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to

U.S. Bureau of Mines
Denver Federal Center
Denver, Colorado 80225

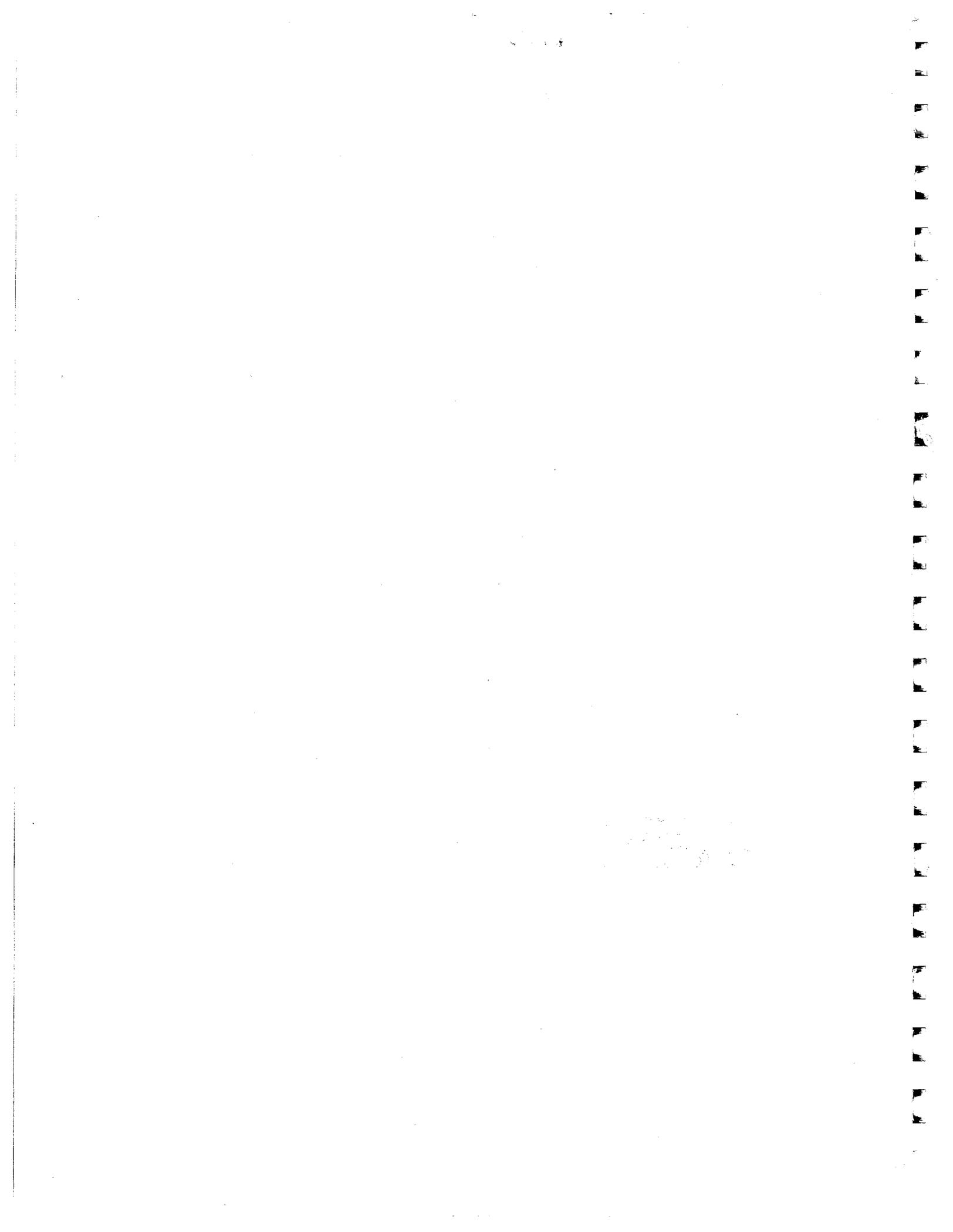
SURVEY OF PAST AND PRESENT METHODS
USED TO CONTROL RESPIRABLE DUST IN
NONCOAL MINES AND ORE
PROCESSING MILLS

(Contract H0220030)

30 April 1974

Bureau of Mines Open File Report 17(1)-75

MSA RESEARCH CORPORATION
DIVISION OF MINE SAFETY APPLIANCES COMPANY
EVANS CITY, PENNSYLVANIA 16033



USBM Contract No. H0220030

SURVEY OF PAST AND PRESENT METHODS USED TO CONTROL
RESPIRABLE DUST IN NONCOAL MINES AND ORE PROCESSING MILLS

S. J. Rodgers

MSA RESEARCH CORPORATION
Evans City, Pennsylvania

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DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
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FOREWORD

This report was prepared by MSA Research Corporation, Evans City, Pennsylvania under USBM Contract No. H0220030. The contract was initiated under the Metal and Nonmetal Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Dr. John Breslin acting as the technical project officer. Mr. Frank Pavlich was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period 26 June 1972 to 31 March 1974. This report was submitted by the authors on 30 April 1974.

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SURVEY OF PAST AND PRESENT METHODS USED TO CONTROL RESPIRABLE DUST IN NONCOAL MINES AND ORE PROCESSING MILLS (Contract H0220030)

INTRODUCTION

MSA Research Corporation, Division of Mine Safety Appliances Company, was awarded a contract to conduct a survey of past and present methods used to control respirable dust in noncoal mines and ore processing mills. The survey covered information reported in mining journals, and U.S. Bureau of Mines Circulars, dust inspection reports, on-site evaluation of dust control methods and systems, and contact with manufacturers of dust control equipment.

Both surface and underground mining operations were visited. Fifty mines and 51 processing plants were included in the survey. Dust control methods for the following types of ores or mines were studied:

<u>Number of Mines*</u>	<u>Number of Mills</u>	<u>Type of Material</u>
3 (1 OP, 2 U)	3	Asbestos
2 (OP)	2	Bentonite
6 (3 OP, 3 U)	7	Copper
6 (3 OP, 3 U)	7	Iron
1 (U)	1	Gold
2 (OP)	2	Granite
6 (2 OP, 4 U)	5	Lead
9 (8 OP, 1 U)	7	Limestone, Sand & Gravel
1 (U)	1	Molybdenum
4 (OP)	4	Phosphate Rock
4 (U)	4	Potash
2 (OP)	2	Sand
2 (1 OP, 1 U)	2	Talc
2 (U)	2	Trona
2 (U)	2	Uranium

*OP = Open Pit, U = Underground

Although this survey covered only a small fraction of the total number of noncoal mines, the mines were selected to give a representative cross-section of the industry. Criteria used for selection included underground and open pit mines, large and small mines, wet and dry mines, and conventional and continuous mining methods. Another factor which became apparent during the survey was the quality of maintenance at various mines.

The Technical Project Officer for the U.S. Bureau of Mines was Dr. John Breslin of the Pittsburgh Mining and Safety Research Center. The program was under the technical direction of Mr. Sheridan Rodgers of MSA Research Corporation. Other MSAR personnel who assisted in the survey were Messrs. Ralph Hiltz, Joseph Friel, Mervin Marshall, William Everson and Herbert Hays. Acknowledgement is also due Mr. Donald Kingery, formerly of the U.S. Bureau of Mines and Mr. Jack Warren, formerly of the Anaconda Company, who served as consultants on the program. Finally, special recognition must be given to mine management, ventilation engineers and industrial hygienists without whose cooperation this program would not have been possible.

SUMMARY AND CONCLUSIONS

Major efforts to control silicosis in the noncoal mining industry were not instituted until about 1935. Since that time the U.S. Bureau of Mines and the mining industry have continuously endeavored to reduce respirable dust with the institution of on-site dust surveys and appropriate dust control practices. The reduction in respirable dust has resulted in a concomitant reduction in the incidence of silicosis. However, overexposure to free quartz has not been completely eliminated.

The survey showed that the major reasons for overexposure to free quartz were poor maintenance and housekeeping. Poor maintenance practices were observed in the form of holes in ductwork, missing pieces of ductwork, worn shrouds, plugged spray nozzles and so on. Poor housekeeping practices were observed as piles of dust collected at transfer points and on rafters and beams. In many cases, push brooms were used to sweep dust, a practice which should be avoided since it causes settled dust to become airborne. Other factors which resulted in overexposures included muck piles not being wetted down, poor design of dumps and chutes, dry drilling and undercutting, undersized ventilation equipment, and flow imbalances in exhaust systems.

It was concluded that in most cases the technology and equipment exists to control respirable dust in mines and processing plants. General procedures are given for the following classifications:

1. Drilling - Drill wet when possible; use exhaust ventilation to capture dust when drilling must be done dry; blow out holes with air-water mist.
2. Blasting - Wet down area prior to blasting; spray mist during blasting; primary and auxiliary ventilation to remove dust and fines; wet down muck piles.

3. Mucking - Wet down frequently; use water deluge when possible.
4. Dumping - Maintain dump entry under exhaust ventilation; use water sprays.
5. Loading and Hauling - Wet down cars and haulageways.
6. Crushing - Enclose and maintain under exhaust ventilation; use spray nozzles at crusher mouth.
7. Conveying - Enclose transfer points; maintain under exhaust ventilation.

Various collection devices such as baghouses, wet scrubbers and electrostatic precipitators can be used to collect dust from exhaust ventilation installations.

REVIEW OF SILICOSIS IN THE MINING INDUSTRY

A literature search was made to determine past and current methods of controlling respirable dust in the metal and nonmetal mining industry. The survey also covered information on respirable dust levels as a function of the type of occupation within the mines, mills and processing plants.

Journals, periodicals, technical reports, mine health surveys and other publications were reviewed. Past studies made by the U.S. Bureau of Mines and the U.S. Public Health Service represented the primary sources of information on respirable dust concentrations and the resultant incidence of silicosis. Current mine health surveys made by the U.S. Bureau of Mines provided information on present day dust concentrations. Publications by the International Labor Organization proved to be a valuable source of information on methods used to abate or control respirable dust.

The literature search showed a significant improvement in dust control methods and a concomitant reduction in silicosis in the past 25-30 years. Unfortunately, the Bureau of Mines mine health surveys showed that, even today, many workers are being exposed to dust levels which exceed the Threshold Limit Values.

Silicosis and Other Health Hazards

The inhalation and retention of dust can result in the development of pneumoconiosis. In the noncoal mining industry the disease generally manifests itself in the form of silicosis. It has been shown that the incidence of silicosis is a function of the free silica content of the ore being mined rather than the type of ore, and of the amount of respirable dust inhaled by the worker.

Silicosis has been a recognized health problem in the mining industry for many years. However, efforts to control this disease did not begin in the U.S. until early

in the 20th century when investigations into the nature of silicosis were conducted by joint efforts of the Public Health Service and Bureau of Mines. The mining industry did not employ major efforts to control the disease until 1935. Because of the long latent period in the development of silicosis, the control efforts were not expected to reduce prevalence of the disease for many years.

Past Studies on Silicosis

Very early studies conducted in the Joplin, Missouri mining district in 1915 showed that of 720 miners examined, 472 or 65.5% had silicosis.⁽¹⁾ Free silica content of the mines in that district ranged from 70 to 90 percent.

A joint (PHS-USBM) study was conducted at the Butte, Montana mining district during 1916-1919. The study revealed that 42.4 percent (1018) miners had silicosis. Dust in the Butte mine district contained 50-60 percent free silica.⁽²⁾

In 1923, 309 miners were examined. These miners worked mainly in zinc and lead mines of the Oklahoma, Kansas and Missouri district.⁽³⁾ Ninety-four (30 percent) had silicosis while 111 (36 percent) were considered borderline cases.

A large scale investigation was made at the Picher, Oklahoma district during the years 1927-1932.⁽⁴⁾ Of 27,553 miners examined, 5366 (19.4 percent) were found to have silicosis.

During the 1935-37 period, studies were conducted by the larger mining companies in the Coeur D'Alene mining district of Idaho.⁽⁵⁾ Routine physical examinations of 6243 miners showed that 2328 or 37.3 percent had silicosis while 1937 (31.5 percent) were considered borderline cases. Average dust concentrations in rock drilling, crushing, mucking and in chutes and airways ranged from 3.7-36 mppcf of air.

During 1939, 727 nonferrous metal mine workers were examined in Utah; 66 (9.1 percent) showed evidence of silicosis and 42 (5.8 percent) more were borderline cases.⁽⁶⁾

Environmental studies indicated that underground workers were exposed to weighted average dust levels ranging from 3.8 mppcf of air for station tenders and carmen to 23.1 mppcf for miners, drillers and muckers, and 37.5 mppcf for bin tenders, carloaders and chute gate tenders. About 86 percent were exposed to dust concentrations between 6-30 mppcf of air and about 12 percent to less than 6 mppcf of air. The average underground worker was exposed to airborne dusts containing 20-40 percent free silica. There were no cases of silicosis in 44 miners who worked less than 10 years and were exposed to dust concentrations of 6-11.9 mppcf. Zero (<10 years), 7 (10-19 years) and 19 percent (over 20 years) of the miners exposed to dust concentrations in the 12 to 17.9 mppcf range developed silicosis. The incidence of silicosis was greatly increased in men who were exposed to 18-23.9 mppcf of air, and was common among all groups who had worked for a long time, i.e., 37 percent prevalence of men who worked 20 or more years.

Later Studies on Silicosis

A more recent joint study was conducted by the Public Health Service and the Bureau of Mines to reevaluate the silicosis problem in metal mines between the years 1958-1961.⁽⁷⁾ An impinger was used for all sampling of airborne dust in the environmental phase of the study because it had been used previously and permitted correlation of health status of miners with their occupational exposure to dust. Therefore, comparisons could be made between past and more recent studies.

1. Health Studies - The 1958-1961 study showed that the prevalence of silicosis increased with mine workers age and years of employment as shown in Figure 1. Table 1 shows the prevalence of silicosis among miners at forty-three metal mines by years of employment and types of general work duties. Excluding years worked, faceworkers had the highest rate of silicosis (5.9 percent) followed by miscellaneous underground workers (4.7 percent); millworkers (4.2 percent); maintenance and construction (surface, 3.1 percent); maintenance and construction (underground, 2.8 percent); underground transportation (2.3 percent) and others in descending order of rate of incidence. Faceworkers represented 62.7 percent of all silicotic workers.

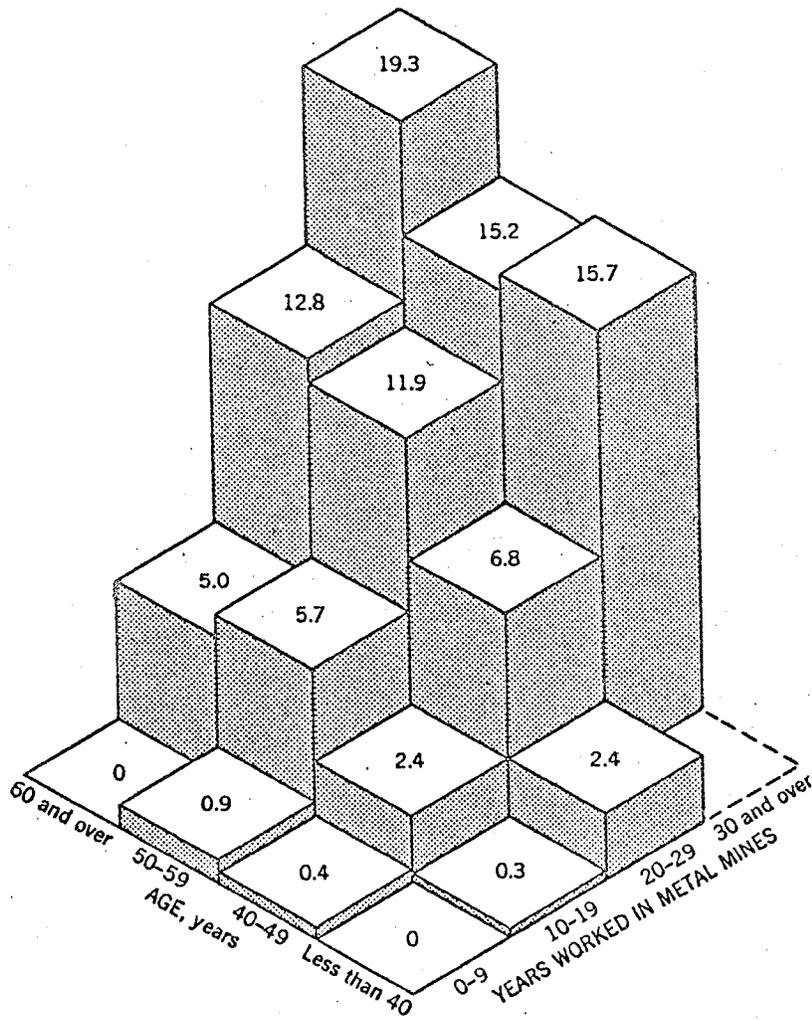


FIGURE 1 - PERCENT OF METAL MINE WORKERS WITH SILICOSIS ACCORDING TO AGE AND YEARS WORKED IN METAL MINES

TABLE 1 - SILICOSIS AMONG METAL MINE WORKERS* BY PRINCIPAL OCCUPATION AND YEARS AT METAL MINES

Years at metal mines	Total	Underground				Surface				No principal
		Face	Transportation	Maintenance and construction	Miscellaneous	Transportation	Maintenance and construction	Mill	Miscellaneous	
Number examined										
Total.....	10,286	4,379	1,109	900	555	263	865	641	513	1,061
0-5.....	2,423	714	305	238	133	41	146	193	104	549
5-9.....	2,347	1,063	268	225	96	65	201	166	124	139
10-14.....	1,884	934	182	145	79	55	171	107	81	130
15-19.....	1,304	579	151	121	71	42	111	81	59	80
20-24.....	1,027	490	95	78	73	25	86	46	58	76
25-29.....	563	255	54	41	39	15	58	27	35	39
30-34.....	444	218	35	32	42	9	45	13	26	24
35 and over.....	294	126	19	20	22	11	47	8	26	15
Number with silicosis										
Total.....	415	260	25	25	26	2	27	27	5	18
0-5.....	7	2		2				3		
5-9.....	31	19	2	3	1	1		4		1
10-14.....	49	27	5	5	1		2	6	1	2
15-19.....	91	60	3	6	5		8	7		2
20-24.....	70	36	6	5	10	1	6	2	1	3
25-29.....	95	67	4	1	6		6	3	2	6
30-34.....	72	49	5	3	3		5	2	1	4
35 and over.....										
Percent with silicosis										
Total.....	4.0	5.9	2.3	2.8	4.7	0.8	3.1	4.2	1.0	1.7
0-5.....	.3	.2		.9				1.8		
5-9.....	1.6	2.0	1.1	2.1	1.3	1.8		3.7		.8
10-14.....	3.8	4.7	3.3	4.1	1.4		1.8	7.4	1.7	2.2
15-19.....	8.9	12.2	3.2	7.7	6.9		9.3	15.2		2.6
20-24.....	12.4	14.1	11.1	12.2	25.6	6.7	10.3	7.4	2.9	7.7
25-29.....	21.4	30.7	11.4	3.1	14.3		13.3	23.1	7.7	25.0
30-34.....	24.5	38.9	26.3	15.0	13.6		10.6	25.0	3.8	26.7
35 and over.....										

*Excludes uranium mines and 7 iron and lead-zinc mines in low free silica limestone formations.

Table 2 shows the occupation of metal mine workers compared with their past work record during their entire career in mining. The results are correlated according to percent with silicosis. For example, among 4474 men faceworking at the time of the study, 3883 had the same occupation throughout their mining careers. Older, less physically able men were often transferred from underground jobs to surface work. This is reflected in the table correlating percent of workers with silicosis, by present and major occupation. The highest silicosis rates were among workers whose major job had been faceworking but were later transferred to surface work.

2. Silicosis According to Ore Produced. - Table 3 and Figure 2 show that the silica content of the dust is more important than the type of ore mined in affecting the rate of silicosis. Groups with less than 10 years in mine work had less than a one percent silicosis rate. In the longest exposed groups, iron and copper miners showed the same percentage of silicosis. Lead, zinc, uranium and other miners had a higher rate of silicosis. In mines with low free silica, the percentage rate of silicosis was also low.

3. Environmental Studies - The results of 14,837 impinger samples taken in the most recent survey (1958-61) in underground mines are given in Figure 3; 1440 (about 10 percent) of the samples showed excessive dust concentrations. Excessive dust concentrations were defined as those levels exceeding the 1962 TLV's set by the ACGIH:

$$TLV = \frac{250}{\% \text{ quartz} + 5} \text{ mppcf}$$

A total of 1683 samples were collected in mills and near crushers; 1258 were collected on the surface and 425 underground. Table 4 shows that a total of 13 percent of the samples were high in dust concentrations. Crushing was the dustiest operation with 21.4 percent of the samples taken very high in dust.

Impinger samples taken at shops and other surface installations are summarized in Table 5. Only 6.7 percent of the total samples showed excessive dust concentrations. However, the table shows that 28 percent of samples taken at concentrate loading operations were high in dust concentrations.

TABLE 2 - PRESENT OCCUPATION COMPARED WITH PRINCIPAL OCCUPATION OF WORKERS AT 50 METAL MINES* ACCORDING TO PERCENT WITH SILICOSIS

Principal occupation	Present occupation							
	Underground				Surface			
	Face	Transportation	Maintenance and construction	Other	Transportation	Maintenance and construction	Mill	Other
	Number examined							
Total.....	4,474	1,468	1,818	1,078	424	1,404	898	923
Underground total.....	4,168	1,257	1,486	876	89	284	77	198
Face.....	3,883	320	456	335	42	145	43	100
Transportation.....	161	858	113	37	33	33	9	21
Maintenance and construction.....	52	52	890	47	11	96	5	18
Other.....	72	21	27	457	3	10	20	59
Surface total.....	41	54	120	59	282	977	706	631
Transportation.....	9	15	9	1	240	18	8	7
Maintenance and construction.....	9	14	68	14	19	863	38	49
Mill.....	15	16	12	10	10	39	628	47
Other.....	8	9	31	34	13	57	32	528
No principal.....	265	157	212	143	53	143	115	94

	Percent with silicosis							
Total.....	2.2	2.3	4.1	5.8	1.9	4.8	4.2	4.8
Underground total.....	2.3	2.5	4.8	6.8	4.5	13.0	14.3	16.2
Face.....	2.4	5.2	11.2	11.9	7.1	22.1	23.2	21.0
Transportation.....	.6	1.4	2.7	2.7	3.0	12.1		14.3
Maintenance and construction.....		1.9	2.0	6.4		1.0		16.7
Other.....	4.2	4.8		3.5			5.0	8.5
Surface total.....				1.7	1.1	2.6	3.8	1.0
Transportation.....					.8			
Maintenance and construction.....				7.1		2.7	7.9	2.0
Mill.....						5.1	3.8	2.1
Other.....					7.7			.8
No principal.....	.4	1.3	1.4	1.4	1.9	3.5		6.4

*Excludes workers in uranium mines.

