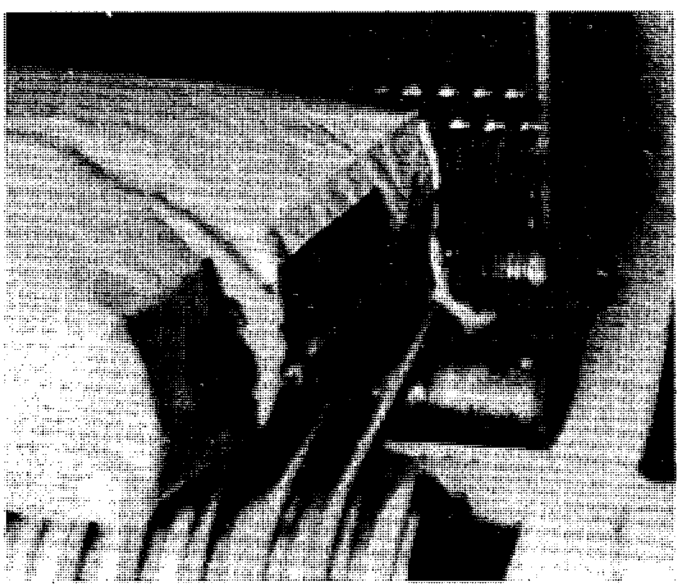

Figure 6 – Leakage from bag sleeve due to improper seal.

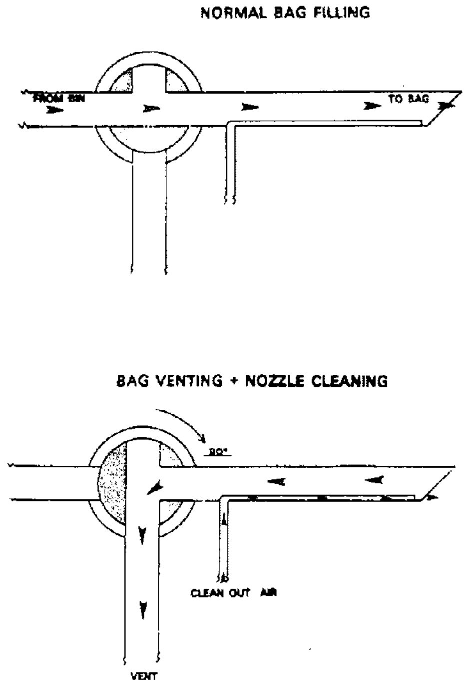

Figure 7 – Concept of bag venting plus nozzle cleanout for flour-type products.

and cracking. Administrative control over bag quality and storage should be maintained.

Background dust

Emission rate data show that background dust levels in both whole-grain and flour mills can contribute to more than **one-half of the total** respirable dust exposure of a worker.

For example, Table I shows area dust measurements taken in the intake air and at the man station of a flour bagging machine prior to installation of dust controls. On the first day, 75 μg of quartz were in the intake air. The worker station was exposed to 118 μg of respirable alpha quartz. For the other days, the intake levels of respirable alpha quartz were greater than one-half of the alpha-quartz present at the worker station.

Clearly, improvement of the exhaust ventilation system on the machine itself would not achieve compliance for two of the three days at this location. Even if the machines were dust-free, it would still be difficult to comply with the standards for the alpha quartz, since the background dust levels were so high. This is not an isolated case. We have encountered significant levels of background dust in most whole-grain and flour silica mills. This dust entered the work area from locations and operations outside of the bagging areas.

Factors that can account for high background dust levels include:

1. Meteorological conditions (amount of precipitation, wind speed and direction) can directly affect fugitive dust sources such as haul roads and stock piles outside the building.
2. The proximity of other dusty operations where personnel do not normally operate or are in controlled booths; for example, the grinding mills found in plants. Open transfer points within the same building, or bulk loading facilities immediately adjacent to the building,

and poor housekeeping practices also contribute to background dust levels.

3. Location of exhaust stacks may be such that fans used for ventilation recirculate dust back into the building and contribute to the background dust problem. Respirable particulate from "controlled stacks" can be a significant background source.
4. The overall topography of the plant site may influence background dust concentrations.