TABLE 3 - SILICOSIS AMONG METAL MINE WORKERS* ACCORDING TO COMMODITY PRODUCED, BY YEARS AT METAL MINES

Mine commodity	Number of years at metal mines				
	Total	--10	10-19	20-29	30 and over
Total examined					
Total.....	14, 076	6, 516	4, 324	2, 125	1, 111
Iron.....	1, 112	375	395	227	115
Lead-zinc.....	2, 622	1, 183	871	395	173
Copper.....	4, 010	1, 538	1, 381	748	343
Uranium.....	1, 589	1, 105	341	109	34
Other.....	2, 542	1, 674	541	220	107
Iron†.....	962	546	239	137	40
Lead-zinc†.....	1, 239	95	556	289	209
Number with silicosis					
Total.....	476	7	93	193	183
Iron.....	47	1	10	12	24
Lead-zinc.....	127	2	27	50	48
Copper.....	146	1	21	58	66
Uranium.....	50	0	11	30	9
Other.....	95	3	22	41	29
Iron†.....	3	0	1	1	1
Lead-zinc†.....	8	0	1	1	6
Percent with silicosis					
Total.....	3.4	0.1	2.2	9.1	16.5
Iron.....	4.2	.3	2.5	5.3	20.9
Lead-zinc.....	4.8	.2	3.1	12.7	27.7
Copper.....	3.6	.1	1.5	7.8	19.2
Uranium.....	3.1	-----	3.2	27.5	26.5
Other.....	3.7	.2	4.1	18.6	27.1
Iron†.....	.3	-----	.4	.7	2.5
Lead-zinc†.....	.6	-----	.2	.4	2.0

*Includes uranium mine workers.

†Includes mines in low free silica limestone formations.

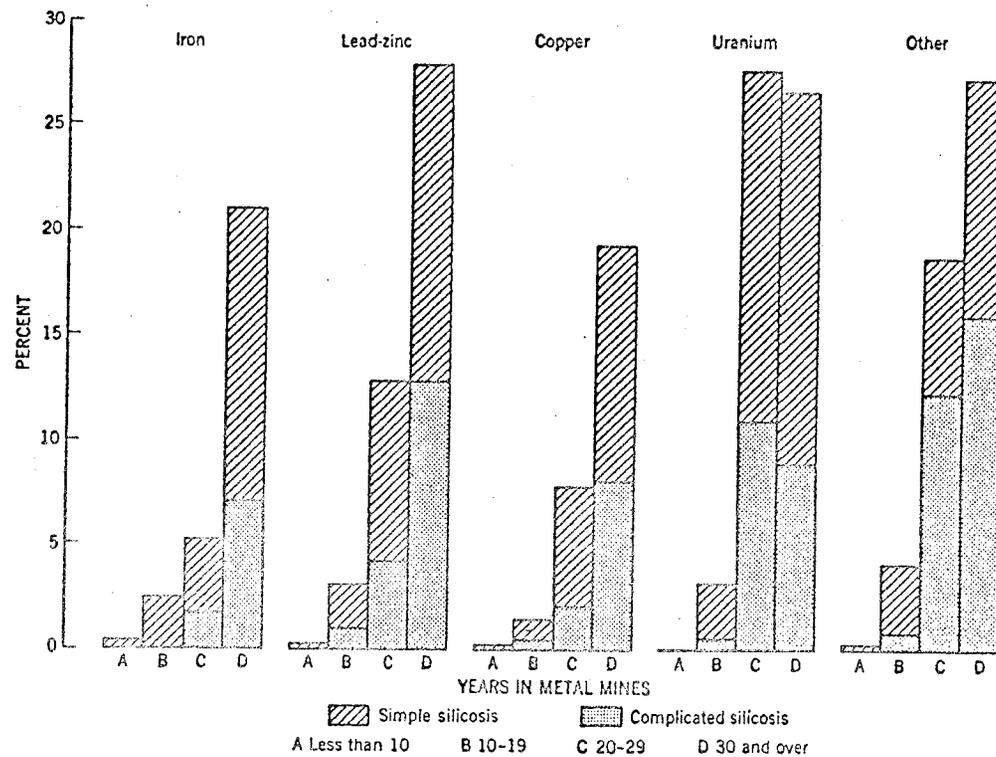


FIGURE 2 - PERCENT OF METAL MINE WORKERS WITH SILICOSIS ACCORDING TO COMMODITY PRODUCED
(Excludes seven iron and lead-zinc mines in low free silica limestone formations)

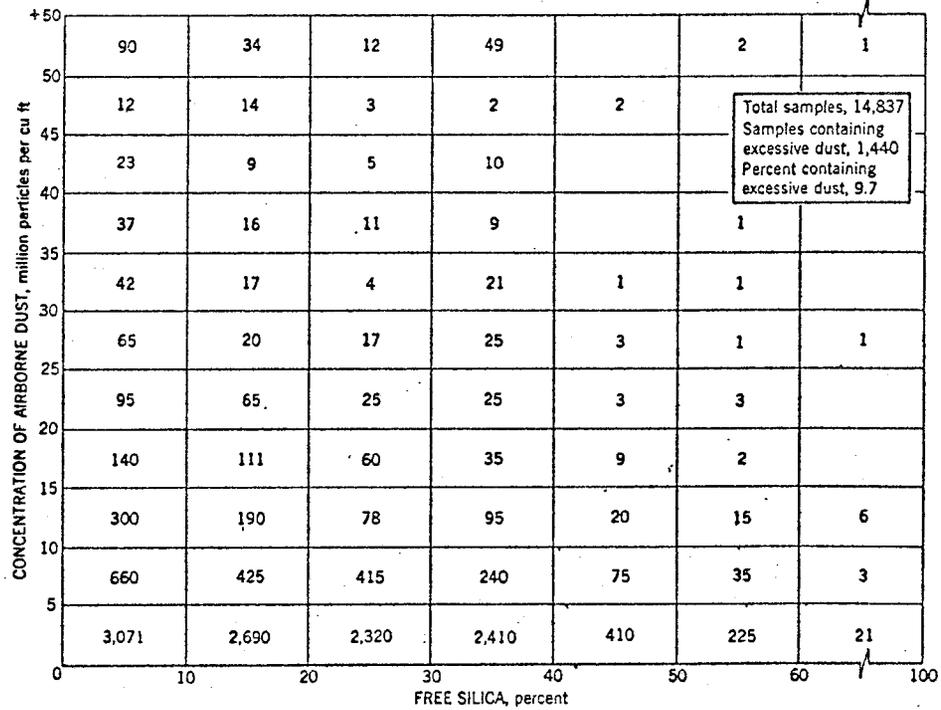


FIGURE 3 - DISTRIBUTION OF MIDGET IMPINGER SAMPLES COLLECTED IN RESPECT TO DUST CONCENTRATION AND FREE SILICA CONTENT

TABLE 4 - MIDGET IMPINGER SAMPLES COLLECTED AT SURFACE AND UNDERGROUND MILLS AND CRUSHERS

Location	Number of samples	Samples containing excessive concentrations of dust	
		Number	Percent
Total.....	1,683	219	13.0
Mills.....	1,145	108	9.4
Crushers.....	459	98	21.4
Assayers in mills.....	79	13	16.5

TABLE 5 - MIDGET IMPINGER SAMPLES COLLECTED AT SURFACE LOCATIONS

Location or operation	Number of samples	Samples containing excessive concentrations of dust	
		Number	Percent
Total.....	1,660	112	6.7
Shops.....	1,032	73	7.1
Toplanders and hoistmen.....	231	0	0
Assay laboratories.....	117	22	18.8
Dumpmen.....	75	0	0
Bullgangs and pumpers.....	62	0	0
Concentrate loaders.....	50	14	28.0
Shovel, compressor, crane, and truck operators.....	66	0	0
Concrete plants.....	18	3	16.7
Sand blasters.....	9	0	0

Comparison Between Past and Recent Studies

In early studies, before dust control, miners were exposed to very high dust concentrations resulting in a high and early incidence of silicosis. The 1939 study of non-ferrous metal mine workers in Utah⁽⁶⁾ presented data which could be compared with data obtained in the 1958-1961 study in 12 lead-zinc mines having similar characteristics.⁽⁷⁾ Table 6 presents the comparative prevalence of silicosis, according to years worked, between the studies. The prevalence of silicosis was found to be 40 percent lower in the more recent study. In addition, there was an 80 percent reduction in prevalence for the group employed less than 10 years and a 72.8 percent reduction for the group employed 10-19 years. For faceworkers, there was a 81.3 percent reduction for the group employed less than 10 years and a 76.5 percent reduction for those with 10-19 years employment.

In regard to the environmental data, Table 7 shows the weighted average dust levels at comparative selected operations during the same two surveys. There was a 53 percent reduction in dust concentrations based on median dust level values at dry crushing, and 78-90 percent reduction at other areas in the 1958-61 study.

Statistical evidence of the value of dust control was shown in the granite industry in Vermont.⁽⁸⁾ During the years 1924-26, dust exposures as high as 200 mppcf occurred, and exposure of granite cutters averaged 60 mppcf. Industry wide dust control practices were started in 1937. At that time incidence of silicosis was 45.3 percent. The industry was surveyed again in 1954 and results showed that incidence of silicosis was only 16.2 percent and dust had been reduced to 1-2 mppcf with few personal exposures exceeding 5 mppcf. Incidence of silicosis had been reduced from 17.9 percent to 2.3 percent over the same period.

Present and Future Outlook

Joint studies (PHS and USBM) have not been conducted since the years 1958-61. A current study is long overdue. According to Ayer⁽⁹⁾, silicosis and other dust diseases have not been eliminated except at the granite mines in Vermont. New cases have developed in bentonite milling and there is no reason to believe that the disease is not developing at other types of mines.

TABLE 6 - SILICOSIS IN WESTERN LEAD-ZINC MINE WORKERS EXAMINED IN 1958-61 COMPARED WITH UTAH METAL MINE WORKERS EXAMINED IN 1939 ACCORDING TO YEARS AT METAL MINES

Years at metal mines	Number examined	All silicosis		Simple silicosis		Complicated silicosis	
		Number	Percent	Number	Percent	Number	Percent
1939 study							
Total.....	727	66	9.1	52	7.2	14	1.9
Less than 10 years.....	394	4	1.0	4	1.0	0	0
10-19 years.....	228	30	13.2	26	11.4	4	1.8
20 years and over.....	105	32	30.5	22	21.0	10	9.5
1958-61 study							
Total.....	2,173	117	5.4	74	3.4	43	2.0
Less than 10 years.....	959	2	.2	2	.2		
10-19 years.....	717	26	3.6	17	2.4	9	1.2
20 years and over.....	497	89	17.9	55	11.1	34	6.8

TABLE 7 - WEIGHTED AVERAGE DUST CONCENTRATIONS (mppcf) AT COMPARABLE OCCUPATIONS IN 12 LEAD-ZINC MINES STUDIED IN 1958-61 COMPARED WITH UTAH METAL MINES STUDIES IN 1939

Occupation	1939 study*—average	1958-61 study		
		Median	Range	
			Low	High
Underground				
Miner.....	23.1	3.1	1.3	17.6
Motorman.....	10.5	2.3	1.5	10.7
Hoistman.....	7.5	1.6	1.0	2.6
Timberman.....	18.9	1.9	.7	10.6
Surface				
Hoistman.....	3.8	.6	.5	2.3
Topman.....	9.4	1.1	.8	2.8
Crusher.....	14.3	6.8	2.1	17.3
Assayer.....	57.9	6.5	2.3	33.8

*1939 figures represent the average weighted average dust exposure for each occupation.

REVIEW OF DUST CONTROL METHODS IN THE MINING INDUSTRY

Over 200 articles and U.S. Bureau of Mines circulars were reviewed for information on dust control techniques. This section presents abstracts of those articles which contain pertinent data on dust control systems and procedures. This information is intended to acquaint the mining community with systems and procedures which have been used to control dust. Aid in designing dust control systems is readily available from manufacturers of dust control equipment.

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ACGIH, Industrial Ventilation, A Manual of Recommended Practice, 1970.

The manual covers all types of industrial ventilation systems. Air cleaning devices for dust removal are described in detail in Section 11. Schematics of the devices are shown. Collection efficiencies of five basic types of devices are plotted against mass mean particle size. An idea of dust collector costs can be deduced if certain factors are known. A dollars per cfm (in thousands) cost chart is given. This manual can be very useful.

Anderson, D.M., "Dust Control Design by the Air Induction Technique", Industrial Medicine and Surgery, p 68-72, 1964.

This article discusses techniques used in the design of dust control ventilating systems for granular solid materials handling material operations, i.e., belt transfer, screening, crushing, etc.

The primary objective of the article is to review existing methods for estimating exhaust volumes and illustrate a new method in the design of dust control facilities. It is very difficult to specify the air volume to be exhausted and the location of ductwork for each unit operation. Author's method is based on an estimate of the air put in motion by falling materials.

A review is given of New York State rules based on the necessary exhaust volumes described in terms of "control velocity". This appears reasonable since most materials handling hoods are in the form of enclosures (not hoods). The control velocity in the N.Y. codes range from 150-200 fpm (for screen enclosure openings, belt enclosure openings, crushers, etc). But these control velocities covered only a few velocities, and an account had to be made of the air velocity put into motion by the action of the materials moving through the systems. Thus, the criteria for belt enclosures were written so that a minimum of 350-500 cfm per foot of belt width was required depending on belt speed. Bins required 0.5 cfm per ft³ of bin volume. Screens were rated at 50 cfm per ft² of screen area. All standards had to be met.

Vendors and engineers therefore designed effective dust control equipment by specifying high control velocities (400-500 fpm). These design velocities were needed to produce sufficient total exhaust volume to counteract the volume and pressure produced within the enclosures (inlet air downstream openings = 100-150 fpm).

The air induction method uses the formula, $Q_1 = 10.0 A_u \frac{RS^2}{D}$

where Q_1 is the induced airstream, A_u is the enclosure open area upstream (i.e., where air is induced into the system by the action of the falling material) in ft^2 , R is the rate of material flow in tons/hr, S is the height of fall in feet, D is the average material particle diameter in feet. Formula is limited, i.e., $D > 1/8$ in.

The author further describes the practical use of the induction formula in belt to belt, chute to belt, belt to bin, chute to bin transfers, screens, crushers.

The induction method was also used in the design of aboveground dust control systems of an iron ore mine and limestone and sand plant.

Anon., Silicosis in Metal and Coal Mines, Industrial Hygiene Aspects of Mining.

TLV's are calculated as follows:

For Particle Counts

$$TLV = \frac{250}{\% SiO_2 + 3} \text{ mppcf}$$

For Gravimetric Samples

$$TLV = \frac{10}{\% SiO_2 + 5} \text{ mg/m}^3$$

Drilling is the major dust exposure operation in underground mines. The second operation causing greatest exposure is in handling of broken rock and occurs during scaling, sampling, loading, scraping, pulling chutes, dumping, transferring and skip loading. Surface dust is dispersed during skip dumping, crushing, screening, conveying and grinding.

Basic methods of dust control are suppression, confinement, dilution and removal of dust. Suppression is best accomplished by wetting and control of compressed air. The best wetting procedure consists of use of a water blast during and following blasting, then fine spraying broken rock before and during loading and scraping.

Drilling dust dispersal can be minimized by restricting leakage of compressed air past the piston and down the hollow drill steel. Compressed air should not be used to clean mine cars, ditches or other rock surfaces.

Airborne dust should be confined by doors, enclosures and exhaust ventilation to maintain indrafts at all leakage paths. Dust escaping suppression and confinement must be diluted and removed from breathing areas by ventilating air. Auxiliary ventilation (fans and ducts) is needed in dead end excavations to sweep operating faces with fresh air at a velocity of 40-50 fpm. General ventilation through stopes and other large openings (at a velocity of 30-40 fpm) is needed for dust dilution and removal. Surges should be controlled using air velocities up to 175 fpm.

Ventilation engineering information is referenced. Special documents referred to are those of Hartman, Kingery and McElroy.

Ayer, H.E., "Proposed ACGIH Mass Limits for Quartz: Review and Evaluation", Am. Ind. Hyg. Assoc. J., p 117-125, March-April 1969.

The author believes that new cases of dust diseases are still developing even though control methods have been installed. Further dust control methods will be costly making it necessary that the method used for dust measurement and control be relevant to the health hazard.

The impinger method is irrelevant when dust agglomerates are present (redispersed dust) because clumps are removed in the upper respiratory tract. Dust escaping from wet processes are discrete, respirable size particles, and although counts may be lower, the hazard may be greater than for agglomerates.

The impinger method is also difficult to reproduce as operators differ in efficiency.

Other collecting instruments suffer some of the disadvantages as the impingers all have difficulties in reproducibility.

Light scattering single particle counters have a high range (100 mppcf) and agglomerates are properly counted as single large particles. Disadvantages include high initial cost, inability to discriminate between dust, smoke, mist and metal fume.

Size selective mass (respirable) concentration methods are desirable as they relate directly to dust health hazards, are reproducible, simple to use and unit cost is low.

Comparable sampling indicates that a respirable dust limit of 10/(% resp. quartz + 2) mg/m³ would be equivalent to the present impinger TLV. A total dust limit proposed is 30/(% quartz + 2) mg/m³. Either mass limit permits use of personal sampling techniques. Quartz analysis are made on the respirable fraction for the respirable limit, and on total dust for total dust limit.

Bardswick, W.A., et.al., "Trends in the Instrumental Assessment of Industrial Dustiness", C/M Bulletin for Oct. 1969, p 1045-1051.

The parameters of airborne mineral particles which create dustiness and the physiological hazards caused by inhalation are reviewed. Particles containing free silica and asbestos are the most hazardous. Some authorities believe that silica from freshly fractured surfaces are more hazardous than surfaces exposed for a longer period of time.

Various techniques of dust sampling are reviewed and analyzed and the above parameters are classified as a basis for methods of assessing the physical, chemical and mineralogical characteristics of dust particle suspensions.

The author surveys currently accepted methods of assessment and reviews other methods and new techniques being developed.

Beverly, R.G., and Bishop, V.J., "Air Sampling Limits Radiation Exposure in Colorado Uranium Mines", Mining Eng., p 962-65, Oct. 1961.

Union Carbide Nuclear Co. studied the problem of radiation control in all its underground mines in the Uravan area of Colorado. The company studied primary and secondary ventilation techniques in lowering the concentrations of radon gas decay products. Primary ventilation systems usually have axial flow adjustable blade fans, varying in capacity from 2500 cfm to 50,000 cfm. Secondary air distribution systems have auxiliary axial flow fans operating at 2500 to 20,000 cfm. In case studies, it took about one hour for the concentrations of radon gas decay products to be reduced to less than the recommended maximum working level. Some ore dust samples were taken. Total ore dust in the air is only 4 to 20% of the maximum permissible dose. Dust samples were taken and counted at least semiannually. Dust counts have usually been below the conservative safety limit of 5×10^6 particles per ft³.

Bureau of Mines, "Health and Miscellaneous Hazards at Metal and Nonmetallic Mines", Mines Circular 57, Metal and Nonmetallic Mine Accident Prevention Course, Section 7, June 1956.

Health hazards of respirable dust are detailed. Ranges of dust concentrations at various mine operations are given. Dust Control (wet methods) - Water is used in drilling, loading, handling and crushing rock ores. A tank car with spray nozzles is used to suppress dust in haulage drifts. Water curtains and misting nozzles are used on drifts and at exhaust duct outlets.

Wetting and washing down surfaces on which dust settles to cake and hold fine particles prevents redispersion of dust. Air water blasts are used for drifts and cross cuts. (Dry method) - Exhaust systems are used at fixed installations such as crushers or screens. Circulation of clean air through work spaces in sufficient volume to dilute suspended dust has been found to be effective in control. Split ventilation systems may be designed to remove dust from working faces and take it directly to return airways. Blower fans and tubing are needed to bring ventilating air close to the face at a velocity sufficient to sweep away dust as it forms.

Bureau of Mines, "Dust Control in Mining, Tunneling and Quarrying in the United States", Information Circular 7760, Oct. 1956.

Literature relating to dust control in 1953 and 1954 was summarized and reviewed in this report by the Bureau. Most material in this report was in regard to coal mines.

In 1953 noncoal mines were considering introduction of industrial hygiene departments; preparation plants were receiving more attention in regard to dust hazards. Many operators were unfamiliar with hazards. A table is given showing dust counts at preparation plants illustrating good and poor practices in dust control.

In rock loading and unloading operations, wetting muck piles before loading was stressed. Dust counts were markedly reduced by wetting as experiments proved. During transportation from quarries, dust can be reduced by wetting.

Fifty-six references are given.

Bureau of Mines, "Dust Control in Mining, Tunneling and Quarrying in the United States, 1955 Through 1957", Bureau of Mines Information Circular 8021, 1961.

Literature relating to dust control from 1955 through 1957 was summarized and reviewed in this report by the Bureau. Uranium mining presents special hazards: ventilation is recommended as the most practical method for reducing radiation exposure, but conventional methods of dust control must also be used. In open pit mining, the application of lignon sulfonate to road surfaces reduces dust of haulage roads. In tunneling operations, dust control methods consist of wet drilling, ventilating before men return to work after blasting and wetting muck pile before and during loading operations.

Wet drilling is widely used in hard rock metal mining if water is available. In the use of small scrapers in metal mining, dust is suppressed by a combination of sprays to keep muck wet and by ventilation to remove airborne dust despite sprays. Where ore quantities are large and sprays are not effective, increased ventilation is used to carry dust away to the surface through untravelled routes. Water and ventilation is used for dust control in mechanical ore loading operations.

It is recognized that sprays, of themselves, are not very effective in removing respirable dust particles, so the trend is toward spray equipment design to produce fog droplets. However, this does reduce visibility.

Electrostatic precipitation use is limited. Tests of wet centrifugal scrubbers were conducted. Conclusions were that wetting produces increased performance but optimum efficiency is achieved only by careful design. Specially designed dust collectors, used in an open pit diatomite mine reduced dust concentrations from 110×10^6 particles per ft^3 of air to 5×10^6 . Centrifugal blowers moved dusty air through a wire screen, surface-type filter impregnated with a special oil, in the primary stage, and through a special filter paper, as the secondary stage.

In stone crushing operations criteria for spray systems include: adequate and continuous water supply, drainage provision, sludge removal, enclosure, protection against freezing, and effective blanket of spray patterns. Spray systems should not be used as the only method of control if stone contains more than 10% free silica.

Reported efficiency of radon daughter filtration using glass fiber filters was only 60-70%. In ventilation practices, multiple entry systems are best. Auxiliary ventilation is used on noncoal mines. Small remote uranium mines use natural ventilation which does not effectively remove radon and decay particulates in air.

Mine equipment manufacturers developed a device for use in face operations in mining. This device provides exhaust ventilation at the face and conducts dusty air to a wet scrubber where dust is impinged upon a series of plates arranged around the internal periphery of a cylindrical housing. Wet sprays wet the plates continuously, and the collected dust is washed from plates and sludged out on the mine floor.

A bibliography of 57 references is given.

Bureau of Mines, "Dust Control in Mining, Tunneling and Quarrying in the United States, 1961 Through 1967", Bureau of Mines Information Circular 8407, March 1969.

Literature relating to dust control was summarized and reviewed from years 1961 to 1967 by the Bureau.

Medical studies conducted on men employed in various mining industries showed a significant reduction in silicosis as compared to earlier years before dust control methods were used. Dust concentrations were measured in lead-zinc mines in 1939 through 1967. A reduction of at least 80% and up to 90% in dust concentrations was indicated.

A dust control program resulting in a desirable environment for copper mine workers stressed the importance of positive ventilation in working areas, use of water for dust generation suppression, use of company-designed dust collection equipment to clean contaminated air for reuse. Compressed air and water blasts were used in sill headings to slow dust dispersion during and after blasting and to wet muck piles.

Proper ventilation is emphasized for control of dust and radiation exposures in uranium mines. References are given for a company practicing this control.

Recommendations for the nation's underground metal mining industry, relating to dust control are given.

In regard to water and wetting agents water is recognized as important for dust suppression. Wetting agents can increase effectiveness of water. The use of <0.5% moisture (by weight) suppressed gypsum rock dust at quarries and plants when wetting agent was added to water. Emulsified asphalt is a more effective agent than lagnon sulfonate for reducing dust on haulage roads at some open pit operations.

A method of dust suppression from dry percussion in quarries, construction sites and open pit mines was developed. Water with added wetting agent is introduced into the air used for flushing drill cuttings from the hole. Surfactant reduces amount of water needed. Proper amount of solution (7 gal/hr for 3-1/2" dia hole) caused drill cuttings to be blown from the hole as damp dust free pellets.

Treatment methods are given for suppression of deposited dust. Changes in some state mining laws are given.

Two hundred-three references are shown.

Bureau of Mines, "Controlling Employee Exposure to Alpha Radiation in Underground Uranium Mines", Vols. 1 & 2, 1970 and 1971.

Vol. 1 - This contains a general discussion of radon daughter control problems. Conventional dust control measures are effective as radon control measures because the finer the rock is broken, the more surface area is exposed, and the more radon released to the mine atmosphere.

Sealants (epoxy and P.E. resins) can be applied to rock and stoppings as coatings to limit entrance of radioactive contaminants into active mine atmospheres. Rock sealing is not widely practiced in the U.S. because its use is impractical. Seal stoppings are widely used with reduced being maintained behind sealed areas. Ventilation - Mines frequently use a split system requiring only one intake air development opening. Boreholes are equipped with exhaust fans which cause intake air to split from intake airway into each mining area and return to the surface. Secondary systems (fans and tubing) are usually relied upon in most uranium mines to move air into dead-ended workings or into open-ended parallel workings where primary systems do not reach. Air Quality Required - A formula is available for calculating the amount of air which must be added to lower radon daughter levels in a given environment. Filtration - Four of the larger companies have commenced applying filtration. Two types of filters are in use, one is a prefilter (fiberglass type) to remove particles 10μ and above, and the other is a final filter (pleated fiberglass paper) reported to be 95% efficient in removing particles 0.3μ in size. Air volumes cleaned averaged 2×10^3 - 3×10^3 cfm; air discharged into working area at only a few tenths of the working level compared with initial air at 3-5 working level. However, daughters develop quickly in the filtered air. Fans, velocities and pressure drops are discussed. Mine officials opinion is that filtration is an expedient way to purify air to make it reusable for a short period of time before exhausting it. Recycling filtered air is not practical unless radon gas buildup can be controlled. Air renewal is essential. Respirators - Half mask facepiece respirators are efficient, but are not a substitute for other control methods. Mine planning is heavily emphasized.

Canadian Mining Journal, "Dust Control at an Underground Loading Station", p 69-71, August 1959.

Methods are given for controlling dust at an underground loading station of a gold mine. Since fresh air is at the mine surface, dust sources were enclosed at the loading station, a dust filter installed and air recirculated. The discharge end of the conveyor is completely enclosed by a housing. Dusty air is drawn from it through a bag filter which is, in turn, connected to a fan exhausting 200 cfm. Bags are treated with "Cuprinol" to retard mildew; this increased bag life to 2-1/2 years.

Canadian Mining Journal, "Dust Control at Dumps and Passes", p 93-98, August 1959.

Article discusses problem areas in dust control at dumps and passes at Pronto uranium mine. An open ore pass became an up-casting airway parallel to the shaft and air entering the pass at one level could escape into the mine at another level. Ore falling down the pass created large quantities of airborne dust. Ore falling down the pass also created a back pressure. An upcasting airflow of 30,000 cfm was reversed at the same rate during dumping of a 6 car train from the level above. Secondary blasting at random also caused contamination complicated by clearing of blasting smoke coupled with surge effects mentioned. Some of the blasting smoke was carried into the main shaft by the mine ventilation resulting in poor air quality.

Control efforts included installation of control chains in the ore pass at the 4th level ending surge problems below the third level enabling subsequent steps to become effective. Ventilation doors were placed between the shaft and passes at all levels. Regulators installed in these doors allowed nominal airflow to the shaft. An exhaust fan of 30,000 cfm was installed at the surface of stockpile raise to keep an increased air current upcasting the ore pass. This reduced time lapse between surges and return to normal airflow. Ventilation doors used to isolate the ore pass grizzly from the mine were not very successful.

Better design factors were used when the mine shaft was deepened. Dust counts were greatly reduced after dumps were enclosed. Dust counts are given.

Canadian Mining Journal, "Dust Suppression at the Milliken Mine", p 48-53, Oct. 1963.

Controlled studies showed dust buildup in relation to stope positions, i.e., type, position and efficiency of water sprays, water pressure and percentage of wet, damp and dry muck.

Water sprays proved very effective and conditions for application are given. Schematics are shown. Areas such as dumps and passes, crusher (underground and surface), loading pocket, grinding were cleared of dust by good ventilation procedures and bag filters.

Canadian Mining Journal, "Fine Particle Dynamics and Dust Control", p 75-78, Oct. 1964.

Article discusses dust particle dynamics. Equations are given to determine particle distance and settling rate. Equations show

that fine dust particles have little or no mobility of their own but follow the air currents which carry them. Dust control problem is really controlling air currents around a particular process. The meaning of dust surges is explained as the main portion of dust entering atmosphere when falling material comes to rest and trapped air escapes. Hood design is discussed.

Canadian Mining Journal, "Dust Control at Ore and Waste Pass Ventilation Dumps", p 85-6, Oct. 1964.

Two large fans, one a 108 in. surface fan, another a 84 in. exhaust fan are used to maintain good levels of fresh air at all levels in a uranium mine. Early dust control at dumps was limited to installing doors on all dumps and exhausting dusty air from the ore pass system to the surface. Air was drawn up using a 30 in. fan at the top of the surface ore stockpile raise. The fan did not correct dusty conditions below the fifth level. Tests showed that connections between the ore and waste passes were important, as they acted as relief valves for surges of dusty air.

Canadian Mining Journal, "Control of Condensation in Dust Filters at Kerr Addison Mines", p 69-71, Oct. 1965.

A gold mine and milling operation in Ontario uses dust filters at various crushing stations located at the surface and at different mine depths. Surface crushing and screen house filters are used in conjunction with cyclone collectors which remove coarse particles so that only fine dust is carried to the filters. Bag life was excellent being about 3.5 years (bags are constructed of untreated cloth with no nap) until a reduction in crushing and screening time resulted in longer shutdown periods. The down time resulted in condensation problems. Rust formed on wire spacers between the bags; the rust left sharp points at the welds causing severe wear on the bags during the shaking cycle. The bags became mildewed. The problem was solved by warming the bag enclosures with electrical strip heaters.

Curtis, C.H., "The Esperanza Concentrator", Mine. Eng., p 1234-1239, Nov. 1961.

Various crushing, wet grinding and flotation operations of the copper and molybdenum ore are given. Dust control throughout crusher operations is achieved using multiple dust collecting units. Dust is controlled at the fine ore bin and attendant feeder belts to the wet grinding sections.

Wet grinding and flotation operations are independent. It is expected that wet grinding operations will be fully automatic. Detailed flowsheets are given of the concentrator.

Dowell Brochure, "Chemical Binder Solves Material Loss. Provides Dust Control".

Various types of wetting agents used to reduce dust in mining operations are described. F65 has been used largely in coal mining operations. F60 wetting agent is used to reduce dust in crushing, grinding, dumping and transfer of minerals. It is generally applied by mixing with water and spraying. Application: M145 binds particles together decreasing product losses.

Drysdale, A.O., "Canada Cement Co. Building Highly Automated Plant in Nova Scotia", Mine. Eng., p 81-86, April 1965.

This article describes a highly automated plant using central control panels to perform all operations of limestone crushing, grinding and raw material proportioning. The plant was designed about the rotating kiln. The four main operations in the kiln department are: kiln feed, fuel system, kiln burning and clinker cooling. About 30% of the kiln feed is dust collected by an electrostatic precipitator cleaning the kiln oven exhaust gases. Dust collection efficiency is about 99.5%, finer fractions are wasted. Raw feed and dust return will be controlled automatically.

Edmisten, N.G. and Bunyard, F.L., "A Systematic Procedure for Determining the Cost of Controlling Particulate Emissions from Industrial Sources", J. Air Pollution Control Assoc., 20, (7), p 446-452, July 1970.

This paper presents basic equipment costs and estimating factors for assessing the total cost of particulate emission control. A procedure is outlined for calculating total cost of various devices for collection of particulates.

A chart is given outlining the criteria for selection of various gas cleaning equipment such as: fabric filters, electrostatic precipitators, wet collectors, mechanical collectors and afterburners. Costs developed in this report are accurate to within $\pm 20\%$ of specific equipment costs and to within $\pm 50\%$ of total capital equipment.

Cost categories are the functions of: (1) capital investment, (2) operating and maintenance costs, and (3) capital charges.

Capital equipment costs largely include: (1) control hardware costs, (2) auxiliary equipment costs and (3) field installation costs.

Purchase cost curves are given for the various devices; collection efficiencies are taken into account as well as gas volume.

Auxiliary equipment and installation are included with the purchase cost; installation is given in a separate table expressed as % of the purchase cost.

Major cost categories and related conditions which establish total cost are presented.

Formulas for calculating maintenance are given.

Calculation of investment and annual costs are computed and given in the straight line method.

Federal Register, "Rules and Regulations, Metal and Nonmetallic Mine Safety", Vol. 37, No. 124, Tues., June 27, 1972.

The latest Federal regulations are in regard to procedures for obtaining variances to radon daughter exposure standards. Rules now in effect state that no variance will be allowed which will permit any person to receive a cumulative exposure in excess of 4 WLM per year. This exposure limit applies to persons and not to any condition at any point in time in the mine. Previously, miners could be exposed to an excess of 4 WLM if a respirator was worn. New regulations do not permit this. Men likely to be overexposed are required to wear appropriate protective equipment to prevent overexposure.

Harris, A.T., et.al., "Quartzite Mining and Processing Methods and Costs at the Honey Brook, Pa. Plant of George F. Pettinos Co.", Bureau of Mines Information Circular 8248, 1965.

Quartzite (amorphous silica) is mined by the open pit method and processed in a mill at the mine. The operation produces different grades of sand and one grade of crushed stone.

A schematic flowsheet of the crushing plant is shown. Mining operations consist of primary and secondary drilling and

blasting, loading and transporting rock to the mill. Stripping, primary drilling and blasting precedes mining. Secondary drilling, blasting, loading and transportation from mine to mill are considered as mining. The preceding operations are described.

A liquid dust control system using a proprietary chemical is proportionally fed by a pump and sprayed using nozzles during crushing operations. The amount of moisture varies inversely with the amount of moisture in the material being fed to the crushing plant. Screens within the plant are enclosed or isolated for further dust control.

Hershey, R.V., Dust Control and Dust Diseases, State of Arizona, Mine Inspector's Office, 1961.

The author provides a good medical background relating to dustborne lung diseases caused largely by silica. Carbon, limestone and marble dust can also produce lung diseases, but the disease is not as severe as in the case of silica dust. The quantity of dust may be more important than the type of dust in influencing the onset of dust fibrosis.

It is strongly believed that fresh broken dust particles have a much greater biological activity than weathered surfaces. Smaller dust particles remain a long time in suspension in air, (8 hr to fall 6 ft for 1μ still air particles, 5μ particles require 1 hr).

Major dust sources in metal mines in order of importance are: collaring and drilling holes for dry blasting; blasting, shoveling or mucking fine dry material at working face, loading cars from chutes, dumping loaded cars into chutes and timbering. Dry crushing in mills is dangerous.

Methods for reducing dust include: prevention of dust formation, ventilation, water sprays after blasting.

Practical steps to limit dust dispersion into the air are given.

In regard to dust control, the author analyzed dust samples at many operations in various mines throughout the state. General dust counts are given, as well as practical advice for dust control. Since this study was made during the years 1951-1961, it is of value in evaluating older practices in metal mining operations.

A chart is shown giving dust sample counts covering various operations for the 10 year period. However, individual mine dust counts are not given.

HEW, "Silicosis in the Metal Mining Industry: A Revaluation (1958-1961)", Bureau of Mines, 1963.

The contents of this book are very general and broad by nature of the scope of the project. Dust control measures are discussed in detail. Conclusions on dust production and control were:

1. Effective use of ventilating currents in the working areas was indicated as a problem needing prompt attention.
2. Water applied to muck piles is effective in reducing dust concentration.
3. Drilling, slushing and crusher operations produced the most dust.
4. Dust concentration in shops is not a problem, except in cleanup operations.
5. Better dust control methods are needed around crushers and concentrate loading.
6. Ventilation is inadequate during welding.

A great deal of statistical and medical information is given.

Hewitt, D.F., et.al., Asbestos in Ontario, Department of Mines, Ontario, Industrial Mineral Circular No. 1, April 1953.

Mining operations are discussed and flowsheets of mills are given. Air discharged from fans is conducted to a settling chamber constructed in the form of a shed in which burlap baffles assist in removal of dust before discharge to atmosphere. These were not very efficient, and are being supplemented by filtration or precipitation. Some plants use electrical precipitation, others use bag filters. Multiple units are built so that air can be diverted periodically by a timing device and at the same time the bags shaken mechanically to dislodge the layer of accumulated dust. Accepted practice is to have sufficient fabric area so that not more than 4-5 ft³/min of free air is being filtered per ft² of fabric. A mill treating 3x10³-4x10³ tons/day and exhausting ~5x10⁶ ft³/min of free air requires an extensive filter system.

Huggins, C.L., "Use of Venturi Blowers to Reduce Dust in Raises at Dome Mines Limited", Canadian Mining Journal, p 66-70, Oct. 1962.

The author describes and recommends the use of a modified Venturi blower to reduce dust in raises (particularly over 25 ft) of mines. Description of the Venturi blower and ducting is given. When fresh air is not available from the bottom of the raise, the Venturi is connected to auxiliary ventilation pipe to supply air.

Konimeter dust counts are given as:

Average Dust Count - 500 spot tests

<u>Venturi</u>	<u>No Venturi</u>	<u>% Reduction</u>	<u>Overall Time</u>
792	409	48.4	3 yr

International Labour Office, "The Prevention and Separation of Dust in Mining, Tunnelling and Quarrying", Third International Report, 1958-1962, Geneva, 1966.

Dust Prevention and Suppression Practices (U.S.) - A brief review of practices and progress achieved since 1958 showed the following:

1. Blasting is done with water tamping or else at the end of the shift in iron mines. If ore is not naturally damp it is wetted during loading. Dust respirators are used when drilling holes for roof bolts.
2. In metal mines wet drilling and wetting of loose materials is practiced.
3. Slate quarries practice wet drilling in all rock tunnels and approximately half of the faces where blasting is done at the end of the shift. Respirators are available but the risk is not great in these quarries.

Tunnels - Dust dispersion is caused by drilling, blasting and mucking. Reduction of dust is achieved by wet working. Water feed machines are used for drilling. Advantages of wetting agents are questionable. In blasting, the trend is toward improving blasting patterns to get more work done using less explosives. Screens of water spray have not been effective. The use of water cartridges for tamping shot holes appears to be effective in producing aerosols which capture dust and hasten precipitation.

In mucking, loose rock is watered with a hose as are dry tunnel walls.

Dust Evacuation - Dust evacuation is begun immediately after blasting. Two lines of ducting are used, carried close to the heading but far enough away to prevent blast damage. One line carries forced air, the other exhaust air. Auxiliary tunnels are used as main return airways. Sometimes subsidiary tunnels are driven running into return tunnels and these facilitate dust evacuation. Sometimes upcast or downcast ventilation shafts insure more rational ventilation of most of the working area. Auxiliary ventilation can be used to lower tunnel temperature facilitating precipitation of dust. Equipment consists of a fan to propel air into cooling equipment, and cold water sprays that cause air to fog, thus wetting and precipitating dust.

Personnel Protection - Measures comprise use of dust respirators and medical exams.

Radiation Control - Company programs are described by Beverly (1961) "Radidation Control in Uranium Mines and Mills", and "Air Sampling Limits Radiation Exposure in Colorado Uranium Mines". A dust control program for a copper mine is described by Laird (1961), "Prac. Dust Control". The latter paper stresses positive ventilation in working areas for dilution of airborne dust, and use of water for suppressing dust generation. Company designed dust collectors permit air to be reused. Compressed air and water blasts (in sill headings) minimize dust dispersion during and after blasting, and effectively wet muck piles.

Water - Wetting ore or rock continues to be the most common practice for dust suppression. Underground, ventilation supplements water use and reduces airborne dust concentration to acceptable limits.

Wetting Agents - The use of <0.5% moisture was required to suppress gypsum-rock dust at quarries and plants when a surface active agent was added to water.

Drilling - Wet drilling is most common practice for dust control in hard rock mining and tunnelling. Water does not completely suppress drill dust, ventilation is required in working areas to keep dust within MAC limits. New drills (pneumatic percussion) collect drill dust efficiently and can be used where water supply is short.

Sampling, Measurement and Analyses - Midget impinger is used as the basic sampling instrument for measuring exposure to airborne mineral dusts. Allowable exposures are limited by the free silica content. X-ray diffraction is used for determining free

silica content. High volume samplers are used for collecting airborne dust. Other instruments were tested.

Jarrett, S.M., "At Braden Copper - Safety Means Economy", Mining Eng., p 1116-1119, Nov. 1959.

Airborne dust was analyzed by x-ray diffraction to determine the free silica content in the -5μ portion. A program was established to reduce dust concentration to below 5×10^6 particles of free silica per ft^3 of air. Results of analyses not given prior to dust control. Control measures - mechanically controlled mine ventilation was installed and new adits were driven to improve ventilation. Fresh air was drawn through portals and distributed to all underground workings by fans with capacities of 5×10^4 - 1.7×10^5 cfm. Ventilation of each level was kept independent of others and production areas have independent fresh air supplies. Air splits, ventilation doors and auxiliary fans were used to prevent recirculation of contaminated air. Methods used to prevent dust dispersion from ore transfer and blasting includes all wet drilling, wet down of all working places and muck piles, use of air water sprays in development and undercutting. Blasting and undercutting are done at the end of a shift.

Johnson-March Corp., Chem-Jet Dust Suppression, Brochure.

Descriptive literature on bag filters and dust suppressants (wetting agents).

Jones, H.R., Fine Dust and Particulates Removal, Noyes Data Corp., 1972.

This book covers the entire field of particulate removal. A useful table gives total emissions from various sources, efficiencies and application of control systems. A chapter is devoted to particle size characteristics and includes tables ranking particles on their contribution to objectionable characteristics.

Control equipment is fully discussed and vendors addresses given. The economics of control and disposal of particulates are covered; parameters such as gas volume, purchase cost, installation and annualized costs are plotted against gas volume and other variables.

A separate chapter covers the Stone, Sand, Gravel, Cement and Clay Industry and is very important to this study, particularly as open pit (quarrying) and mill operations are common to other types of mines.

Journal of the Mine Ventilation Society of South Africa, "Control of Dust in an Underground Crushing Station at the New Broken Hill Consolidated Limited Mine, Australia", p 223-233, Nov. 1961.

This very informative article discusses the successful methods used to control dust in an underground crushing station receiving ore from zinc and lead mines. The crusher started operating in 1955 and dust control methods were very effective. A second crusher now being considered (1961) will contain more simplified dust control filters as a result of experience with the existing crusher. The article details mining methods, ventilation, description of ore and rock, dust control problems, choice of dust extraction equipment, description of dust bag filters and auxiliary equipment, ventilation, dust counts performed and equipment used, pressures and flows at various station points and proposed modifications for a second crusher. Schematics of crusher and dust filter layout, details of dust bags and viscous traveling curtain after filter are given.

Each section of the plant where dust was created was enclosed and placed under negative pressure.

Filtration equipment specifications called for a plant to handle 10,000 ft³/min and cleaned air could not contain more than 180 particles per cc. Extensive underground tests showed that about 96% of particles in mine air were -5μ . Preliminary dust counts of exhaust air from the surface crusher plant after passing through a Roto-Clone hydrostatic precipitator (American Air Filter Co., Inc. Type "N" Size 20) averaged 90 ppcc over an operating shift. Flannel bag filters at one of the ore tips were enclosed inside length of ducting and dust counts taken in air leaving the ducting. Under severe dust loading the filtered air contained an average of 53 ppcc. A Westinghouse "Continental" type viscous traveling curtain filter was used as an after filter.

The flannel bag filter system (enclosed in an air tight chamber) was comprised of 18 bags, each 18 in. diameter and 7 ft, 6 in. long. Cloth is 30-30 weave high grade flannel. The dust fan (Richardson No. 4-1/2 Radial Blade Centrifugal Fan, 1090 rpm, 9000 cfm at 8 in. W.G.) exhausts air from the bag chamber; maximum velocity through cloth never exceeds 25 fpm (14,800 cfm).

Ventilation fan velocities at various points are given in detail.

Dust counts showed that the after filter was of limited value. Dust counts without bag filters averaged 3500 ppcc. Dust counts using single bags ranged from 35-60 ppcc at various location points in and about the crusher. Pressure differentials across bags and air velocities in exhaust ducts are given.

Proposed modifications for a second crusher suggests elimination of the viscous curtain after filter in favor of a two stage bag filter, making the bag chamber semi-portable, use of 8 in. dia bags, include an automatic bag shaker, modify make-up of bag collars, use of terylene bags with an inside napped surface.

Kane, J.M., "Guides in Dust Collector Selection", Heat. & Vent., Oct. 1954.

The author states that the choice of dust collection equipment be governed by the following:

1. On the basis of known and recognized collector design for the particular problem, or
2. An evaluation of the dust characteristics, the carrier gas stream characteristics, and requirements of the dust control device.

Regarding (2), a check list of information required and decisions to be made for a solution to a specific dust collector application include: dust characteristic of particle size and range, concentration, abrasive characteristic of dust (particle size is most important as smaller particles are more abrasive) - (use a pre-filter for larger particles), bridging characteristics, fire or explosion hazard, foreign materials, corrosive gases.

Gas Stream Characteristics - The total volume of gas to be cleaned will influence collector selection in several ways such as: unit collectors should be used for small systems (few thousand cfm), large volumes from numerous sources will be broken into several smaller systems, since dust collector systems effectively decrease with size; costs rule out some designs, gas temperature, fabric collectors are only good for temperatures of about 170-180°F; high vapor content can harm some collectors.

An outline of dust collector characteristics is given in a table showing that in the 1-10 μ range, and taking into account all variables, fabric collectors are best, followed by wet collectors. Electrostatic precipitation is fair followed by high efficiency centrifugals and cyclones.

A table shows that in metal mining, fabrics are the method of choice.

Kingery, D.S., "Introduction to Mine Ventilating Principles and Practices", Bureau of Mines Bulletin 589, 1960.

This bulletin explains the basic laws and fundamentals of mine airflow and their application to the solution of ventilating problems. This manual presents a practical guide to mine ventilation problems.

Kingery, D.S., et.al., "Studies on the Control of Respirable Coal Mine Dust by Ventilation", Bureau of Mines Technical Progress Report No. 19, Oct. 1969.

Studies conducted at five mines (using continuous mining machines) show reductions in dust concentration can be attained by increasing the volume of air movement across the face and by control of the airflow pattern.

In experimental systems, an airflow near 100 fpm across the entry was maintained; this reduced the concentration of respirable dust by factors as large as 6.4. Face generated dust concentrations were reduced below 3 mg/m³. Conclusions reached were that controlled face ventilation using a high pressure auxiliary fan with other components will greatly reduce concentration of respirable dust at the working face of underground mines. An airflow of 70-100 fpm maintained across the entry resulted in an average respirable dust concentration (at the continuous miner) of <3 mg/m³. For a system to be most effective, dust controls must be applied to all dust generating points in the incoming air passages.

Engineering studies showed that the desired entry velocity could be achieved using a high pressure auxiliary fan and by maintaining the end of the exhaust tubing ~5 ft from the face. This was supported by the concept that airflow at the face confines coal mine dust generated ahead of the operator and captures dust particles. Dust can be then transported by the system and discharged into the return entry, where it can be treated or collected.