Because of low TLVs, background dust levels are very important. Protecting the operator from background dust may involve three basic approaches:

1. To define the specific background source and control it.
2. To isolate the bagging operations from possible background dust sources and/or conversely locate the dust sources away from the bagging operations.
3. To provide the operator with a source of clean makeup air, either by locating the makeup air inlet away from the dust sources or by filtrating according to guidelines for makeup air systems established in the ACGIH[3] ventilation handbook.

A filtration approach was taken at a whole-grain bagging operation where dust from an adjacent bulk-loading facility was being drawn into the bagging building by the exhaust ventilation system of the bagging machine. The company, in consultation with the Bureau of Mines, engineered and installed ventilation hoods, a nozzle cleanout system, and a makeup air ventilation system. Respirable dust levels at the new installation were in compliance as measured by MSHA.

Conclusion

Improved dust control techniques for whole-grain bagging operations are available. Properly designed ventilation hoods, nozzle cleanout, makeup air systems and good housekeeping can bring whole-grain bagging machine operators into compliance. Flour bagging operations present greater challenges, but efforts are being made to treat them by techniques that have been successful for whole-grain operations. Research and development are also needed in the ventilation of enclosed cars and trucks being loaded with bagged products. Additional emphasis should also be given to the role of background dust levels.

In conclusion, although flour bagging references have been included in this report, they are preliminary but indicative and will be addressed in a future paper dealing with the results of an ongoing study of flour bagging.

Addendum

Dust emission rate sampling

Dust emission rate sampling is an engineering research technique that provides more control over an experiment than conventional, personal, or area sampling techniques. Although reducing personal exposure to dust is the objective, measurement of individual dust exposure is not the most effective way to evaluate the dust reduction achieved by a control technique. General area sampling eliminates much of the variability associated with the worker's routine but does not take into account variations of background dust levels, varying volumes of diluting air or changes in production rate. The technique of emission rate sampling eliminates these unknowns. It provides results in terms of dust generated per unit time, which is easily converted into dust generated per ton of material processed, dust per container processed, or dust levels generated per shift. Emission rate techniques are already used in process emission controls and monitoring of roadway fugitive dusts. Need for emission rate sampling to evaluate various control techniques in the silica industry became increasingly apparent because of the low respirable dust threshold limit value required by law. The effect of a control technique could be falsely enhanced or diminished by small variations in background dust level or operating parameters. Emission rate sampling provides the most quantitative measure of the actual dust generated by a particular piece of equipment.

A simple model demonstrates the method used for measuring an emission rate. In Figure A-1, a single dust generation source is located in a small building having two doors and no other openings. A natural or mechanical ventilation pattern is established through the building from one door to the other. Air velocities through the doors and the area of the doors are used to compute air volume. The balance of intake and exhaust air volumes is an indication of the confidence of the emission rate measurement. Dust concentrations at each door are also measured. The mass rate of dust through a doorway can be calculated by the equation:

$$\text{Mass rate (mg/min)} = \text{volume (m}^3\text{/min)} \times \text{dust concentration (mg/m}^3\text{)} \quad (1)$$

The difference between the mass rate "out" and the mass rate "in" is the mass of dust generated only within the building:

EMISSION RATE MODEL

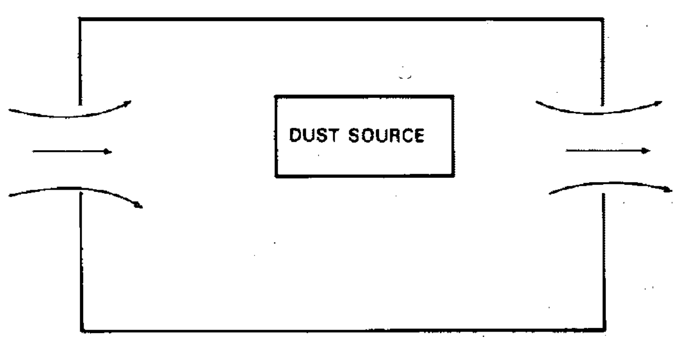

Figure A-1 — Model of emission rate test method.

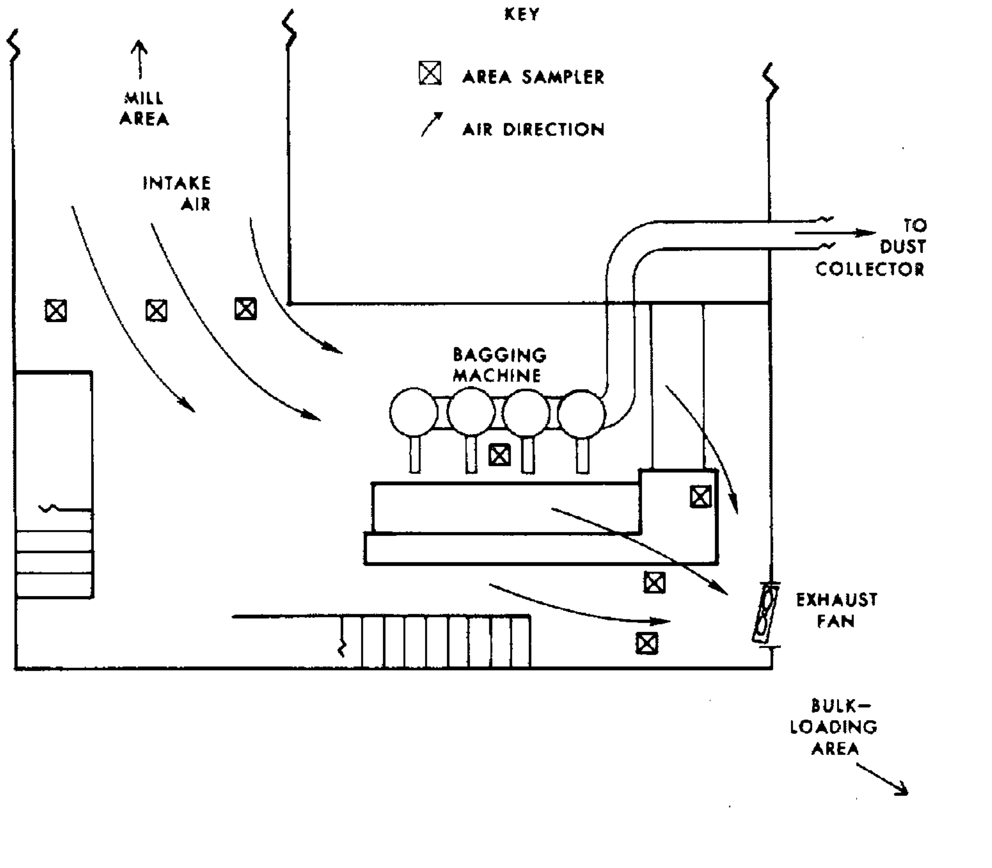

Figure A-2 – Example of field site where emission rate was measured.

$$\text{Mass rate}_{out} - \text{mass rate}_{in} = \text{dust generation rate of operation} \quad (2)$$

The emission rate technique was applied to a mineral flour bag packing facility that used a four-nozzle fluidized valve packing machine situated on the second floor of a three-story structure. Adjacent to the operation were the flour-grinding mills and the bulk-loading facility. Natural ventilation flows were observed to be coming from the mill area over the bagging machine and into the exhaust ventilation system. Little air was observed entering from the bulk loading side of the building (Figure A-2). A 280 m^3/min (10,000 cfm) free-air fan was used to enhance the natural ventilation by exhausting air through the bulkloading door. Sampling points were located at the entrance from the mill area into the bagging area and adjacent to the bulk loading door. Dust concentrations were measured using personal gravimetric samplers arranged in area packages. An area package contained 4 personal samplers with the cyclones arranged in a 6-inch linear horizontal array. The area package concept was used to reduce the normal variability associated with field operations of personal sampling systems. Three area packages were evenly spaced at each sampling site and their results were averaged to give a representative dust concentration at that location. Vane anemometers measured velocity at the sampling locations and a temperature compensation hot wire anemometer measured velocity in the exhaust duct work.