The method of investigation centered on the use of a 60 HP auxiliary fan. The theory for the control of coal mine dust is that dust particle <10 μ behaves like a gas and the control of respirable dust is a function of the volume and velocity of air moving across the coal face. In addition, the zone of contaminated air must be maintained as close to the face as possible.

Previously established methane control airflow patterns were used to determine that exhausting air from the face in sufficient volume to assure a sustained velocity near 100 fpm across the entry would result in minimizing the concentration of respirable dust. Diagrams also showed the need for maintaining tubing within 5 ft of the coal face. Experiments related HP requirements to air velocity and air volume under different operating conditions. From this data it was calculated that entries having a 56 ft² area, a 15 HP high pressure auxiliary fan used with a 20 in. dia tubing was needed. For 96 ft entries, a 30 HP fan used with 24 in. tubing would be required to obtain the same results. Noncollapsible tubing is needed because of the high exhaust pressures.

For an effective ventilation system certain criteria must be met:

- a. Intake to exhaust system must be maintained within 5' of the face, volume of air must be adequate to provide a minimum velocity of 70 fpm across the entry.
- b. Recirculation of methane and respirable dust must be prevented by insuring that the volume of air being delivered to the cross-cut is in excess of the demand of the exhaust system.
- c. Coal must not be allowed to accumulate at the tail of the mining machine which would restrict airflow.
- d. Incoming air must be nearly free of dust.

Kingery, D.S., "Water Gauge, Anemometer and Tape", Coal Mining and Processing, p 54-56, June 1972.

A technique is described for making a quick evaluation of primary mine ventilation efficiency. The technique is based on the determination of actual ventilating pressures existing between intake and return air courses measured with a water gauge.

The data, in conjunction with calculated pressure losses and air quantity measurements, can be used to determine ventilation deficiencies.

Survey procedures and air quantity determinations are given. Examples are given and calculations shown for determining ventilation efficiency.

Mining Association of Canada, "Design Guidelines for Dust Control at Mine Shafts and Surface Operations", Draft No. 3, August 1971.

This is a manual in which general and specific guidelines are given for use in design of effective installations to control dust. The guide gives stepwise instructions for control at various ore handling operations and facilities in and around a mine shaft, and dry reduction processes on the surface.

Note: Guidelines are too brief, although good schematics are given. Emphasis is on confining rather than collecting dust to prevent inhalation.

Mining Eng., "The New Butte Concentrator--A Reality", p 58-68, May 1964.

Crushing, grinding and flotation operations are described for this copper ore open pit mine. Coarse ore is crushed to 8 in. by a jaw crusher in the primary crusher, stockpiled, then fed to the secondary crusher which reduces ore to <1 in. This is conveyed to fine ore bins for rod mill feed. Dust control is extensive. Each piece of equipment is interlocked with the one following it, except for the crushers.

Nelson, K.W., "Control of Dust by Water Mists", reprint from A.M.A. Archives of Ind. Hyg. & Occupational Med., 4, p 25-31, July 1951.

Dustiness in crushing operations can be greatly reduced by adding mists from pneumatic atomizing nozzles to dust sources. Wetted particles settle near the source instead of being dispersed. Crushed material is surface-moistened only.

Phimister, G., "Ventilation and Dust Control in an Underground Crushing-Conveying System", Journal of the Mine Ventilation Society of South Africa, p 1-10, Jan. 1963.

The author describes an underground crushing and conveying system in a large underground copper mine. The dust control and filtration methods are discussed. The ventilation system consists of a main shaft exhaust fan, local exhaust fans at dust-producing points discharging air through filters and a large volume low pressure centrifugal fan (capacity 110,000 cfm at 1.5 in. W.G.) positioned at the top of the conveyor ventilation raise, to prevent too great a recirculation of filtered air. Total air volume is 330,000 cfm.

Dust control systems are located at main tips, crushers, conveyor transfer points and shaft loading boxes. The systems entail: enclosure of the dust-producing process, local ventilation exhaust systems creating negative pressure and all air leakage is in-leakage, filtration and dilution of vitiated air.

Jaw crushers are ventilated with centrifugal-type fans (capacity 30,000 cfm at 10.0 in. W.G.). The crusher is almost totally enclosed, the dusty air from each crusher is exhausted and ducted to individual return air raises linked to a common collecting trunk. Three chambers from this trunk are evacuated and each chamber houses a filter unit and fan; 90,000 cfm of air is returned and filtered for the three chambers.

Axial flow fans (19 in.) are used for ventilation and dust control at conveyor belt discharge points; 6,000 cfm is exhausted and air is filtered. Fishtail exhaust ducts are placed close to transfer points.

The storage pocket is enclosed. Other dust producing points, reclaim systems, cross-conveyors, main tips, and shaft loading boxes are exhausted using axial flow fans. Dusty air is ducted and filtered.

Water atomizers spray water at a transfer belt, crusher discharge chutes and other belt points. Water is not added to the ore stream since mud and spillage would occur.

Flannel bags are used to filter air and are preferred over mechanical and electrostatic filters. Bag life is given and varies according to where they are used. Air velocity through bags does not exceed 26 fpm.

Coconut-matting screens are effective prefilters.

Later events in the history of the mine indicated that a direct return ventilation system was more economical than filtration.

Preston, G.T., Dust Control in Underground Mines, Garrett Research & Development Co.

Research work was done to evaluate types of commercially available dust collection equipment. The methodology was to analyze the fundamental mechanisms by which dust collection devices operate, to model these mechanisms mathematically and to test representative commercial devices to prove or disprove the models. The respirable dust fraction was analyzed. Of the basic mechanisms (gravity, inertia, diffusion, electrostatic

attraction, porous filtration, radiation, magnetism, and agglomeration) only inertia and porous filtration are technically feasible in a mine. Because of space limitations, inertial is the most promising.

The object of the experiments were to model the potentially applicable inertial systems and to test collection devices which used these mechanisms to confirm or disprove the models, i.e., to determine applicability of device to collect dust and to determine if existing theories are adequate to describe the performance of devices using these mechanisms.

Mathematical models were developed and dust tests performed on: a multiple cyclone dry collector, a packed bed scrubber, a wetted screen collector, an impingement scrubber, a venturi collector.

The test apparatus consisted of a dust feeder, air intake and mixing stage, upstream and downstream ducts and a 700 cfm blower. The blower exhausted to a cyclone to remove larger particles ($>5\mu$).

Test results indicated that currently available knowledge of dust collection mechanisms is adequate to explain performance and provide basis for design of dust collection systems. In regard to applicability, tests indicate: a dry centrifugal collector can not perform adequately; wet dynamic dust collectors depending on curved passages, impaction on wires, or fibers, or impingement on solid or liquid may meet current needs if operated at optimum conditions, and if dust content is not too high. A high-energy venturi scrubber will satisfy current and future dust loading standards. However, disadvantages are a high pressure drop, large water requirements and large size.

Robbins, H.E., et.al., "Development of El Salvador Mine, Mining Eng., p 350-374, April 1960.

Article describes all aspects of the development of the Andes Copper Mining Co. mine at El Salvador. Safety is stressed by the parent company. Molybdenum also occurs in the ore body. Schematics of the general plant layout, flowsheets describing materials handling plan of crushing plant, concentrator, flotation section, etc. are given.

Dust control systems are treated as part of the crusher and conveying operations. Wet fan scrubber tower type collectors are used throughout the plant. These were used because efficiency is high and dust can be disposed of in the concentrator mill circuit. Water sprays are used at the outdoor dumping pocket. Dust

control systems were unitized to correspond to the grouping of plant equipment. Ventilation fan velocities are given for the various crushing operations.

Sargent, G.D., Dust Collection Equipment, Chem. Eng., p 130-150, Jan. 27, 1969.

This article describes many types of dust collection equipment giving illustrations, principles of operation, and comments regarding engineering data. This data includes advantages and disadvantages of the equipment, performance, efficiencies, rough costs. An equipment applications table simplifies a review of the whole collector field. Descriptions, illustrations, and efficiency curves are given and can be used with the table to select the proper equipment.

Segsworth, V.K., "Modern Ventilation and Dust Control", E/MJ, p 97-99, Feb. 1970.

This article details the dust and ventilation control methods used at a modern nickel ore crushing and concentrating plant. While nickel does not come under contract study, controls methods used here may be useful for control at other ore crushing and concentrating plants.

The Frood-Strobie Plant (Canada) was built in 1967 and designed to control contaminants. Control was accomplished by enclosing and venting sources of dust dispersal and providing continuous air supply of makeup air sufficient to change the air in the mill completely four times per hour and five times per hour in the crushing plant; 270,000 cfm outside makeup air is required for the mill, 120,000 cfm is necessary for the crushing plant. This is the amount normally supplied to a mine producing ore at 10,000 TPD.

Direct fired fan heater units were used to bring the full volume of outside air into the mill. These gas fired air heaters range from 4×10^6 Btu per hr unit handling 47,000 cfm of outside air to small units.

Exhaust air escapes from the mill through one large roof ventilator over the grinding aisle and a second large vent over the fine ore bins.

In the crushing plant, all belt dumps, screens and the crusher feed and discharge plants are enclosed and vented to a single bag type dust collector with a capacity of 60,000 cfm.

Ducts are sized for a velocity of 3500-4000 fpm to prevent settling of coarse dust. The baghouse exhaust fan is a high pressure vane-axial unit. Undersize material from water washed screens passes to a sump and is plumbed directly to the mill grinding circuit. This is done to reduce percent of fines to mill feed and moisture to the mill feed to the point where dusting from belt dumps, tripper and bin is moderate. Collected dust from the bag collector is passed to the sump and pumped to the mill with the undersize.

Dust producing points in the concentrator are sealed using a system of covers to keep bins indraft. Air is drawn from tops of bins to a 40,000 cfm bag filter. The baghouse also has an axial exhaust fan and returns clean air to the atmosphere over the grinding mills. Dust producing points in the plant are hooded, then ducted through baghouses.

The crushing plant baghouse has an air to cloth ratio of 6.16:1 and a velocity through the cloth of 6.16 ft/min. The main mill collector has an air cloth ratio of 4.96:1. Heavy weight, heavy nap 100% terylene cloth is used. Dust counts from the filter are usually below 100 ppcc and bags have not needed to be replaced after 7 years of continuous severe operation.

The efficiency of a dust filter in cleaning air is a function of the static charge induced in that cloth by the air flow through it. Terylene or dacron are very effective, cotton is poor and wool is intermediate.

Dust control for the sample preparation plant is provided by a separate 5400 cfm bag filter; cleaned air is returned to the mill. Fume hoods with exhaust fans discharging to the atmosphere are used in the laboratory. A small 2000 cfm bag filter to ventilate the belt dump, screens and loading points are used at the belt transfer house. A direct fired fan and heater unit (capacity 9000 cfm) provides makeup air for the transfer house. Electric switch rooms are ventilated and cooled with outside air filtered through rolled media filters.

The sample crushing and splitting tower has a separate dust control system venting all dust producing equipment to a 20 inch diameter duct leading to the main mill baghouse. All bag filters are shaken intermittently by manual control. Dust is passed through a conveyor to a repulping plant.

Seiler, P.E., "Efficiency and Practicality", Air Conditioning, Heating and Ventilating.

Collection efficiencies of various particulate removal devices are plotted against particle sizes. Rough comparisons of some of the devices are made.

Skillins Mining Review, "Dust Control System at Black Rives Falls", p 7, March 11, 1972.

A Chem-jet dust control system was installed at an iron ore crushing plant of Inland Steel Company. The system involves spraying the crushed ore with a wetting agent. Article reports that this system produces good dust suppression, requires less water and prevents freezing problems.

State of Arizona, Mining Code, Jan. 1971.

Dust prevention practices include ventilation, suction or exhaust methods of dust removal, wet dust settling methods, and use of respirators when exposure conditions are temporary or intermittent. A table of hazardous dust limits is given which includes:

<u>Toxic Dust</u>		<u>Mineral Dusts</u>	
<u>Name</u>	<u>mg/m³ of Air</u>	<u>Name</u>	<u>Million part.per ft³ of Air</u>
Lead	0.15	Asbestos	5
Uranium (sol)	0.05	Dust with no free silica	50
Uranium (in sol)	0.25	Mica <5% free silica	20
		Cement	50
		Talc	20
		<u>Silica</u>	
		>50% free SiO ₂	5
		5-50% free SiO ₂	10
		<5% free SiO ₂	50
		Slate	50

Power drilling, producing dust, must be controlled by wet drilling, spraying or approved dust catching devices.

Haulage roadways and banks where equipment is working must be maintained and provisions made for controlling dust.

Rules for ventilation are given.

State of Missouri, Mine Inspection Laws, 1967.

State inspectors examine noncoal mines for dust concentrations deemed injurious to health. If MAC concentrations of dust are found, owners must install a water line. Mine faces, surfaces and drill holes must be kept wet to prevent dispersion of dust.

State of Wyoming, 1969.

Ventilation requirements are detailed. Noncoal mine regulations are not set forth specifically but are included as part of mine regulations in general.

St. Pierre, G.R., The Use of Semi-Rigid Polyethylene Pipe in Auxiliary Mine Ventilation, Canadian Mining Journal, p 76-78, Oct. 1965.

At the Macassa Gold Mine, it was necessary to ventilate raises for cooling, reduction of blasting fumes and dust suppression. This is a deep mine with new levels below 5600 ft.

Six-inch polyethylene pipe was used in raises under varying conditions. The pipe was found to be very durable and well suited for this use. The air supply should be nearly dust free and a minimum of 20 cfm of air per ft² of working area is required, with air sweeping the immediate working area. Dust concentrations will thus be reduced. A heavy duty fan between 6-12 in. in size, and capable of delivering 1000 cfm of air at 9 in. static pressure, using 6 in. pipe, is recommended.

Auxiliary ventilation of development headings - 12 in. dia. polyethylene pipe was found to be much better than galvanized or plastic tubing for auxiliary heading. A 12 in. fan was used in conjunction with the duct. The inlet brought in fresh air from below the level and the discharge was kept within 30 ft. of the face. With air blowing, blasting did not damage the system. Pipe couplings consisted of a push-on sleeve type which was satisfactory. The pipe can be used in either a blowing or exhausting system and has some flexibility. Long pipe lengths should be joined by heat sealing resulting in a leak proof system.

Dust samples were taken (Konimeter) where pipe was used in ventilation of raises. During the drilling cycle with the pipe below the drilling platform the dust concentration was reduced from 1000+ ppcc to 830 ppcc. When the pipe was extended to the drilling platform, dust was reduced from 1000+ ppcc to 487 ppcc.

Further testing indicated that duct should be no more than 50 ft from the working face. At 30 ft, or less, fan delivery could be reduced.

Thomte, W.L., "The Story of the Erie Mining Co.--Mining the Taconite", Mine. Eng., p 39-52, May 1963.

Iron ore mining and milling operations of the Erie Mining Company's plant in the Mesabi range near Duluth are described.

Stripping - Jet and rock drills are used to strip rock. Shovels remove the rock with the soft overburden being removed by trucks and the rock goes by rail.

Drilling - Rock is very hard and abrasive making it necessary to use jet drilling. In this method fuel oil is burned with O₂ to produce a temperature of 4250°F. The water cooled burner causes a spalling action on taconite, the rock fragments are expelled from the hole by steam formed.

Blasting - A blast width of 76 ft is caused by the pattern. Blast length is from 1200-2500 ft. Powder factor is 0.7# of explosive per ton of rock broken.

Milling - Crushing, grinding and concentrating the taconite ore into a suitable feed for the pelletizing operation is a function of the ore dressing department. Magnetite is recovered. Coarse crushing is handled by one man. The dust collection system is both wet and dry, with a total capacity of 250,000 cfm. The dust collected is slurried and pumped to the concentrator where the iron units are recovered. The control system holds the dust count below 5 ppm. Vibrating feeders, located under the coarse ore bins feed the ore by conveyor into the crusher units. Ore is crushed to less than 1 in. in size. A small surge bin is located under each crusher; from these bins vibrating feeders draw material to feed the vibrating screen ahead of two shorthead crushers. The fine crushing plant and conveyor system taking the ore from the fine crushers to the fine ore bins located ahead of the mill lines are automatically controlled.

Concentrator - This includes fine ore bins, grinding and concentrating sections, pumping, equipment and power and water distribution control centers.

Yourt, G.R., "Mine Air Conditions--Scrupulous Care Needed", Canadian Mining Journal, p 134-138, June 1957.

Instructions are given for engineers on how to survey mine

air conditions. These include mapping, airflow measuring instruments, contaminant measuring instruments and tabulations.

Yourt, G.R., et.al., "Tests on Drill Dust", Canadian Mining and Metallurgical Bulletin, p 5-8, 1957.

A field study was made to reassess the dust dispersal characteristics of various kinds of percussion drills so that users and manufacturers would have a guide to maintenance of good air conditions. Tests were done underground in quartz-porphry. A summary of suggested practices include:

1. Collar all holes at beginning of a drilling cycle using automatic air and water throttles without hand controls. Adjust throttle gradually.
2. Drill holes a few degrees below the horizontal.
3. Adopt features in drilling equipment which:
 - a. Facilitate maximum delivery of water to the cutting edges of the bit and wetting of dust before it leaves the hole.
 - b. Prevent leakage of compressed air from the rock drill through the rod to the bit.
 - c. Do not use dull bits.
 - d. Use the smallest bits suitable for the drilling that is to be done.

SURVEY OF CURRENT DUST CONTROL METHODS IN METAL MINES AND PROCESSING PLANTS

During this study, 24 underground mines, 28 open pit mines and 51 processing plants were visited. Each visit involved a preliminary interview with one or more members of the mine operating staff to determine what dust problems existed and what dust control measures were being employed. This was followed by a tour of the mines and processing plants to observe the dust control systems or methods being used.

Most of the underground mines were hard rock mines using conventional drilling and blasting methods. A few mines were soft minerals where mining machines were used. The natural moisture content of the ore was a major variable from mine to mine, hence the amount of water required to control dust at an acceptable level varied. The amount of water which could be used was also a function of the type of mineral being mined. For example, water was used extensively in copper mining while little water was used in mining water-soluble trona.

A brief summary of the problems and methods of dust control used at each mine and processing plant follows. Each mine has been given a code number to protect the identity of the mine.

Asbestos

A-1 - A-1 is an open pit mine. The equipment used in the mine (shovels, dozers, graders, trucks) are fitted with a positive pressure filtration system. The system has provisions for heating or cooling the incoming air, and weighs 280 lbs. Filters in the system are changed daily.

Primary drilling is done with a Saunders cyclone drill fitted with a baghouse to collect the dust which is generated. Dust generated during secondary drilling of large boulders is controlled with water.

All material is processed in a dry state, but the plant is being renovated to allow wet grinding (rod mill) followed by drying. Operator rooms are pressured to 0.5 in.

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water with filtered air. All workers outside of the control room must wear respirators. The workers pick up a respirator at the beginning of a shift and return them at the end of the shift. The company cleans, sterilizes, replaces the filter and packages the clean respirator in a sealed plastic bag for reuse.

Dust generating sources are hooded or enclosed and the dust is collected in baghouses. Clean-up of fugitive dust in the plant is accomplished with a centralized vacuum system using 30 ft long hoses at the intake. Fines from the baghouses and vacuum system are bagged and submerged in the tailings ponds.

The finished product is transported to a loading point in covered trucks. The material is then loaded into railroad cars. A dust collecting hood with rubber skirting is placed over the loading port of the hopper car and maintained under negative pressure. A baghouse is used to collect the dust. All filling operations are controlled from a filtered and pressurized operator's booth.

Dust samples are taken on a monthly basis at all critical dust areas. In addition, the U.S. Bureau of Mines conduct a semi-annual dust inspection.

A-2 - A-2 is an open pit mine. Dry drilling is used in the quarry, and the drills are fitted Rotoclone dust collectors. Respirators were provided for the quarry workers, but their usage is not mandatory. No provision is made to supply filtered air to the driller, dozer or truck cabs. Haulage roads from the quarry to the plant are not wetted down, but the road beds are crushed stone so it is unlikely that asbestos fibers become airborne as a result of traffic on these roads.

The mill is composed of 5 floors, and material is transferred by belt, gravity or air aspiration. At the time of the visit, a major overhaul in dust abatement and control equipment and procedures had been instituted. A group of 2 technicians, 4 maintenance men and a part-time engineer had been assigned to the problem. An attempt was being made to completely enclose all dust sources such as conveyor belts, crushers and shaker screens. These enclosures were being maintained under negative pressure and exhausted to baghouse collectors. Although the renovation had not been completed it was estimated that the fiber count throughout the plant had been reduced by 50%.

Each floor of the mill is divided into seven sampling zones according to the type of operation being performed in any given zone. Every zone is monitored each week and a current fiber level is derived by averaging the previous week's value plus twice the current value. On this basis, respirators are mandatory in zones where the fiber level is greater than 5 fibers/ml. These zones are posted at entries to each floor. In addition to providing personal protection when needed, this method of zoning aids in isolating problem areas. Sterilized, clean respirators are provided for the employees each day.

Fugitive dust was noted on all beams, ledges and support members. In addition, piles of dust were observed on the floors. Floors are swept with dry push brooms at least once per shift. Management felt that mobile vacuum sweepers created more of a dust problem than hand sweeping, but management also recognized that neither method was satisfactory so a control vacuum system was being installed.

Samples are taken on a weekly basis. There are 60-70 personal samples (membrane filters) and 50 area (impinger) samples taken.

A-3 - A-3 is an underground asbestos mine. The material is mined by conventional methods. No water is used during drilling, and ventilation is the only method used to control dust in the mine. A recent survey by the U.S. Bureau of Mines on high risk workers (driller, miner, trammer, ore bin operator) showed that all of these categories were well below the TLV of 5 fibers ($>5\mu$)/ml.

In the mill, the belts, screens and mill rolls are completely enclosed and maintained under exhaust ventilation. The exhaust is ducted to a baghouse collector. The jaw crusher, bagging operations, tailing bins and mill atmosphere are maintained under exhaust ventilation and are ducted to a dry cyclone.

The product is hand bagged in a room which is maintained under exhaust ventilation. All baggers are required to wear respirators, although this is not a solution to the dust problem. Aside from the bagging operation, the mill is exceptionally clean and is within the allowable TLV for asbestos fibers.

Summary of Asbestos Mines and Processing Plants - The incidence of asbestosis in construction workers using asbestos-bond insulation has led to strict rules and regulations in regard to asbestos concentrations. The asbestos mining industry has recognized the potential hazard, also, and the mines which were visited had instituted extensive sampling programs and all were upgrading the dust control systems. All mines recognized the need for good housekeeping, and centralized vacuum systems are recommended. Where possible, screens, crushers and beltways should be completely enclosed and maintained under exhaust ventilation. Roadbeds are a source of asbestos fibers and should either be wet or be covered with crushed stone to prevent the generation of fugitive dust.

Bentonite

B-1 - B-1 is an open pit bentonite mine. The mineral contains about 25% natural moisture content so wet drilling is not used. It was stated that the roadways can become dust sources in the dry summer months so they are sprayed with water. No additives are used. The product is hauled from the pit only during the summer months so icing of the roads is not a problem.

The mill employs a completely enclosed exhaust ventilation system except for bagging and loading operations. A dry cyclone system is used to collect the dust, and the dust is fed back into the process stream. Although the bagging operation is hooded and exhaust ventilation is used, the operation is obviously dusty. A shroud is used over the railroad car filling ports and the dust is collected in a baghouse collector.

B-2 - B-2 is an open pit bentonite mine, also. The moisture content of this material is high so wet drilling is not used. The haulage roads are wet down but additives are not used.