The daily balance of air volumes through the bagging area was computed (Table A-1) For day 1, total air in averaged 308 m^3/min; total air out averaged 361 m^3/min. There was an

TABLE A-1
Daily Balance of Air Volume through Bagging Area

	Day 1	Day 2	Day 3
Intake air m^3/min	308	283	307
Exhaust air m^3/min	361	371	351
Unaccounted Volume (in) m^3/min	53	88	44
% Unaccounted Volume	15%	24%	13%

TABLE A-2
Emission Rate Dust Data

	Day 1	Day 2	Day 3
Mass rate$_{in}$ mg/min	25.9	106.4	105.7
Mass rate$_{out}$ mg/min	68.5	174.8	185.8
Generation rate mg/min	42.6	68.4	80.1
Shift rate grams/shift	20.45	32.85	38.43
Bags per shift (50 and 100 lb)	1170	1890	2100
Dust per bag mg/bag	17.5	17.4	18.3

unaccounted volume of air entering the building of 53 m^3/min, this represents 15 percent of the total measured air. Unaccounted air was to be expected because of numerous gaps in the sheet metal building. The unaccounted volumes for the next two days were 24 and 13 percent. These percentages give some idea of how successfully the emission rate was measured.

The generation rate of the bagging machine was calculated from equation 1, using concentration and volume of air entering and leaving the building. Exhaust ventilation air volume plus the volume of air leaving the bulk loading door, times the dust concentration of the loading door was used to calculate the mass flow rate out. Table A-2 shows the mass flow rate out, and the difference, which is the generation rate of the machine for a particular day. When the generation rate (mg/min) is converted into the total number of grams per shift generated by the machine no correlation is evident, between days. However, when the amount of production on each shift is considered in terms of the number of bags processed per shift, there is much better correlation between the generation rate and the number of bags. The total weight of dust generated for each bag of material produced can be calculated easily. The average amount of dust generated per bag, **prior to installation** of dust control devices discussed earlier, was 17.7 mg. The coefficient of variation between three different days was 2.8 percent. This number then can be directly compared to any future modification made to this machine and sampled in a similar manner. Thus, the percent effectiveness of a particular control device on the machine can be evaluated. The 17.7 mg/bag of dust generated by the machine is not indicative of the operator's exposure at that machine, since this is the total mass of dust put into the total volume of air in the bagging area.

References

1. **Details of this design** are available through Bureau of Mines Technology News Brief #54, *Dust Control Box for Bag-Filling Machines.* Technology Transfer Group, Bureau of Mines, 2401 E Street, NW, Washington, DC 20241.
2. **Lapple, C. E. and C. F. Schadt:** *Portable Mine Dust Concentration Instrument.* Final Report BuMines Open File Report 6-73 NTIS PB 215-150/4 (1973). Available for viewing at Bureau of Mines Technical Libraries.
3. **American Conference of Governmental Industrial Hygienists:** *Industrial Ventilation.* Ann Arbor, Mich., pp 7.1 (1974).
4. **National Industrial Sand Association:** *Guidance and Solutions to Reducing Respirable Dust Levels in the Bagging of Whole-grain Silica Products.* 900 Spring Street, Silver Spring, MD 20910

Appendix II

1. The operator should write standing operational procedures which govern the selection, use, and care of respirators.

2. The operator should select respirators which are jointly approved by MSHA and NIOSH for protection against dust containing free silica.

3. The operator should instruct all workers who may be required to use a respirator, in the proper fitting and use of the respirator. Minimal training should include the following:

   a. Instruction in the nature of the hazard, whether acute, chronic, or both, and an honest appraisal of what may happen if the respirator is not used.

   b. A discussion of why this is the proper type of respirator for the particular purpose.

   c. A discussion of the respirator's capabilities and limitations.

   d. Instruction and training in actual use of the respirator and frequent supervision to assure that it continues to be properly used.

4. Where practicable, the respirators should be assigned to individual workers for their exclusive use.

5. Respirators should be regularly cleaned and disinfected; they should be stored in a convenient and sanitary location.

6. Respirators should be inspected during cleaning to ensure retention of their original effectivenss. Worn or deteriorated parts should be replaced.

7. Workers who are physically unable to use respiratory protective equipment, as determined by a physician, should not be assigned to tasks requiring respirator usage.

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