The mill employs a completely enclosed exhaust ventilation system. The dust is currently collected in baghouses, however the high moisture content of the material results in frequent clogging of the bags. The company is considering the installation of electrostatic precipitators. Exhaust ventilation is used effectively during bagging and bulk loading operations.

Summary of Bentonite Mines and Processing Plants - The mines which were visited were open pit type and the material had a high moisture content. Because of the high moisture content,

drilling was done dry. The only dust source in the pit were the haulage roads and dust was controlled effectively by wetting down the roads.

The processing plants employed closed systems maintained under exhaust ventilation. Dry cyclones appeared to be the preferred method of dust collection since bags were rapidly clogged with the wet dust. Neither company had a routine dust sampling program, but both appeared to be relatively dust free except for the bagging operations.

Copper

Cu-1 involved a general discussion of a corporate approach to dust control. Facets of dust control which were discussed included:

1. Manufacturer's claims versus actual performance of dust abatement equipment.
2. Transfer belt speeds.
3. Transport velocity of dust through ventilation ductwork.
4. Cost of dust control.
5. The importance of maintenance, automation and good housekeeping.

A number of electrostatic precipitators have been purchased for control of emissions at localized operations within the plant. Manufacturers generally claim an electrostatic precipitation efficiency of greater than 95% for particles less than 5 microns diameter. This company has found efficiencies as low as 45%.

Transfer belt speeds were indicated as being critical in regard to generation of dust. High belt speeds not only generate more dust but also make dust control more difficult and in most cases impossible. This is true whether localized ventilation, water sprays or other dust control methods are used. Some belts are operated at speeds up to 500 fpm, but this company has set a top limit of 250 fpm.

Transport velocity of dust through ductwork was discussed. Based on both theoretical calculations and actual tests, a transport velocity of 4000 fpm is required. Good engineering practices in designing ductwork and duct sizes as a function of the distance from the collector was stressed. The cost of dust control equipment including installation was estimated at \$5.00 per cfm.

Three important aspects of dust control were stressed:

1. Maintenance
2. Automation
3. Housekeeping

Periodic inspections of dust control equipment is absolutely essential. Possible problems include wear (in ductwork, machinery, enclosures, etc), clogged water spray systems, inoperative equipment and so on. Automation, where practical, should be used since operators cannot be depended upon to activate systems. For example, when a transfer belt is started sprays should be automatically activated. Housekeeping cannot be overstressed. Some dust always escapes and eventually settles somewhere in the mine or mill. Hand-sweeping is more detrimental than helpful since the dust is reaerosolized. Vacuum sweeping is acceptable. One mill used a \$35,000 vacuum sweeper (mobile baghouse) while another mill installed a central vacuum system (\$100,000).

C-2 is an open pit copper mine. Wet drilling is used for shot holes and no evidence of dust was seen during the drilling process. After the shot holes are filled, the area is wet down. Blasting is performed in areas remotely located from ore loading areas. After blasting, the ore is wet down for at least 24 hours before loading is initiated. In addition, wetting with water sprays is continued during loading. No wetting agents are used. The shovel operator is protected with filtered air but no dust was observed and the truck operator moves away from the area during loading.

Roads from the mine to the mill are kept in good shape. At one time, emulsified oil was used, but this led to formation of potholes. Later, wetting agents were used and were effective until the water evaporated. Finally, a soil binder was used. This has proved to be a satisfactory solution to the

problem. The safety engineer stressed the fact that even if dust control were not required, the roads would be maintained in this fashion to increase the lifetime of the trucks and truck tires. Truck engine wear is excessive in dusty environments and tires are easily damaged by poorly maintained roads.

Water sprays are used at the mouth of the crusher and the crusher operator is housed in a cubicle supplied with filtered air. Rotoclone systems are at the two 7-foot Symons cone crushers and three 7-foot Symons shorthead crushers. Local exhaust is used at transfer points in this process and collected in Wheelabrator baghouse installations for recycling. The material is transferred to a hopper which in turn conveys the ore to storage bins. The discharge from the hopper, a longitudinal slit in the deck, is covered with a rubber protective seal. The area is frequently cleaned with a mobile industrial vacuum sweeper. All operations beyond the storage bins are wet processes.

Samples are taken once per year for free silica and returned to the corporate laboratory for analysis. Area samples are taken about twice per year at the following sites:

- Drilling
- Loading
- Primary crusher control room
- Secondary and tertiary crusher building
- Storage bin hopper (6th floor)

All of these samples were less than the allowable TLV. A letter from the state mine inspector congratulated this company on the clean operations at the mine and mill. The safety engineer stated that the dust control equipment pays for itself in the form of reclaimed copper ore from the dust collection systems.

Cu-3 is an open pit mine. Shot hole drilling is done wet and there was no visible evidence of dust. The material has a high moisture content so the muck pile is not wet down prior to loading. Driller rig, truck and shovel operators are instructed to keep their windows closed. Occasionally dust surveys of the truck and shovel cab atmospheres indicate little or no dust. The roadways are wet down with water spray trucks. Free silica content of the ore body runs from 18% to 40% and free silica content of the drill cuttings run 50% to 65%. The mine is sampled on a yearly basis.

At the mill, the ore is sprayed with water prior to dumping and water sprays are used at the mouth of the primary crusher. Inspection of transfer belts revealed worn and, in some cases, completely missing skirting. Take-up pulleys on the belts were running in muck which had built up around them. At one transfer point, a short conveyer had been installed. The enclosure over this conveyer had no maintenance access openings, so openings had been cut in the enclosure but no covers were placed over the openings. As a result of the above factors, the belt transfer system was a dust source.

Ore from the primary crusher is fed to ore storage bins. The bins are maintained under negative pressure but the sealing belt on the tripper feeder was broken, thus the effectiveness of the dust control system was reduced.

The free silica content of the mill dust runs from 25 to 41%, and dust contents range from 1 to 5 mppcf. Dust sampling in the mill is done on a quarterly basis.

The major cause of dust problems seemed to be the lack of a routine maintenance program. Maintenance personnel spend essentially all of their time on production maintenance. General comments on dust control by the Industrial Hygiene Supervisor were:

1. There is a general corrosion problem with dust collectors.
2. Some dust collectors require weekly inspection and maintenance.
3. Water sprays are plugged frequently with mill water impurities.
4. A preventative maintenance program is essential for effective performance of dust control systems.

Cu-4 is a copper company which has both underground and surface mining facilities. The mine has a high natural water content, yet additional water is used in all dust producing operations. Prior to drilling the heading is thoroughly wet down. Drilling is done wet and an air-water interlock valve is used to assure that water is delivered to the drill

bit prior to drilling. An air-water mist is used during and after blasting. The muck pile is wet down after blasting and during loading. In addition to water, auxiliary ventilation fans are used in the working places. Most haulageways are wet, but those that are not are wet down with water spray trucks. Water sprays are not used at the ore dumps and, although the ore is extremely wet, dust can be seen billowing from the pocket during dumping. Ore dumping seems to be the only dust problem which exists underground.

Wet drilling is employed in the pit when the weather permits it. The truck cabs were not supplied with filtered air, but mine management was considering the use of pressurized cabs. Water spray trucks wet down the haulage roads, again when the weather permits. No additives are used. The ore is hauled to the loading pocket by truck. A spray system was being installed at the mouth of the loading pocket.

A baghouse collector is used on the primary crusher. Transfer points and the secondary crusher are maintained under exhaust ventilation and the dust is collected in wet scrubbers.

Cu-5 is an underground copper mine. Wet drilling is used in development headings. Water sprays are installed at the grizzly lines, but it is up to the individual worker to turn on and control the amount of water which is used. The workers attempt to use as little water as possible since the water passes through the grizzlies and collects in the ore transfer raises. Difficulties were encountered with plugging of spray nozzles with undissolved solids in the mine water as well as corrosion products which were dislodged from the inside of the pipe walls during blasting. Water sprays are used at the haulage level also with the chute puller manually adjusting the flow according to the wetness of the ore being drawn. Because of the amount of water used at the grizzly line and at the chute puller station, the haulageway is wet and does not need additional watering down. Ventilation air is used throughout the grizzly line with auxiliary, compressed air, venturi-type blowers used as required. Blasting is done during lunch hour and between shifts; the air was visibly dusty in the working places after blasting.

Ore is transferred to the ore pocket by rail. The pocket is located at the return air shaft so any dust generated is exhausted through the shaft. The locomotive operator and dump operator are located upstream of the dust source.

The pan feeder, primary crusher, crusher discharge and transfer points are maintained under exhaust ventilation. The dust is collected in a baghouse system. The secondary crusher is maintained under exhaust ventilation, also, and the dust is collected in wet scrubbers.

Cu-6 is an open pit copper mine. Drilling is done wet and blasting is done off-shift. The area is wet down prior to drilling, after drilling and during loading. Truck cabs are supplied with filtered air, but the drivers will not keep the windows closed during the hot summer months. Roadways are wet down with water spray trucks; no additives are used.

Water sprays are used at the ore storage pocket and at the mouth of the primary crusher. The primary crusher operator is housed in a positive pressure booth. The secondary crusher and associated transfer points are maintained under exhaust ventilation and water sprays are used. The dust is collected in a baghouse. Dust from the baghouse is returned to the process stream, a procedure which should be avoided because the dust can become airborne again. A plant-wide vacuum system was used to clean up settled dust.

Summary of Copper Mines and Processing Plants - Wet drilling was used in open pit mines when the weather permitted. During extremely cold weather, water was not used because the lines froze. Some mines used continuous sprays on the muck pile during loading while other intermittently sprayed as the piles became dry and dusty. Some driller, loader and truck cabs were supplied with filtered air and others were not. None of the cabs were air conditioned so the windows were frequently open, negating any benefits from the clean air supply. Roadways were frequently watered down and one company used a soil binder.

Water sprays were used at ore pockets, but their effectiveness varied from mine to mine. All but one system had been designed in-house, and the number and location of sprays were based on estimates of the required coverage. In all cases, water sprays still permitted escape of dust during loading. Some of the primary crushers were enclosed and maintained under exhaust ventilation while others had only water sprays. Baghouses appeared to be the preferred dust collector

at primary crushers. In some cases, the collector system had to be located outside, and in those areas which had extended periods of sub-freezing weather, wet collectors were not practical.

Secondary crushers, ore storage bins and transfer points were enclosed and generally maintained under exhaust ventilation. Wet collectors appeared to be the most frequently used method of dust collection at these points.

There was a very negative attitude on the use of water additives to suppress dust. There were three primary reasons for this:

1. Insufficient evidence that additives significantly improve dust control.
2. Potential effects of the additives on flotation processes.
3. Added costs.

These reasons were given not only in the copper mining industry but in the rest of the metal mining industry. The first reason, insufficient evidence of additive effectiveness, seems to be justified on the basis of the literature review which was made. The second reason, potential effects on the flotation process, is a justified area of concern, but evaluation of any possible effects could be evaluated by the mining companies on a pilot plant scale. All companies agreed that if additives were required to attain compliance and if the additives did not affect the flotation process, then they would be willing to accept the additional cost.

Lack of preventative and routine maintenance was obviously one of the major reasons for the presence of airborne dust. Poor seals on inspection and maintenance ports, open ports, settled dust, inoperative sprays and holes in ducts are a few examples of existing maintenance problems. Production maintenance personnel are generally responsible for maintenance and repair of dust control systems, and production maintenance obviously has the higher priority. A maintenance crew specifically assigned to dust control systems, along with frequent inspections by the plant safety engineer appears to be necessary to control dust in mines and processing plants.

Gold

Au-1 is an underground gold mine using a cut and fill method. The ore is dry and hard and contains 20-30% free silica. All primary drills are fitted with air-water interlock valves so that water is fed to the drill bit before drilling is initiated.

Air and water (no additives) are used extensively to control dust. Over a million cfm of air is used to ventilate the main raises and stopes. Auxiliary fans rated at 3000-5000 cfm are used in the stopes with the tubing exit 3-15 feet from the men working at the ore drop. In addition to ventilation, water is used on the slusher and at the drop hole. Muck piles are wetted down with hand-held hoses. In spite of the fact that auxiliary ventilation and water are used at the slusher, this still remains a dust source and the men are required to wear respirators.

Bore hole drilling between levels is also a dust problem area. A 7 inch pilot hole is drilled then the hole is reamed to a 54-60 inch hole. Ten gpm of water is used to cool the bore hole drill and then is used to control the dust. The material washes down the hole. Sometimes, however, the muck and water seal off the hole building up a head of water which is dangerous when it lets go. When this conditions exists, dry drilling is done until the hole is reopened.

There are 100 stopes in operation. Two men are continually sampling. Some stopes are sampled every 3 months, some every 6 months, some only once a year. The amount of sampling depends on the problems in the particular stope.

The ore is dumped from cars into the primary crusher. Water is used to wash all the ore from the cars. Three crushing operations are used. The ore is belted throughout the plant. The main problem appears to be material falling from the belt on return trips. A dry cyclone dust collected is used in the plant with hoods at transfer points and at the crusher.

The major problem in this mine, as in other mines, is that part of the air is recirculated. Air which has been

used to ventilate a stope may be returned to the main airway on the same level or to an upper level through a borehole. This contaminated air is then used to ventilate other stopes.

Iron

Fe-1 is an open pit, magnetite, iron ore mine. All drilling is done wet and all blasting is done off-shift, usually about once per week. The ore is shovel loaded into trucks for haulage to the processing plant. Although the shovel operators and truck drivers are enclosed in cabs, the windows of the cabs are open.

The ore is hauled to and dumped at the primary crusher. The crusher operator is housed in an enclosed area and water sprays are used for dust control. (The water spray system cannot be operated during the winter months, but the safety engineer stated that when the temperature is below freezing, and particularly when there is snow on the ground, the amount of dust generated by the crusher is considerably less than that generated during the summer months.)

Ore which has been crushed to less than 5 inches is delivered to storage bins by belt. The beltway as well as the storage bins were enclosed so the area was free of dust. However, the return belt did produce dust, particularly at the take-up rollers. This is a problem area that is frequently neglected and deserves more consideration. Wetting of the material on the belt before it is discharged is not a solution since it tends to cake and stick to the belts and cause severe cleaning problems. Vacuum type dust collectors at the two principal points were tried with extremely limited success due to the large area of belt producing dust. The present procedure is to provide air locks at each end of the beltway in an attempt to contain the dust within the gallery. This is of only limited effectiveness since complete air seals are not possible with a moving belt and ventilation patterns are such that the dust is normally sucked up the gallery into the mill rather than being moved in the opposite direction.

In general, the mill is an exceptionally clean operation. Housekeeping throughout the plant was excellent. The excellence of this operation is due to the wet process

of grinding, transport and recycling, plus covered discharge points to conveyors and copious use of water. The excellent engineering design, maintenance and overall organization were also influencing factors.

Fe-2 is an underground, hematite, iron ore mine. The ore body is very friable and contains a sufficient amount of clay to allow pellet formation without the addition of other materials. Mining is by sub-level block caving in which ore blocks or stopes are blocked out by drifts driven above the level of the haulage road. These drifts become slusher loading entries and from them ore passes are driven at angles into the ore block above. When the ore body is broken it then flows through the ore pass holes to the slusher drift where it is scraped to the ore loading pass to cars beneath.

This mine is very wet and workers wear boots. Very little suspended dust was observed. Dust control is principally the result of the inherent wetness of the ore. Drilling is by wet process. A primary ventilation system delivers air to the working levels where it is partially controlled by doors and auxiliary ventilation systems.

The operations which were observed were overhead stope drilling, which was virtually dust-free. The slusher scrapers showed some evidence of creating dust. A cross cut was observed ready for drilling. The face was ventilated by a push-pull ventilation system with the blower discharge approximately 25 feet from the face and the exhaust intake somewhat closer to the face.

Ventilation in the slusher areas was of the same character. Air movers with auxiliary ducting are used to force ventilate the individual slusher areas during operation. It takes 15 to 20 minutes after a blast has been set off before the area completely clears using this type of ventilation. The dust and smoke is discharged into the haulage way at the foot of the slusher. This might be satisfactory if only one slusher were operating off that haulageway. Unfortunately, this is not the case. There are several of these operating off a single haulageway. As a consequence, the dust and smoke blown out of the upstream areas tends to be sucked into the succeeding operations downstream by virtue of the ventilation pattern. Thus, the quality of the intake air into the individual workings decreases in quality as the distance to the vent hole decreases.

The ore is transported to an improvement plant where it is processed to a sufficient concentration to allow it to be pelletized. Because of the high quantity of clay in the ore body, it is impossible to consider any form of wet grinding, thus all processing is done dry. It should be noted that this is a fairly old plant. It was neither designed nor built with any thought of dust control in mind. It should be further recognized that this plant by its nature is fast becoming an uneconomical operation.

During an earlier visit, the company was in the process of evaluating an extensive water spray system incorporating wetting agents which had been supplied by Johnson-Marsh. Their findings with their particular ore was that water of itself was not a sufficient dust suppressant and a wetting agent was necessary to get penetration into the material traveling along the belts. With this system, however, severe caking and clogging occurred both in their grinding mills and in their screening operation. For this reason they were forced to reduce the wetting agent addition to a very small percent of the recommended concentration and then only in a few isolated positions.

They had in the past tried dry collection systems with only limited success. The nature of the operation, including the grinding areas, made it almost impossible to enclose and contain the dust generating positions. For reasons which are tied to the moisture content of the ore and the humidity in the air, dry collection systems tended to clog up periodically causing severe maintenance problems and reduced effectiveness. Heaters have recently been added to the inlets of the dry collectors and seem to be beneficial. There is no doubt that the heating has improved collection efficiency but the amount of dust in the air is still tremendous.

Fe-3 is an open pit taconite mine. Wet drilling is employed in the pit and blasting is done during off-shift. Fugitive dust situations do exist in the pit during loading. Although the cabs of the equipment are enclosed, in most cases the windows are open during operations. In this mine, ore is transported to the processing plant by train rather than truck. The cars are side dump, with each train operated by a single man who also controls the dump.

Dumping is on the surface level connected to a dump house complex of five levels. Crushed ore goes to storage and to secondary crushing and grinding. Dust control within the crusher house is by bag collectors which worked satisfactorily except for trouble with the screw-type discharge which was wearing abnormally.

The company uses dry primary and secondary crushing operations and a dry process through the classifiers and the magnetic separation. The system is enclosed using ventilation to prevent dust from escaping into the mill area. This mill uses a multiple system of wet collectors with each scrubber servicing only one or two dust generation points. Conversely, Fe-4, which will be described, uses a large central scrubbing system which services all the dust generating points within the mill. There does not appear to be any significant difference between the effectiveness of the two arrangements. The latter system is less costly because of the large single scrubber but the disadvantage is that the failure of the large scrubbing system immediately shuts down the plant because of the inability to collect dust from multiple points. Where multiple scrubbers are used, the failure of a single scrubber provides dust only in a localized area and for the short term at least it is not necessary to terminate operations.

Although a dry process is used throughout much of the operation, dust control was considered excellent. Residual dust noted on the floor or operating decks and overhead structures was minor. The excellence of this operation is thought to be due to design and operational control, but certain problems were discussed, mostly caused by cold weather operations and operational "bugs" appearing in various new equipment and installations.

Fe-4 is an open pit taconite mine. Dust control in the pit was similar to that described for the other open pit mines, i.e., wet drilling and blasting during off-shifts. Drillers, shovel operators and truck drivers had enclosed cabs, although again in most cases the windows were open. Water was used on the haulage roads to allay dust. During the winter these roads are not wetted, but due to the cold weather, truck drivers generally keep the cabs tightly closed.

This plant also uses a dry process through primary and secondary crushing, grinding, classification and magnetic separation. The various processes and transfer points are enclosed and maintained under negative pressure. As stated before, this plant uses a central scrubber for removal of dust from the ventilation stream and in the event of any problems with the central scrubber, the entire operation has to be shut down until maintenance and repairs are completed.

Fe-5 is an underground magnetite iron ore mine. The ore is mined by an open stoping method. All drilling is done wet with air-water interlocks used on primary and secondary drills. Water is not used at the draw points, but the ore body is naturally wet and dust does not appear to be a problem.

The ore is transported underground on belts and water sprays are used at transfer points. Belt scrapers are used on the return belts. Water sprays are used at the primary and secondary crushers. The subsequent grinding and magnetic separation operations are wet process and are not dust sources.

The ore is pelletized and the green pellets are not dust sources. Once the pellets are fired, potential dust sources exist, but these are well controlled with enclosures and exhaust ventilation to wet scrubbers. Material collected in the wet scrubbers is recycled through the pelletizing process.

Fe-6 is an open pit, taconite iron ore mine. Drilling is done wet and shovel cabs are enclosed, although the windows are not always closed. All blasting is done off-shift. The ore is transported to the primary crusher by rail. The crusher operator is housed in a positive pressure enclosure and exhaust ventilation is used at the crusher. Due to temperature extremes, the dust from the primary crusher is collected in baghouses located outside the crusher building. All other dust collecting systems are wet scrubbers and are located inside the building to prevent freezing.

Transfer points in the processing plant are completely enclosed and maintained under exhaust ventilation.

Belt washers are used on the return belts. Ore storage bins are maintained under exhaust ventilation, also. A central vacuum sweeping system was being installed.

This was one of the cleanest processing plants which was visited. All dust sources were well enclosed and ventilated and water was used freely. A small crew of men were permanently assigned to maintenance and repair of dust control equipment. The Safety Engineer had the authority to terminate any operation in the plant if the dust concentrations were above the TLV.

Summary of Iron Ore Mines and Processing Plants -

The survey of iron ore mining operations and processing plants exhibited a wide range of variables which influence the type and effectiveness of dust control measures. Open pit operations were generally limited to the use of water during drilling and on haulageways during the summer months. Freezing of water lines and icing of roadways were problems in the winter, hence little or no water was used during periods of extremely cold weather. Filtered air to shovel and truck cabs, heated during the winter months and cooled during the summer months, would have provided protection to these heavy equipment operators.

The two underground mines posed different problems in dust control. One was naturally wet and all grinding in the processing plant was done wet. Conversely, the other mine was dry and had a high clay content which dictated limited use of water in the mine and processing plant. Because of the high clay content, all crushing and grinding had to be done dry. As a result, the latter mine had to install extensive exhaust ventilation systems while the former mine was able to use water extensively and required little in way of ventilation systems.

Selection of dust collection systems was influenced by the nature of the ore as well as climatic conditions. Wet dust tended to clog baghouse filters and in one case, the air stream was heated to minimize plugging of the bags.

Significant differences were noted in the maintenance and housekeeping procedures of these mines. Another factor which was noted was the age of the processing plant, with the newer plants having much better dust control equipment.

Granite

G-1 is a granite quarry and mill with most of the granite being used for monuments. The granite contains about 25% free silica. Each employee is given an annual chest x-ray and a pulmonary volume test.

Wet drilling is used at the quarries. Hot water is supplied by a central heating plant so granite is mined throughout the winter months in spite of the cold weather conditions. During the winter, production drops off by about 25%. Cutting at the quarries is done with an oxygen-fuel oil torch. A water spray is provided at the torch to reduce the dust generated by the spalling granite. The torch cuts a path of up to 18 ft deep and 2 1/2 inches wide. Both the drilling and cutting operations appeared to be essentially dust free.

The blocks of granite are transported by truck to a cutting mill. All cutting is done wet using a wire saw and a carborundum slurry. This operation was also dust free.

In the manufacturing plant, dust is controlled either by wet grinding and polishing or with a central ventilation system. Employees who had to shape the monuments are provided with a local, flexible vacuum system connected to a central baghouse type air cleaner. Some sand blasting is done in an enclosed area with the workman outside of the hood. In other cases, sand blasting is done in an air tight, evacuated room with the workman inside the room. The workman is provided with a hood with a fresh air supply.

Pneumatic tools were introduced into the granite industry between 1895 and 1900. Industry wide dust control had its beginnings in 1937. In 1927 workers were exposed to dust levels ranging from 40 to 60 mppcf. In 1937, when dust control procedures were instituted, the level dropped to an average of 12 mppcf. In 1950 the average had dropped to 5 mppcf and a recent evaluation showed an average of 3 mppcf with a high of 8.3 mppcf and a low of 0.5 mppcf. Before dust control was instituted, some cases of silicosis were found after as few as 5 years of exposure. There have been no cases of silicosis found in any person whose exposure was limited to the 35 years since dust control which was started in 1937.

G-2 was a granite quarry with most of the product used for structural purposes and the remainder for monuments. All personnel are given annual medical and x-ray examinations. SiO_2 content of the granite is 41%. Samples of dust in the plant showed 10-16% free SiO_2 .

In the quarry the granite is rough cut with oxygen-fuel oil torches, wire saws with carborundum slurries and core drills. Drilling is done wet. There did not appear to be any dust problem in the quarry.

The granite blocks are cut in the plant with wire gang saws using a carborundum slurry which is recycled. The blocks are finished with carborundum wheels and iron oxide. Holes are cut by use of diamond hole saws and drills. All these processes are wet. Some hand and pneumatic sculpturing is done. The dust collection is central with individual flexible ducts for each work area. The dust collectors are baghouses. There are overhead fans for dilution of the plant air which exhaust 11,000 to 12,000 cfm. All sand cutting rooms have the operator on the outside.

The company has no air sampling program, but air samples are taken by the U.S. Bureau of Mines and the state bureau of mines. Dust levels are below the allowable TLV.

Summary of Granite Mines and Mills - Dust problems in quarries have been minimized by the use of wet drilling, wet cutting and water during jet torch cutting. Hand chippers and cutters in the mill are provided with local exhaust ventilation. Grinding and polishing is done wet and when dry finishing is required, negative pressure booths are used. Undoubtedly, the work done in the mid-thirties on silicosis in the granite industry has been an influencing factor in dust control in the granite industry.

Lead

Pb-1 is a lead mine with the free silica content of the ore body ranging from 3-5%. Dust samples at the mine and mill are taken on a monthly basis.

Although the ore is wet, all drilling is done wet. Blasting is performed during off-shift. Autoloaders and scrapers are used to load the ore. Maximum dust levels in the mine range to 7 mppcf.

Ore from the mine is transferred to an underground primary crusher where it is reduced to 6 inches. Water sprays are used at the crusher. Ore is then transferred by beltway to the processing mill. Secondary crushing is done within the mill and is one of the primary dust sources. Fugitive dust was noted in the crushing area. One of the ventilation blowers had a hole in it and a stream of dust was noted issuing from this hole. All transfer points had ventilating ducts but the points were not enclosed. Following secondary crushing, the ore is transferred to mill storage bins. From there, ore is transferred by belt to rod mills where the ore is wetted and remains wet through the ore improvement process.

The concentrate is then dried and ultimately loaded into box cars or gondola cars for shipment to the smelter. A ventilation system is provided at the drier but not at the loading point. The operator's booth at the loading point is not ventilated and fugitive dust was noted there also. All ventilating systems in the mill are connected to wet scrubbers.

Pb-2 and Pb-3 are two underground lead mines. The ore is a vein deposit containing 30% free SiO_2 and the surrounding rock is quartzite containing 55% free SiO_2 . The company maintains a 3 man safety department and a ventilation engineer. The ventilation engineer is responsible for all ventilation systems as well as dust sampling.

The general mining method consists of driving mains at 200 ft vertical intervals 100 ft off the vein and then driving cross cuts into the vein at 200 ft intervals. Areas are mined by a cut and fill raise type system. After each slice is removed, the resulting void is sandfilled. A 21 inch cooling and ventilation duct is run 200 ft maximum up through the sand fill to the working face and delivers 5000 to 7000 cfm of air at 80°F to the working face. A 10 HP fan along with a fin and tube heat exchanger and a large particle filter installed ahead of the fan is used to cool and ventilate all working faces. As the air is cooled a great amount of water condenses out and with the water some of the fine airborne dust particles are dropped out.

All drilling is done wet. Foggers are not used during blasting. A 5 foot diameter boring machine with both wet and dry type dust collectors are used in the raises.

Another boring machine equipped with foam and water spray dust suppression equipment was tried in a drift but only 350 ft was driven with this unit before abandoning it as impractical.

Dust surveys are run in the mine only when there is a reported dust problem. Respirable dust counts in the mine are generally less than 2 mppcf.

A milling and concentrating plant is operated at each mine. The mills consist of a primary jaw crusher, secondary gyratory crusher and tertiary and secondary crusher. Because of the wet character of the ore and under capacity operation, very little dust collection equipment is required. The only dust collector in use was a wet cyclone on the secondary crusher. The mill was extremely clean. All spilled material was mucked off the grating onto the concrete floor and either washed into sumps with high pressure water hoses or shoveled back onto belts. The one dust problem which does exist is at the concentrate loading points. The concentrate is passed through a drop chute into railroad cars and a hand held blow pipe is used to break some of the material loose. Dust surveys are run on a quarterly basis in the mill. Aside from the concentrate loading point, the respirable dust levels are less than 5 mppcf.

Pb-4 is an open pit lead mine. The ore deposit has a free silica content of about 10%. All drilling is done wet and blasting is done off-shift. Shovels and truck cabs are enclosed, but since the windows are frequently opened, the operators are advised, but not required, to wear respirators.

Water sprays are used at the primary crusher. The secondary crusher is enclosed and maintained under exhaust ventilation with the dust collected in a wet scrubber. All transfer points are enclosed, also. The concentrate dryers are also maintained under exhaust ventilation.

The dry concentrate is loaded into railroad cars. The loader operator is located in an enclosed control booth supplied with filtered air.

Pb-5 and Pb-6 are two underground lead mines operated by the same company. The ore body is quite wet, but wet drilling is used and the muck piles are wetted during load-out. Dust samples taken by the Bureau shows the dust concentration in the mines to be well below the TLV.

Ore from both mines are fed to a common processing plant. Water sprays are used intermittantly at the primary crusher depending upon the wetness of the ore. Use of water is based on visual observation of dust in the area and the judgement of the crusher operator. Subsequent operations are enclosed and the exhaust air ducted to wet scrubbers. This company had two full time maintenance men for dust control systems, both underground and in the processing plant. The dust levels in the mill were well below the TLV.

Summary of Lead Mines and Processing Plants - All of the mines which were visited were inherently wet, yet water was still used during drilling and mucking operations. The major dust problems seemed to occur after the ore had been concentrated and dried. The loader operator had the high risk job and the protection afforded him in terms of supplying filtered air to the control booth varied from mine to mine.

Limestone, Sand and Gravel

Q-1 is a sand quarry with the product containing about 98% free silica. As a result of the high free silica content, the TLV for respirable dust was 0.1 mg/m^3 . The company recognized the need for strict dust control measures and had extensive in-house engineering capabilities in dust control and collection systems. One of the major dust sources was the primary crusher where dust concentrations as high as 1.23 mg/m^3 existed prior to installation of dust control equipment. To reduce exposure, the primary crusher operator was housed in a positive pressure booth with electrostatic precipitator installed in the incoming air stream. Respirable dust concentrations in the control booth were reduced to 0.005 to 0.019 mg/m^3 after installation of the electrostatic precipitator.

The Chief Engineer for the company was cooperative in discussing dust control at various points throughout the processing plant. During the early processing phases, where the particles are large, cyclone separators are used. Later in the processing scheme where particulates of respirable size are present, baghouse collectors are used. These served not only to protect the workers but also to recover product which had undergone a considerable amount of processing, and therefore an economic advantage is realized. In certain cases, wet venturi or impingement collectors are used, but

these are expensive to operate due to the high ΔP through the system. For baghouse installation, operation and maintenance, a value of \$2.75 to \$3.25 per cubic foot of air processed was given. These values were for ambient temperature and humidity conditions. The Chief Engineer felt that small companies must rely on outside consulting firms for design of dust abatement installations.

Q-2 is an open pit mine producing flux for phosphorous reduction. The free silica content of the material ranges from 95-97%. Blasting is done during lunch hour and the dust has cleared by the time the workers have returned to their jobs. Shovels and trucks have closed cabs but the windows were open during loading. No wetting is used during loading operations, but no dust was observed during loading.

Trucks dump to a primary crusher and this material is screened to remove the fines which are primarily dirt. The coarser rock goes to a series of cone crushers which reduce it down to a maximum 1/4 inch. This material is washed and the coarse and heavy material transported to further separation. Coarse materials, greater than 1/8 inch, are shipped for use as a flux. The fine silica material is sold to local cement operations. Dirt removed in the washing operation is carried to a settling pond.

There are a number of dust generating points in this operation. The two principal dust generators, however, are the discharge points from the bottom of the two dry cone crushers. Water systems have been installed at various points in the operation and periodically increasing amounts of water have been supplied at each point. The water suppression system had had little effect on dust control. This appears to be due to the difficulty of wetting silica materials with plain water.

In addition to the discharge points in the cone crusher, there are minor but measurable dust generating points at the two primary crushers and at the discharge point onto the surge pile. At the present moment, the addition of wetting agents to the water is being considered. Further addition of water at the discharge points of the primary crusher will be used in an attempt to suppress dust. The discharge point from the cone crusher, however, does not lend itself to an acceptable solution at the present time.

Q-3 is a limestone quarry and plant producing rock dust and agricultural lime. Two inches of snow had fallen the night prior to the visit so the stone was wet. It was stated that the process is normally much dustier. Stone is blasted in the quarry, loaded onto trucks with bulldozers and transported to the plant by rail.

No dust control is used at either the primary or secondary crusher. In spite of the fact that the rock was wet, these operations were obviously dusty. The only dust control which is used in the whole plant is at the cinder crusher where a water spray (single nozzle) is used at a transfer point and a baghouse collector is used at the crusher and screen. During the visit, the water line for the spray was frozen and the ductwork to the baghouse was nearly completely plugged.

No dust control is used at the final grinding or bagging operations. This was extremely dusty with visibility limited to about 20 feet. Since this material is ground to <200 mesh, it is assumed that the respirable fraction is probably quite high. Some of the product is shipped in open hopper cars. No dust control measures are used at the hopper car loading point.

This company has just recently been purchased by a major mining company and during the visit we had the opportunity to talk to the Chief Industrial Hygienist of the new parent company. He was appalled at the conditions in the plant and envisions expenditures of at least a few hundred thousand dollars to bring the plant into compliance.

Q-4 is a limestone quarry producing crushed road stone. Water is used on the drills and it was reported by management that the drill operators never exceeded the TLV. It was also reported that shovel operators and truck operators rarely exceeded the TLV. The dustiest areas were in the plant. Sprays were used at the jaw crusher, but the jaw crusher operators frequently exceeded the TLV. No dust control was provided for the loader operators and they occasionally exceeded the TLV. Transfer points were well enclosed and maintained under negative pressure.

Q-5 is a limestone quarry operated by the same company that operates Q-4. The TLV for this operation was lower than for the Q-4 operation due to a higher silica content.

Water was used more extensively in the pit and the drillers, loaders and truck drivers never exceeded the TLV. Water was used extensively in the plant but the crusher operator appeared to be in a high dust area.

Q-6 is a limestone quarry and plant producing fine crushed limestone. Dust control practices in the pit were excellent with large quantities of water being used. However, the dust control measures in the plant were poor. Housekeeping was poor with inches of dust accumulated on the rafters, machinery and floor. In those areas, where localized exhaust ventilation was used, holes in the ductwork were observed. It appeared that greater than 50% of the spray nozzles were plugged. Enclosures around screens and hammermills were improperly designed. This mill was an outstanding example of improperly designed dust control equipment and poor maintenance and housekeeping.

Q-7 is a limestone quarry and plant with the major product being rock dust. Water was used extensively in the pit and the dust seems to be well controlled. Dust control measures in the plant were excellent. All transfer points were enclosed and maintained under negative pressure. Water with wetting agents was used at the primary crusher and the spray nozzles were routinely cleaned. Crushers and grinders were enclosed and maintained under negative pressure. Hoods and exhaust fans were used at the bagging operations. The dust control measures at this plant demonstrated what can be accomplished with proper dust control system design, housekeeping and maintenance.

Q-8 is a sandstone quarry producing specialty sands. The company operates two facilities. Primary sales outlets are the railroads (for traction), coal mines (rail traction), steel industry and brick production, the latter for dusting brick to keep it from sticking during the firing operation.

The plant is routinely inspected by the Bureau of Mines and the state. Just recently a dust survey was conducted by an outside firm. The manager estimated the free silica content of the sand to be from 95% to 97%, as one would expect, but the consulting firm listed the free silica as 1% based on a rafter sample (Talavite Method). The following table lists the results of the survey and shows that all job classifications are less than the TLV based on less than 1% free silica. However, if the material does contain 97%

TABLE 8 - DUST SURVEY

<u>Job Classification</u>	<u>Location</u>	<u>TLV mg/m³</u>	<u>Time Weighted Average Exposure (mg/m³)</u>
Bagger	Preparation Plant	7.5	1.47
Dryer Operator	" "	7.5	.98
Crusher Operator	Crushing Plant	7.5	.86
Pan Feeder	" "	7.5	.49
Clam Shell Operator	Yard	7.5	.122
Maintenance	Varies	7.5	.49

free silica, then the TLV (total dust) should be:

$$\frac{30 \text{ mg/m}^3}{\% \text{ quartz} + 3} = \frac{30}{97 + 3} = 0.3 \text{ mg/m}^3$$

If such is the case, all personnel except the clam shell operator are being overexposed.

The sandstone is surface mined with the operations as follows:

1. stripping the over-burden with a bulldozer.
2. drilling with a conventional surface drill.
3. blasting done usually only once a month on a major basis, but occasionally some secondary blasting to break up larger rocks.
4. loading - conducted with a diesel shovel.
5. hauling - truck haulage to the processing plant.

None of these operations use any dust control measures. The manager stated that the stone is usually moist and has no appreciable dust problems at any point in the operation. Truck haulage routes are not wet down.

At the processing plant no dust control is employed. From the primary crusher the stone is belt transferred to a surge or storage bin and from there to a grinding pan. The grinding pan is a 9 foot wet pan, and consists of two rolling wheels rotated over the pan surface. The rock is ground to $-3/8$ inch. The rock-water slurry feed is regulated by an operator positioned over the grinding pan. Obviously dust controls are not necessary in this location. From the grinder the slurry drops into a bank of screw washers where silt and loam are removed and from there to a stock pile for drainage.

After allowing as much water to drain as possible, the sand is transferred by a clam shell into a holding bin and transferred by means of belt to the rotary drier. The dried sand drops from the end of the drier into a sump and is elevated by a belt bucket to sizing screens. Neither the drier nor the elevator operation have dust control equipment. The building in which they are housed has an exhaust fan and vents, primarily for keeping down the heat. The inspection showed the area to be extremely dirty, so far as fugitive dust was concerned, but not visibly dusty.

The sizing screens are located overhead of the storage and loading operation. The sand flows by gravity, or is transferred by bucket elevator to the appropriate storage bin. No dust control measures are evident in this area. The production manager said that the operator has very little occasion to come into the area and does so only during malfunction of the screens. He estimated no more than 5 minutes on the hour. Under certain conditions of climate and wind, he said that this area gets extremely dusty, and the results were in evidence by a pileup of fine sand on all surfaces. Respirators are available to personnel who must enter the area and according to the foreman, they do wear them.

The final product is gravity fed to enclosed railroad hopper cars or trucks. The split is about 50-50. Although some dust was in evidence during truck loading, the operation took approximately 5 minutes and caused no severe dust problem.

A minor portion of the sand is bagged. The bagging operation is conducted in the same building as the screening and storage bin area, but on a lower level. Sand is bagged and shipped in both 50 and 80 lb bags. The drying, sizing and bagging are visibly dusty.

Q-9 is an underground limestone mine with most of the product used for road construction. The mine is naturally wet and little water is used underground. A primary crusher-feeder is operated underground, but is located in the return airway. The stone is transferred to the surface by belt.

The secondary crusher has water sprays at the crusher entry and the belt at the crusher discharge is enclosed and maintained under exhaust ventilation. The only apparent dust generating source in the plant is at the hammer-mill and screening operations. The need for dust control at this operation was recognized by the company and dust collection equipment had been ordered.

Summary of Limestone, Sand and Gravel Operations - In general, the small companies had not installed dust control equipment but the larger companies had. The philosophy of stone being a nuisance dust undoubtedly influenced the rationale for not installing dust control equipment. One of the sand operations showed exceptional care in installing and maintaining dust control systems. The other sand operation did not but this was probably due to the unrealistically high TLV set during a dust survey.

Molybdenum

A total of 1,400,000 cfm of air is circulated underground. Approximately 50,000 cfm of air is by-passed from the main haulage way through the slusher drifts. Water sprays are also used in the slusher drifts. At the underground crusher, both water sprays and exhaust ventilation is used. (It was calculated that the upward air velocity generated by rock falling into the crusher approached 60 mph.) Dust samples are taken at monthly intervals at permanent underground stations. Mine ventilation surveys are also made.

The major problem areas underground included:

1. Protecting the slusher operator.
2. Trains running in the intake air.
3. Short circuiting of air when opening up or getting an area to start caving.
4. Leakage caused by blasting.

Wet collectors are used at the crushers. The air velocity in the ductwork is maintained at 2100 to 2300 fpm. This velocity provides adequate dust control yet minimizes abrasion of the duct work.

This company is experimenting with a system to keep the muck wet on the belts. Water is allowed to flow onto the surface of the muck at a rate of about 6 gpm. The water nozzles are arranged so that approximately 90% of the surface is wet but the edges (and belt) stay dry. The purpose of this approach is to minimize adherence of dust to the return belts.

Wet collectors are used at transfer points. Approximately 50 tons per day of ore is collected and recycled. The major problems appear to be wear on skirts, enclosures, fans and dust collectors.

This company is progressive in its efforts to control dust. Housekeeping and maintenance on the dust control equipment was excellent. A routine sampling program obviously provided indications of the existence of dust problems.

Phosphate Rock

P-1 consisted of two phosphate rock, open pit mines feeding three processing plants. Phosphate rock is removed from the open pit by dragline and deposited in a slurry pit where high pressure water guns are used to slurry the phosphate rock. The sludge is then pumped to the processing plant. The only dust problem in the mine is on the roadways and no measures are used to abate dust.

The wet processing begins with a washing operation, which separates the clay (a material of extremely fine particle size which presents a considerable water recovery

problem), phosphate rock (which goes directly to wet storage) and a fines fraction, containing phosphate ore and sand. The fines material is further sized into a coarse and fine grade with 35 mesh being the separation line. The fine feed goes directly to the double flotation process whereas the coarse goes through a spiral separation and finally to the double flotation process. After water separation, both are finally sent to wet storage and from there to the dry processing section.

None of the processes in this plant have any dust problems. All materials are either handled as a slurry, or as a moist product. Roadways can obviously become dusty but no special measures are taken.

P-2 is a phosphate rock, open pit mine using drag-line and slurry methods of recovery. No dust problem exists at this mine except on roadways.

Materials from wet storage at the mine are dried by either a rotary drier or a vertical fluidized solids drier unit. Transfer to the drier is by underground belt operation which, with the moist material, has no dust problem. In the three plant complexes, dust from the driers is handled by several cyclone-wet scrubber combinations. The rotary drier has a cyclone scrubber followed by twin wet scrubbers. The fluidized solids drier unit employs wet cyclones followed by wet scrubbers. Both scrubbing systems have good efficiency, but one unit has less maintenance problems. This plant also has a calciner which operates only about 5% of the time. It employs a cyclone followed by the twin wet scrubbers.

The rotary drier operation is enclosed. The materials are fed from the drier by belt with several transfer points. Dust at the dump end of the drier was several inches deep on the floor. The vertical drier is open to the air. The transfer point at the base of the drier is hooded, and the belt feed to the common transfer point which feeds the storage areas located at the back end of the rotary drier is also hooded. However, all of these transfer points showed dust emissions since the enclosures are not exhausted.

The drier area operators have an air conditioned control room. The drier area employs 4 operators per shift

exclusive of maintenance men. Mask respirators are not required here nor in any area within the plant.

The feed from the driers is transferred by enclosed beltway to the silo storage area. All silos are enclosed and employ dust control methods on displaced air during the filling operation. The silos are served by two wet scrubbers. Keeping the ductwork opened on the silo scrubbers is a problem. The hot material from the drier has considerable moisture (90-95% RH). As it enters the ductwork it cools rapidly forming moisture on the walls. Dust accumulates and clogs the ductwork. As a result, it was estimated that the silo scrubbers are functional only about 40% of the time.

Ducting for handling the dust has been a problem. One solution has been to duct the dust from the collecting points on the silos immediately to a high point, install misters at this point, and drop the duct from there to a wet scrubber unit. The misters keep the ductwork washed clean. This, however, has not completely solved the problem.

The grinding operation is handled with two ball mills and three hammermills. Dust collection from the two ball mills is handled with individual baghouse units which have flows of 4300 cfm. Each hammermill has a baghouse unit with gas exit flows of 2500 cfm. Keeping ductwork clean in the grinding area is also a problem, since much of the material to be ground is still hot, but not nearly as much of a problem as the silo area. The baghouse units have been insulated to keep down the amount of condensation.

Settled dust, 1 to 1-1/2 in. deep was noted on the floor throughout the plant site, especially in the areas of the tail end of the rotary drier. Lesser quantities were present in the grinding room area. The grinder operators are located above the mills in an enclosed and vented area, but have neither air conditioning nor positive pressure in the enclosed area.

The general loading facilities are typical of the phosphate industry. Loading is accomplished manually from overhead storage by an operator standing on a cat walk at the roof level of the railroad car. This is a dusty operation

and management sees no way at present of changing the problem. All of their drop areas have flexible rubber couplings which deliver the rock to within about 2 ft of the top of the loading door. This helps direct the rock; however, the problem in the loading is not dusting caused by the drop, but by the pickup of dust in the displaced air from the railroad car.

P-3 is a phosphate rock, open pit mining operation employing the same mining techniques as the others. This operation includes mining and phosphate rock processing. The product is sold as phosphate rock of different grades to other companies for further processing and fertilizer blending. The operation is spread over two locations. One site has mining and ore separation and sizing, and the other has drying and blending.

No dust problem is involved with the mining operation. At the ore processing area the operation is either totally wet or the material handled moist and dust was obviously not a problem. Ore refining includes drying and some grinding and finally a blending operation. The rock is shipped by rail. This operation, especially after the drying, usually has dust associated with it.

At the wet processing site, the ore goes through a wet screening process which separates clay and recovers two grades of phosphate rock and a fines fraction. The fines consist of a mixture of sand and fine phosphate ore. Provisions are available on the wet screening unit for crushing and recycling oversize material.

The two grades of phosphate rock are transported by belt directly to a loading facility and onto rail cars. The fines go to a concentrator to separate the ore from the sand. The phosphate ore is floated to the surface in this flotation step, and sand is taken off the bottom. In a second treatment, the fines are further treated and the sand is brought to the top and the phosphate taken off the bottom. The fines are also loaded on railroad cars for shipment to the treatment plant.

At the treatment plant, the railroad cars are dumped and the ore stock piled for drying and blending. Stock piling is accomplished with beltways to open storage areas. The materials retrieval is by underground belts, with blending being conducted of the various grades at the

drier to meet customer specifications. Up to the point of drying, the ore is still moist. No dust is evident either in the stock piling operation or in the underground/retrieval system. As mentioned previously, dust was evident in the remainder of the facilities. Rotary kiln driers had cyclone separators for dust control.

The blended materials are moved by beltways to storage bins and thus to rail haulage. All of these operations are dusty with little or no provisions for dust control.

P-4 is a phosphate rock, open pit mining operation. There are two mines feeding the processing plant. The ore is moist even during the mining operation. Roads can become dusty, but these are simply used as access roads and no one is routinely exposed to dust as part of his job. They are not wetted down.

Wet screening produces three sizes in addition to the fine concentrate. Slimes are returned to the field and fines taken through a flotation process. Here the sand is separated and returned to the field and fines taken onto the drying area. Dust in the work processing area is not a problem either in the processing or on the roadways because of the immense quantities of water employed.

The moist segregated rock is brought in from the wet processing area, dumped and stored above ground with overhead belt conveyors. From here, according to the buyer's specifications, the ore is selected from the storage areas using underground retrieval belts, blended and fed to four rotary kiln driers. The driers are designed to take the ore down to a 1 to 3% moisture content. Generally, the 1 to 2% region is achieved. At the exit, the dried material is dropped into a dump chute and transferred with bucket elevator to overhead transfer belts for moving to storage areas. The dump bucket elevator and drop zone to the transfer belts are all enclosed and operated under a slight negative pressure. The sweep air as well as that from the rotary kiln driers is taken through a dry cyclone separator which returns separated material to the processing stream, and then to a wet scrubber.

The lower levels of the drier building were generally clear. At the upper levels, and especially where the cyclone separators and bucket elevator dumped on the storage transfer

belts, the work area was dusty. There were obvious holes in the dust collection systems, especially on the drop leg from the bucket elevator to the transfer belt. It was stated that these were probably inspection ports which were not completely replaced. At least in one case the dust was obviously coming out of an inspection plate area.

The dry materials are transferred by beltways to storage bins. All transfer points are hooded, operated under negative pressure, and have wet scrubbers to clean effluent. An attempt is being made to control the dust in the storage bin areas. New storage bins are closed with enclosed belt feeds operating under negative air pressure. Each bin has a 50,000 cfm wet scrubber. These, however, will still not meet emission requirements. The dump area is dusty. No employees, however, are stationed in the area.

The dry bin operator controls all belt deliveries from the driers to the storage areas. He is stationed outside of the dry bin area and presently his station is only partially enclosed. He must use a respirator and anyone who enters the dry bin storage area must use respirators. They have plans in the future to enclose the control area for the dry bin man.

From storage, better than half of the material is loaded out for shipment by rail or truck. The remainder is ground to customer specifications. The loading operation is by gravity from the overhead storage bins. The loader is stationed on a cat walk at the roof level of a railroad car. From here he can step out and open up the railroad car hatch and manually regulate the dumping of the rock. This operation is dusty and open to the air. No attempt is made to control the dust, and they have at present no ideas on how to handle it. They have used flexible rubber chutes to control the flow of material from the silo port to the railroad car hopper, but with little success in reducing dust. The drop distance is approximately 4 ft. Truck haulage is done by independent trucking contractors. They are responsible for loading their own trucks. There are no regulations concerning wearing a respirator for the truck operator.

Approximately 30 to 40% of the phosphate rock is ground to customers' specifications, which usually means 60 to 80% through 200 mesh. The two ball mills have separate bag collectors (17,000 cfm and 7,500 cfm) and the small hammermills have 2 small units (400 cfm) serving two mills.

As long as the baghouse units are well maintained, they are adequate. Fines are recovered and sent back into processing. However, the units require high maintenance and the company is trying to decide whether the recovery of materials is worth it. If not, they will go to a wet scrubbing process. They admit, however, that from their experience the wet scrubbing process will not meet their emission standards.

The ball mill operator has an enclosed, air conditioned area. No dust measurements, however, have been taken in this area. Although the air was not noticeably dusty, there was some dust present on the instruments. The hammermill operators have no enclosed area. They are not required to wear respirators, but they are available. In general, the dust concentration in this area was low.

The ground material from the grinding mills is fed through beltways to individual storage areas. The beltways are enclosed for the extremely fine product. However, dust was emanating from the transfer point to the belt going up to the storage silo. These belts were installed at too steep an angle and the fine dust slides back down, causing the dusting. At the one transfer point one could see that the dust falling back down the beltway causing dusting problems. Also, one section of the enclosure on the beltway was not properly reinstalled. The four storage bins for the fines are enclosed and individually vented to control dust in the displaced air. The baghouse units are rated at 2800 cfm.

Summary of Phosphate Rock Mining and Processing Plants - Mining of phosphate rock does not appear to be a problem since the material is slurried. However, roadways could be a dust source, but none of the companies were wetting the roadways.

The drying and calcining operations are the major dust sources in the processing plants. Both wet and dry collectors are being used to control dust, with wet collectors preferred by most companies. Baghouse collectors are susceptible to plugging with moist dust and are being phased out by some companies; one company has solved this problem by insulating the collector to minimize condensation. Condensation has been a problem in ductwork, also. The condensed water traps particles and results in plugging of the ductwork.

Potash

K-1 is a potash mine extracting material from a vein which contains both sylvite and langbeinite. Conventional mining techniques are used in the room and pillar operation. Underground equipment includes a jumbo driller, cutter, front end loader, shuttle car, feeder belts, jaw crusher feeder and a primary jaw crusher.

No water is used underground. Ventilation is used with a main intake and return airway complemented by a 24 inch auxiliary fan at the entrance to each room and a 48 inch auxiliary fan in the return airway. No ducting is used into the room and the operation is dusty. Downstream rooms are plagued with the air being laden with dust from upstream operations. The underground primary crusher is near the end of the return airway and the operation is extremely dusty.

The ore is lifted to the surface in skips. Crushing and screening of the sylvite and langbeinite are extremely dusty and only limited amounts of water are used. Fog sprays (1-2 gpm) are used on the screens at the exit of the secondary crusher. The material goes to a tertiary crusher and then is put through a froth-flotation cycle. Following froth flotation, the separated material is dried, screened and transferred for either storage or shipment. Dry cyclones are used on the drier and screening operation, but the plant manager attributes their use to recovery of a finished product rather than for control of respirable dust. No dust control is used at storage areas or railroad car bulk loading points. A dry cyclone is used at the bagging points, also. No data were available on dust concentrations in either the mine or processing plant. The mine and particularly the processing plant were extremely dusty.

The philosophy at this plant, as with the other potash companies, is that the dust is non-toxic and non-hazardous since it contains low silica and therefore dust control is not necessary. Dr. Herbert Stokinger, Chairman ACGIH, was contacted and questioned as to his opinion on trona and potash dust. Dr. Stokinger stated that these minerals should definitely be governed by the TLV's for nuisance dust levels recommended by the ACGIH, i.e.,

$$\text{Respirable} = \frac{10 \text{ mg/m}^3}{\% \text{SiO}_2 + 2} = \frac{5 \text{ mg}}{\text{m}^3} \quad \text{or} \quad \frac{300 \text{ mppcf}}{\% \text{SiO}_2 + 10} = 30 \text{ mppcf}$$

$$\text{Total} = \frac{30 \text{ mg/m}^3}{\% \text{SiO}_2 + 3} = 10 \text{ mg/m}^3$$

Much of the confusion apparently stems from the fact that neither trona, potash, nor any of their products are listed in Appendix E (Some Nuisance Particulates) of the ACGIH publication. Dr. Stokinger stated that the materials listed in Appendix E were typical examples and not meant to be all-inclusive.

K-2 is a potash mine using conventional, room and pillar techniques. All underground equipment is standard coal mine type equipment. Blasting is done during the lunch break or at the end of the shift. No water is used in any of the operations. The mine has a main ventilation system and auxiliary ventilating fans are used in the working areas. The only enclosure in the mine is the control room for the feeder crusher operator.

Ore is loaded into open rail cars and transported to the mill (about 10 miles). The belt loader operator is in an enclosed booth but no filtering or ventilation is provided for the booth. The potash ore is discharged from the bottom of the rail car onto an underground belt and fed into the mill where it goes through single impeller impact crushers. From the crushers it goes over vibrating screens. Prior to going over the screens, one gpm of water is sprayed on the material. The coarse material is recycled through the crusher, then to a froth-reagent flotation system. The potash is then skimmed off. Up to this point, the only dust control used is the one gpm of water.

The refined potash then goes through rotary drum driers. At the exit end dust control methods are used but this is primarily to recover the purified product. Large 12,000 cfm dry cyclone dust collectors are employed for draft on the driers and removal of the potash from the stack. This is an economic measure where the potash fines represent \$20/ton. The efficiency is about 99% because the dust collectors are over designed due to part of the intake air being used for drier draft. A large dry cyclone is employed at the compactor and recrushing-rescreening area. This also is a 12,000 cfm dust collector. In this process the dry material flows under pressure rolls where it is pressed into

thin cakes about 3/8 inch thick and of various widths up to 15 inches wide then onto a belt, a crusher (impactor) and a screen then to large storage areas and enclosed rail cars. All dust is reclaimed from the cyclones. At the transfer point where the material flows to the storage bins only one belt is used. The belt is enclosed when it is in the mill (about 20 ft). The dust generated here is collected by a 6000 cfm exhaust fan pulling through a 20 inch main trunk of about 40 feet vertical height. The trunk is reduced to 12 inches about 2 feet above the belt hood.

Two small 4 inch ducts also are connected to the 20 inch main and collect the dust generated from a small compactor which processes the fines from the cyclones of the drier stacks. The fan exhausts into the atmosphere and the dust cloud is clearly visible. Most of the processed potash is shipped by bulk in enclosed rail cars. No dust control is used at this point. A discharge spout is manually swung into the intake ports of the rail car. This was not in operation but from the surrounding area it would appear to be dusty. The finished product is stored in huge round, dome top buildings. A small 400 cfm cyclone is used here also with the material being recycled dry.

The mill was visibly dusty and leaks in the ventilating system were evident. Many of the work areas exceeded the TLV for respirable dust. Poor maintenance and a general attitude that the dust was not harmful appear to be the major factors in the poor condition of the processing plant.

K-3 is a potash mine with a seam of sylvite and a seam of langbeinite. The potash is mined by a conventional room and pillar technique. Plant management considers the dust only as a nuisance and claims that there has been no illness due to potash mining during the 27 years of operation.

The sylvite seam is relatively moist so no water is used in the mining or processing steps. The langbeinite seam was visited since it is the more dusty of the two seams. Three active sections with 11 entries per section are being mined. Intake air enters through the ore hoist shaft and the return air is exhausted through the men and equipment shaft. On the 11 panel system, intake air enters on the 5-left entry, passes across the face and is exhausted on 5-right. Recent measurements show a fresh air intake of 75,000 cfm on the langbeinite level and 102,000 cfm on the sylvite level. Small 5 HP fans (11 to a section) are used on face operations as new entries are driven and a 25 HP fan is located on the 5-right exhaust.

The mining operations consists of cutting, drilling, blasting, loading out and roof bolting. The seam is cut to a depth of 8-9 feet and is the dustiest operation even with the auxiliary fan blowing across the face at a distance of 25 feet. Drilling is done with a double beamed jumbo unit. This, too, is a dusty operation since no water is used. Blasting is done only at the end of a shift. Loaders are used, but are not fitted with spray heads. Wetting of the muck piles is placed at the loader operator's discretion. No dust control is used during roof bolting and no analysis for free silica content has been made. Shuttle cars transfer the ore to a crusher which in turn feeds to belts. Belt speeds range from 500-700 fpm which is unusually high although dust did not appear to be a problem at transfer points.

At the skip hoist, the ore from both the sylvite and langbeinite levels drop into separate hoppers where it is hoisted to the surface. The air at the hoist area was clear. Both beltway heads are enclosed and the whole dump and hoist area closed off from the pocket bins below. With the combination of entry air coming down the materials shaft and the enclosure techniques mentioned, this area was kept clear of dust.

Ore is transferred by rail car to the processing site, where the sylvite and langbeinite are handled separately. The langbeinite goes first through a crusher and dry screening process where it is taken to -6 mesh. It then goes through a series of wet screening slurry and leaching steps through a drying rotary kiln, where screening is again conducted to collect the fines at -65 mesh, through a roller mill and through several steps where the magnesium sulfate is separated and the potassium sulfate separated, screened, milled to -325 mesh, agglomerated and granulated for final product storage.

Dust control measures are used throughout the processing plant where dry product material is handled. Wet scrubbers are employed on the first crusher and screening process. They appear to be very effective. Dry cyclones are used in the screening process after the rotary kilns. Fines collected are recycled back into the process stream. Dry cyclones are again employed on the roller mill and screening operations of the K_2SO_4 after the magnesium sulfate separation. According to the plant superintendent, all of these techniques are very effective. The one place where

he is dissatisfied with the dust control measures is at the drilling discs, where the potassium sulfate fines are granulated for final product. A baghouse dust collection system was tried in this operation and was ineffective. A dry cyclone is presently employed.

The sylvite, or KCl type ore is taken through a crusher, similar wet process purification steps, through a drying rotary kiln and screening operation, and from there to a compacting plant and final granulator. Dry cyclone filters similar to the type used in the langbeinite steps are employed throughout. According to the plant superintendent, no dust problems are present with sylvite processing.

K-4 is a potash mine employing a continuous miner, room and pillar operation. A dust collection device is used on the continuous miner but we were not permitted to see it because it was designed by the company and was proprietary. No information on the collection device design, operation or effectiveness could be acquired. The ore is loaded from the tail piece of the miner to shuttle cars and then to a feeder and belts. The mine has 45 miles of underground belts. No dust control except the device on the continuous miner is used underground.

In the processing plant ore is fed to a primary crusher (hammermill). A small amount of water (1 gpm) is applied to the ore before it enters the crusher. After crushing, a wet flotation method is used to separate the product from the waste. Following separation, the product is fed to large rotary drum dryers. From this point on, dust collectors are used, but their primary purpose is to recover finished product. Dust control is effected with 50 dust collectors. Some of these are dry cyclones, but most have been fabricated by the potash company. Dust collectors are used on the bulk loading (90%) and bagging (10%) operations.

This was the cleanest potash facility which was visited, but the company was most reluctant to discuss the details of their dust control system.

Summary of Potash Mines and Processing Plants - The major problem in the potash industry seems to be that the industry believes that potash dust is not harmful. The major incentive for dust collection equipment is recovery of product material rather than dust control. In the mines, water is used very sparingly. Ventilation is the primary means of dust control and it appears to be ineffective in maintaining acceptable dust levels.

Trona

Na-1 is a trona mine using conventional and continuous mining methods. The conventional section uses a tandem drill with no dust control and a cutter with water sprays. The volume of water used on the cutter was not known. The cutter cuts a path from top to bottom in the center of the face then the face is shot with ammonium nitrate at the lunch break or end of shift. The material is loaded with a front end loader, with no dust control, onto a diesel ram car. It then goes to a feeder which has a breaker and then to a belt. Ventilation on the conventional sections is achieved by positive pressure auxiliary fans. These fans are 5 HP with 12 inch ducts.

The continuous sections use fixed head continuous miners loading directly onto electric ram cars then to the feeder, breaker and belt. About 15-20 gpm of water are used on the continuous miners. Additional dust control is used on the continuous miner sections using a negative pressure auxiliary fan. These fans are 40 HP with 18 inch ducts. The ductwork intake is kept ahead of the miner operator on the opposite side of the operator. There is no dust control on any of the feeders or breakers. Roof bolters are used and these have suction type dust collectors on them. The material is crushed underground using a roll crusher with no dust control. The crushing area is very dusty.

The plant superintendent was asked if the dust control methods were effective and he said no and that most of the operations were very dusty. The USBM has not taken any dust surveys and no numbers are available. The superintendent said maintenance of the dust control equipment is always a problem. All ductwork had numerous holes in it.

The entire dust control system for the processing plant is being remodeled and additional dust control equipment is being installed. At the present time it was nearly impossible to see in the mill area. Most employees were wearing respirators.

Na-2 is a trona mine using conventional, room and pillar methods with a standard seven entry system. Mining is conducted in three working panels, two of which are always in operation and a third which is under development.

in 1970 a survey by an outside consulting firm was made for this company. The silica content of the trona is <1% while the silica content of the overburden is 6.55%. This is the only trona or potash producer which has given consideration to adhering to the TLV's set by the ACGIH. The following TLV's are in effect in this mine:

$$\text{Trona mining \& processing} = \frac{10}{2} = 5 \text{ mg/m}^3$$

$$\text{Roof bolting} = \frac{10}{6.55 + 2} = 1.17 \text{ mg/m}^3$$

Results of the survey indicated that the cutter operator and roof bolter were exceeding the TLV.

A cutter is used to make a cut 6 inches wide by 10 feet deep by 25 feet across the entry. A single water spray of 6 gpm is used for dust control and is ineffective. The cutter operator cannot be seen when the cutting machine is in operation. No water is used during drilling since the area is claimed to be wet from the cutting operation. Blasting is done on shift as part of normal operation and produces excessive dust concentrations. Water curtains have been tried to contain the dust but setting up the sprays is time consuming and has been discontinued. Water is used on the muck pile after blasting.

A front end loader is fitted with two spray heads with a total capacity of 6 gpm. The ore is dumped to an underground crusher-feeder which is fitted with water sprays but no water supply lines have been installed. The ore is transported on 36 inch beltways traveling at 550 fpm to a 42 inch main beltway operating at 700 fpm feeding the main underground crusher. No dust control is used at transfer points, but 3 gpm water sprays with additives are used at the crusher. These are effective when operative, but they pose considerable maintenance problems. A water spray curtain is used at the exit of the crusher. This whole complex is being redesigned and will be enclosed with baghouse collection of dust.

General dust control throughout the mine includes 20,000 cfm across the last open crossing and 3000 cfm within 30-40 ft of the face. Main haulageways are wet down at least twice daily.

The ore fed at a nominal 6 inches to the hoist is raised from the mine and to the surface. Here it is fed either to the stock pile or directly to the crusher area. That which goes to the crusher is screened into fines, middlings, and coarse. The fines go directly to the crushing circuits. Middlings may be taken to the crushing circuits or along with the coarse to stockpile for later recovery and crushing.

The grinding mill which is only about 8 months old is completely enclosed and has all transfer points enclosed and equipped with baghouse units. When viewed in operation, however, the crusher area was extremely dusty. All operators were wearing masks. The control room was clear and is equipped with positive ventilation.

The feeders to the mills and from the mills to the screens are totally contained but have no exhaustor dust collection system. Operators in these areas where the dust problems are extremely bad wear dust masks. The ore from the stockpile is brought back through a tunnel by beltway. A baghouse collector was in operation in the tunnel and appeared to be extremely effective.

The refining operation consists of a calciner, dissolver, filters and driers. Four such refiners are in operation. Dust problems occur only at the point of entry of the crushed ore to the refiner building. These transfer points are either enclosed now or being enclosed with baghouse units. No other dust problems are present in the refinery with the exception of the shipping area where the final dried product, the soda ash, is transferred by beltway to storage silos, and from there to enclosed hopper cars. The calciner in one refiner has an electrostatic precipitator for collecting fines. This is replacing a wet scrubber system which was unsatisfactory. Similar precipitators will be put on all driers and calciners with the exception of one such unit which is presently equipped with a wet scrubber. Dust concentrations measured at specific locations in the mill indicated that the refinery bulk loaders are near the suggested limit. All other refinery workers are less than 25% of the suggested TLV.

Summary of Trona Mines and Processing Plants - The trona industry is faced with the same problems as is the potash industry, that is, that the material is water soluble

and very friable. The use of water has to be limited during mining operations, thus ventilation is the primary means of dust control. The industry has recognized the need to meet TLV's but question whether the technology exists, particularly in underground workings.

Talc

T-1 is a talc operation with both underground (10%) and open pit (90%) operations. The silica content of the talc ranges from 1 to 7%. Dust content in the underground mine runs about 5 mppcf. (An outside firm does the dust sampling for the company.) Drilling is done wet and good ventilation practices are used in the mine. Wet drilling is not used in the open pit mine. It was claimed that winter conditions preclude the use of water.

A tour of the processing plant revealed a serious dust control problem within the plant. The accepted threshold limit for this material is 10 mppcf and the following dust counts were made at bagging and loading stations.

Bagger	25 to 69 mppcf
Bagger	26 to 49 mppcf
Bagger	40 to 55 mppcf
Car Loading	20 to 160 mppcf

Although the bagging operations appeared to be the most prominent dust sources, many other uncontrolled dust sources were observed. The transfer points were not enclosed and thus the exhaust system provided marginal ventilation. Repeated clogging of various branches in the ductwork was mentioned as a problem. Some of the ductwork had low points which resulted in settling and clogging. One of the blowers was undersize by a factor of two. Another was also slightly undersize and clogging was a problem in both of these ventilation networks. Some of the ducts had been eroded with holes of up to 2 inches diameter being observed. Severe leakages were also noted at the rod and ball mills. Fugitive dust was present in all areas of the mill with depths of up to 6 inches seen in some areas. Cleanup of this dust was performed by hand sweeping with a push broom.

This mill is an example of poor ventilation design and poor maintenance. Plans have been made to modify the ventilation system, but the company has not yet allocated the money for this program. Unless steps are taken immediately it is likely that this mill will have to discontinue operations.

T-2 is an open pit talc mine. The open pit operation is small and consists of an air track drill for blast holes, bulldozer with ripper and front end loader. The foreman of the operations admitted that the dozer operator was exposed to a lot of dust during the summer months. All blast hole drilling is done wet.

Talc is trucked 30 miles to their processing plant where it is first passed through the primary roller crusher. From a stockpile the material feeds into a secondary cone crusher and then into one of three different grinding mills depending on the size of material needed. Baghouse collectors are used on the dust exhaust system. A large amount of talc was on the floor in all work areas. Cleanup is done by broom.

The plant manager commented that the major problem was erosion of bag collectors - the steam from the fluid energy mill deteriorates the bags. However, the primary cause of dust appeared to be poor housekeeping.

Summary of Talc Mines and Processing Plants - The talc industry appears to have many of the same problems as other nonmetallic ore industries. Lack of proper dust control appears to be based on the assumption that talc is not harmful although the TLV for talc (20 mppcf) is specifically listed by the ACGIH. Talc poses a special problem in that most of the product is finely ground, hence a proportionately large fraction of the material is in the respirable size range.

Uranium

U-1 is an underground uranium mine. The ore is a soft, easily crushed sandstone formation. Mining is by conventional stoping procedures at 3 different levels in the deposit. In the mine, ventilation is the primary method of dust control. It is quite efficient because of the need to control radon gas as well. With one exception, which will be discussed separately, all drilling and boring operations underground are wet. The principal method of ventilation is by means of exhaust fans operating out of vent holes. In addition to primary ventilation a series of flexible ducts are connected into the vent hole and carried along the entryways. This auxiliary tubing is taken up into slusher points and raises within the mining area to provide ventilation of each of the mining areas. Because of the softness of the ore, its high moisture content (14 to 15%) and the need to control the radioactive hazard, dust control in the mine workings is quite good.

The company is having two dust control problems, both associated with the material with a free silica content approaching 60%. The development entries being driven below the ore body tend to be in silicate rock. An alpine miner is used for the great majority of this work at the present time. Measured dust levels vary between 5 and 15 million particles/cu ft depending upon the hardness of the rock being cut by the miner. As in the stopes, 24 inch diameter auxiliary ducts are situated along side the miner to control the dust generated in the operation. When the machine is operating at full capacity, such ventilation is not adequate. Water sprays have been evaluated but have proved inadequate due to the high silica dust. Wetting agents have not been evaluated. Increasing the water spray rate was found to be detrimental in that the resultant air turbulence tends to displace the dust being generated beyond the intake of the auxiliary duct.

The second problem lies with a back filling operation. Because of high pressure aquifers above the mine level, they are back filling stopes with a fine sand drawn from the surface to prevent caving and the necessity for extensive pumping. This material is high in silica. Although the dispensing system has a water ring at the end for wetting, it was found that water is not sufficient. Again, wetting agents have not been investigated. At this time all men in the area of the back filling operation are required to wear respirators.

Because of the porous nature and wetness of the ore, there is little dust generated in the crusher and the subsequent transportation to the mill through the tripper floor and the belt galleries. External to the mill there are fugitive dust problems with tailings pile. An extensive program is underway to plant the tailings pile and thus control erosion and windage losses.

U-2 is an underground uranium mine. This mine is a stope type with open stopes into haulageways. This type mining is a modified room and pillar. Auxiliary fans and ducts are used for ventilation at the faces. The ore is shot then machine mucked with diesel front end loaders. The ore is hauled out with diesel cars. The dust level appeared low, however, the diesel fumes were heavy. Wet scrubbers are used on the diesel motors in summer but because of freezing they are not used in winter.

The plant processes ore from its own mines and purchases ore from other area mines. Dust control equipment in this plant includes three baghouse collectors. Hoods are installed above the primary, secondary and tertiary crushers and the belt transfer points. The dust is recycled by being dumped back onto the belts. This procedure was required by the AEC at the time the plant was constructed. The logic of the procedure related to the uniformity and accuracy of the in-line sampling procedure. It has proven to be an unnecessary precaution but the system remains as installed. The system of dumping the dust back on the belts causes the dust to be collected again at the transfer points along with the new dust being generated and causes an overloading of the dust collector and bad wear in the dust collector ducts which are not lined.

All grinding is a wet and continuous process. A central vacuum system is used for clean up. The only other dust control method is a wetting agent/water spray system installed at the ore screen prior to the primary jaw crusher.

Summary of Uranium Mining and Processing Plants -
High dust concentrations in underground uranium mines are non-existent since high volumes of air are required to maintain the radon concentration at acceptable levels. The radiation hazards associated with uranium dictates that dust be extremely well controlled in the processing plants, also.

SUMMARY OF UNDERGROUND DUST CONTROL METHODS ACCORDING TO JOB CLASSIFICATION

A total of 24 underground mines were visited. Most of the mines used conventional drilling and blasting methods, although a few were mining soft minerals where continuous mining machines were being used. Preliminary interviews with mine management revealed the general approach to dust control, and a tour of the underground facilities revealed the actual dust control practices which were being used. The following sections describe dust control methods which were used according to job classification or specific operations.

Drilling

All mining companies recognized the need for wet drilling. However, the effectiveness of water in allaying dust varied from mine to mine. These variations were due primarily to the water flowrate through the drill steel to the cutting face of the bit. As with many other mining operations, lack of maintenance appeared to be the primary reason for insufficient water supplies. Inoperative booster pumps, plugged filters and broken lines were observed in some of the mines.

Wet drilling in trona and potash deposits is limited due to the solubility of these minerals in water. Dust control during drilling in trona and potash mines was controlled in most cases by pneumatic collection of dust at the drill holes.

Ventilation practices during drilling varied according to the type of mining procedure. Auxiliary ventilation was generally provided in dead end stopes and drifts. One practice which was observed, and should be eliminated, was the reuse of return air from stopes in other stopes downstream in main air courses. This results in successively higher dust levels at each succeeding stope or other working place.

In spite of the fact that the mining industry recognizes the need for water and ventilation during drilling, this was one of the most frequently cited violation in the dust survey reports which were reviewed.

Blasting

Most mines blasted during off-shift periods or at lunch time although three of the mines blasting during the shift. Seven of the mines also performed secondary blasting during the shift. Wetting the area surrounding the blast location was standard practice in all of the mines. All but three of the mines used a water-air mist during blasting. The water-air mists not only reduced the amount of respirable dust but also served to wet the muck pile.

Since dust inspections cannot be made during blasting, none of the dust inspection reports had any information regarding dust concentrations during blasting. Current work being done for the Bureau of Mines indicates peak submicron particulate concentrations in excess of 100,000 particles/cm³ (2.8x10⁹ particles/ft³). This work also showed that it took about one hour for the submicron particulate level to return to the normal average concentration.

Mucking

Various types of mucking operations including hand mucking, mechanical slushing and load-haul-dump methods were used. Water and ventilation were the primary means of dust control. Figure 4 shows a typical mechanical slushing operation with both ventilation and water sprays to protect the slusher operator. Samples taken at the slusher operator station showed the area to be consistently less than the TLV.

Other mucking operations which were observed were not as well designed as the one shown in the figure. A block caving operation employed water sprays at the discharge from the finger raises. However, the amount of water which was used was limited due to collection of the water at the lower haulage level. Ventilation was also used in this operation. However, with two men working a series of finger raises, the man downstream of the man nearest the intake air was always exposed to levels exceeding the TLV. This still is a problem at the mine.

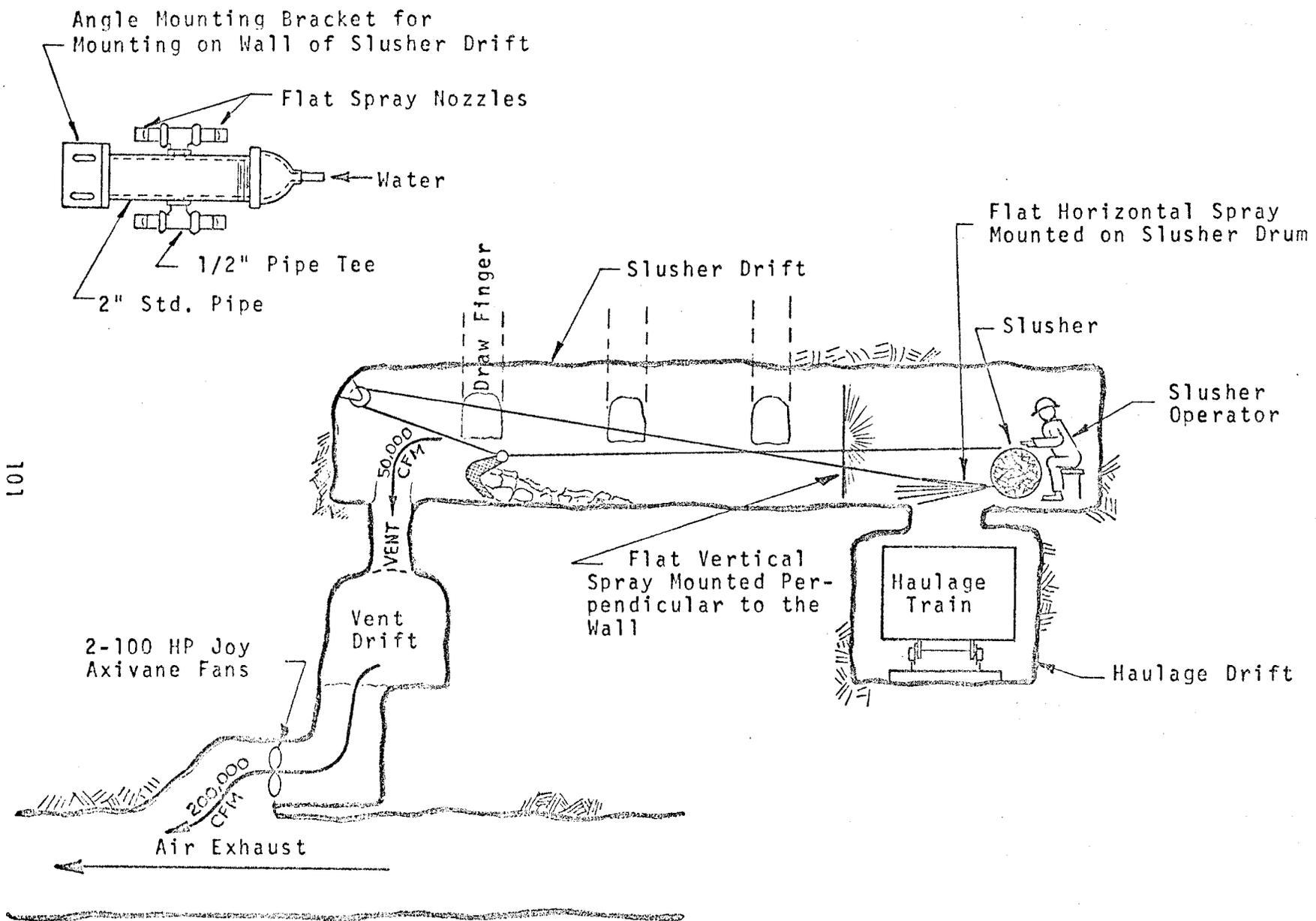


FIGURE 4 - DETAIL OF SLUSHER DUST SUPPRESSION

Muck piles were wet down in all of the mines which were visited. In most cases, this was done with a handheld hose. The depth of penetration of water was shallow thus dry, dusty material was continuously exposed during mucking. In most cases, the pile was not wetted again during mucking except in the case of six mines where continuous water sprays were used. Only two of the mines used water additives to aid in water penetration although nine of the mines had tried water additives at one time. Reasons given for discontinued use of water additives were (1) it did not appear to help or (2) it "might" interfere with the flotation process.

Ore Chutes and Dumps

Ore chutes and dumps pose a special problem in that the ore is coated with dust from previous operations and additional dust is generated due to the grinding action of rock against rock as it falls. In addition, the upsurge of air created by the falling rock causes the dust to become airborne.

In the mines which were naturally wet, no dust control was used at chutes and dumps. In the dry mines, all chutes and dumps were equipped with water sprays. In some cases, the water sprays were controlled manually while in other cases the spray control was automatic. The latter was observed most frequently at rotary and tip haulage car dumps.

Ventilation was also used to control dust at chutes and dumps. Figure 5 shows one type of ventilation system which was used. In other mines, air exhausts were located part way down the raise. In three of the mines, the air was filtered and fed back into the intake air. One mine used wood doors over the dump entry. These doors were operated pneumatically and the chute was maintained under negative pressure.

All mines with rotary car dumps housed the operator in an enclosed booth. Air to the booth was filtered. Some of the booths were evidently dusty in spite of the fact that filtered air was used. Poor maintenance of the filtering system was obvious in these cases.

The survey showed that chutes and dumps are a major problem in regard to dust control. Complete enclosure is not practical since a pathway is necessary for ore flow. Many variables including the type and size of ore and the distance that the ore falls affects the amount of dust produced.

Haulage

Haulage of ore from underground to the surface may be by truck, rail, conveyor, belt or a combination of these. Of the 98 underground mines listed in International Directory of Mining and Mineral Processing Operations (1972), the methods of haulage were as follows:

Rail	- 32
Truck	- 29
Belt	- 9
Rail and truck	- 16
Rail and belt	- 5
Truck and belt	- 6
Rail, truck and belt	- 2

Rail and truck haulage is used almost exclusively in hard rock mining, while belt haulage is used with the soft minerals such as potash, trona and gypsum. Only two of the mines visited used belt haulage.

Dust is generated during loading of haulage vehicles with the amount of dust depending upon the moisture content and the distance of fall of the ore. Four of the mines used sprays during loading and six of the mines sprayed the ore after it was loaded. Spraying during loading did not appear to be effective in controlling dust generation. Spraying after the ore is loaded does reduce dust generation during haulage and the amount of water required is small compared to the size of the load.

Haulageways can become serious dust sources, particularly when truck haulage is used. The mine operators recognized this problem and frequent wetting of haulageways was standard practice in dry mines where dust was a problem. Additives were used to stabilize the dust in some cases.

Summary of Underground Operations

Personnel responsible for dust control at the mines which were visited seemed to be quite knowledgeable in regard to current dust control methods. Most of the mines were making an effort to control dust but the effectiveness of these control measures varied considerably according to the type of mining operation, type of ore, acceptable moisture content of the ore, specific operation and so on.

The two major problem areas were (1) loading and dumping of ore and (2) slushing and chute tapping. Loading and dumping are problems since they not only generate dust but also are difficult to enclose by nature of the operation. Auxiliary ventilation systems at loading and dumping points have reduced the dispersion of dust. Water sprays have also reduced the dust concentration, but the operators are hesitant to use too much water since the moisture content of the ore can affect later operations such as crushing, grinding and screening. Control of dust during slushing and chute tapping is limited by the same factors as with loading and dumping.

One practice which was observed and should be eliminated was failure to discharge contaminated air immediately to a return airway. In many mines, the contaminated air was used to ventilate subsequent working sections.

Finally, lack of maintenance negated the effectiveness of dust control equipment, especially spray nozzles. Frequently only a few of the spray nozzles were operating. In some cases, the line filter was partially plugged rendering all of the nozzles ineffective due to low line pressure. Any attempt to improve dust control measures should be preceded by a thorough maintenance program on existing dust control systems.

SURVEY OF OPEN PIT DUST CONTROL METHODS ACCORDING TO JOB CLASSIFICATION

A total of 26 open pit mines were visited. Again, each visit involved a preliminary interview with one or more members of the mine operating staff to determine what dust problems existed and what dust control measures were being employed. This was followed by a tour of the pit to observe the dust control systems or methods being used.

Dust problems in open pits are less severe than those which exist in underground mines. Open pits do not have the confined work areas which underground mines have and natural air movement can be used for dilution ventilation. In addition, open pits in many parts of the country are wetted by frequent rain or snow storms which keep the ore wet. However, one should not infer from these comments that there are no dust problems in open pit mines.

The following sections describe the dust control methods which were used according to job classification or specific operation.

Drilling

Wet drilling is a universally recognized method for dust control and was practiced by all of the mines which were visited, weather permitting. Twenty-three of the mines used multiple drill rigs and three used single drills. The multiple rigs collared the holes wet, but the three single rigs used dry collaring.

The use of wet drilling cannot be over emphasized. Tests have shown that with wet drilling, dust levels of 0-5 mppcf can be expected while dry drilling for 3 minutes produced a dust level of 460 mppcf.

The granite industry was a leader in the use of wet drilling, and all granite quarries now use wet drilling. The various granite companies have installed central water heating systems so that wet drilling can be used during the

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most adverse winter conditions. The hard rock open pit mines in the northern tier of states discontinue the use of water during winter because water lines will freeze. The open pit metal mines are much larger than the granite quarries, however, it should be feasible to provide heated water for drilling at these pits.

Blasting

Blasting was performed either during off-shift periods or at locations where dust and fumes generated by the blast did not enter work areas. Dispersal of dust and fumes from the pit is accomplished with natural air currents.

Loading

Loading of the ore was done with either shovels or front end loaders. Prior to loading, rock piles were wetted. The amount of water used varied from mine to mine depending upon the amount of water which could be tolerated in the processing plant. Some companies used handheld hoses while others used automatic sprinklers. One company routinely wetted the pile with automatic sprinklers for at least 24 hours prior to loading. As with drilling, water was not used in the winter.

Haulage

Roadways are the primary dust source during haulage. All mining companies recognized the need for watering of roadways. Three of the companies used a soil binder to minimize formation of potholes. Care of roadways was stressed by many companies not only in regard to dust control but also to minimize wear and damage to haulage vehicle tires.

Roadways in open pits in the northern tier of states were generally not wetted during the winter months. Open pits in the warmer parts of the country were wetted during the entire year.

Some companies had installed filtration equipment on the truck cabs. However, the effectiveness of this approach was frequently negated because the drivers would not keep the windows up. This was especially true in the southwestern states during the summer.

Summary

Drilling can be a major dust problem if wet drilling is not used. In those geographical areas where winters are severe, a central hot water system is necessary to avoid freezing of water lines. Haulageways are the other major dust source in open pit mines. The use of water with additives or binders can control this problem.

SUMMARY OF DUST CONTROL METHODS IN PROCESSING PLANTS ACCORDING TO OPERATIONS

Fifty-one processing plants were visited during the study. The major areas of interest included crushers, grinders, transfer points, ore storage bins, driers, and concentrate loading stations. Mine management appeared to be very knowledgeable in current methods and equipment available for dust control. Large sums of money have been spent on dust control equipment. However, it was observed that lack of routine and preventative maintenance has rendered many of these systems ineffective.

Primary Crushers

The type and extent of dust control measures used on the primary crushers which were visited were influenced primarily by the location of the crusher and the method of feed to the crusher. Crushers which were located outside generally had no dust control devices, or at best a water spray system. Crushers which were housed inside buildings were fitted with better dust control systems ranging from water sprays to complete, negative pressure enclosures.

The type of feed to the crusher included dumping from a truck, rotary car dumps, tip car dumps, discharge from ore storage bins, pan feeders and belt feeders. Direct dumping from trucks or railroad cars was used almost exclusively in the nonmetal industries such as crushed stone and sand. Metallic ores were generally fed from ore storage bins using pan feeders or belt feeders.

Crusher operators were housed in control booths where ore feed rates and water spray rates were controlled. The degree of protection from dust afforded by these booths varied considerably. At one installation, the windows were broken and there was no door on the booth. Most booths had provisions for maintaining a slight positive pressure with filtered air. One installation which processed sand (98% free quartz) used an electrostatic precipitator to clean the incoming air and maintained the dust level inside the booth at less than the TLV of 0.1 mg/m^3 .

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The types of water sprays used at the mouth of primary crushers varied from home-made devices to completely automated systems using wetting agents. One home-made type of spray was a piece of copper tubing flattened on the end to provide a flat spray. Other companies installed the plumbing and purchased spray nozzles from suppliers. Most nozzles were a flat spray, wide angle type. Three companies employed automated spray systems which were activated by the feed. All three systems used water additives which were automatically premixed to a designed concentration in a large holding vessel and were subsequently pumped to the spray sites.

All efforts to correlate the number of water sprays or the amount of water used with the size of the crusher or the daily throughput proved fruitless. This was due to a number of reasons including the variability in the estimated requirements made by the mining company engineers, the natural moisture content of the ore, the variation in flowrates which resulted from adjustments made by the crusher operator and finally to the number of plugged nozzles. Plugged or partially plugged nozzles were observed at all of the installations which were visited. Plugging was caused primarily by dirt in the water lines lodging in the orifices. Water pressure and the resultant water flowrate also varied according to the increased pressure drop across in-line filters as they became clogged with dirt.

Sprays can reduce dust at crushers. However, the state-of-the-art in regard to the number of sprays, type of sprays and water flowrates is poorly developed. Research in this area could provide useful guidance to the mining community for control of dust at crushers.

Some companies completely enclosed the feed to the crusher thus eliminating the need for water sprays. This approach is more effective than water sprays since all of the dust is contained and captured if the enclosure is properly constructed and maintained. In addition, the moisture content of the ore is not increased hence crushing, grinding and screening problems are not created. The disadvantages are the high initial cost of dust capture and collection equipment, the operating cost of the equipment and the maintenance costs. Furthermore, this method is not practical where direct dumping rather than pan feed, belt feed and gravity feed from ore bins is used.

When enclosures are used, the enclosure is maintained under negative pressure and the exhaust air is delivered to a collector. If complete enclosure is not possible, the necessary air flow can be estimated by multiplying the area of openings (in sq ft) by 200 ft/min. The type of collectors which were used included baghouses, wet centrifugal scrubbers and venturi scrubbers. When wet scrubbers were used, the collected dust (slurry) was transferred to a later wet processing step. With dry collection, the dust was generally returned to some point in the dry processing stream. This latter practice is undesirable since the fine dust returned to the ore stream can easily become airborne again.

Ore from a crusher may discharge to a storage bin or directly to a conveyor belt. Poor practices were noted quite frequently in these areas, perhaps due to the fact that these areas are generally unmanned. However, airborne respirable dust can migrate to manned areas and result in exposures exceeding the TLV.

In most metal ore processing, the discharge from the crusher was enclosed and maintained under negative pressure. However, this was one of the areas where poor maintenance procedures were observed. Skirts and shrouds were worn and loose fitting. Inspection doors were frequently left open and poorly fitted. In seven cases, the ductwork was worn through and visible plumes of dust were observed issuing from the holes in the ductwork.

Secondary and Tertiary Crushers

The dust production rate increases as the size of the product decreases. The mining industry realizes this and dust control measures were significantly better at secondary and tertiary crushers than at primary crushers. The use of wet scrubbers at these operations far outweighed the use of dry collectors.

As with primary crushers and other dust producing sources, the effectiveness of the dust control systems at secondary and tertiary crushers was a function of the design, construction and maintenance of the capture, transport and collection systems.

Improper shrouding and worn or poorly fitted skirts were major contributions to the escape of airborne dust. Other

factors included undersized ductwork, plugged ductwork and improperly balanced flowrates. A general rule of thumb of 4000 fpm for transport velocity was used by most companies.

Screens at the crushers were major dust sources. In most cases, these were enclosed and maintained under negative pressure. Poorly fitted enclosures were the primary cause of dust release.

Transfer Points and Beltways

Transfer points were major dust sources in processing plants. Although enclosures were used, loosely fitting skirts allowed dust to escape. The height of ore fall and belt speed are the two main factors in dust generation. One company rigorously limited the height of ore fall to 6 ft and belt speed to 250 fpm; dust surveys which had been made at this company's processing plant showed consistently low dust concentration ($<0.2 \text{ mg/m}^3$).

In addition to enclosure, water sprays were used frequently at transfer points. In some cases, these were manually activated while in other cases, the sprays were activated automatically. Plugged spray nozzles were observed in many of the processing plants.

One asbestos company completely enclosed all beltways. This was, of course, a major understaking, but it did eliminate the problem of airborne asbestos fibers. Ports for clean out and maintenance were provided. These were tightly fitted and gasketed.

Belt cleaners were used by some of the companies. These should be used especially when belts are long and moist dust has time to dry and become airborne. Brushes, scrapers and washers were used. Brushes and scrapers should be housed in an enclosure maintained under negative pressure to prevent the dust from becoming airborne. Belt washers appeared to be the most effective means of belt cleaning.

Storage Bins and Loading Operations

Storage bins and loading operations are major dust sources. At this stage of processing the ore is fine and contains a large amount of dust in the respirable size range. Loading these fines to storage bins displaces air and produces large quantities of airborne dust.

Two methods were used to avoid overexposure of employees:

1. House the chute operator in a positive pressure enclosure with filtered air.
2. Cover the bin or railroad car port and maintain it under negative pressure.

Dust samples showed that enclosures, when properly sealed and provided with filtered air, did an effective job in protecting the operator. However, fugitive dust from the operation can migrate to other areas of the plant and cause overexposure of other personnel. Maintaining the inlet port under negative pressure prevented the dispersal of fugitive dust. However, in many instances the exhaust volumes were too low to handle the air surges and thus the system was ineffective.

CONCLUSIONS

The major conclusion which was reached as a result of this survey was that lack of routine maintenance was the primary factor in failure to control dust. Specific trouble spots were:

1. Plugged water spray nozzles
2. Plugged water line filters
3. Holes in ductwork and clogged ducts
4. Worn skirts
5. Settled dust
6. Loose fitting ports
7. Missing bolts and open bolt holes in enclosures.

It is obvious that production maintenance has priority over dust control maintenance. However, it is unfortunate that hundreds of thousands of dollars have been spent for dust control equipment at a single processing plant and yet a dust problem still exists due to lack of maintenance.

Failure to clean up fugitive dust was cited in many of the dust survey reports which were reviewed. The three methods used to clean up dust were push brooms and shovel, mobile vacuum sweepers and integrated, plant-wide vacuum systems. The use of push brooms should be avoided since this aerosolizes the dust and thus creates a hazard. Mobile vacuum sweepers are better, yet three companies do not use them maintaining that the respirable dust fraction is not collected by the bag. A plant-wide vacuum system is by far the best method since the collected dust can be transported to a remote baghouse or wet scrubber.

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RECOMMENDATIONS

A review of available dust collection systems showed that units are available which will effectively maintain dust concentrations below allowable TLV's. However, the effectiveness of the collection equipment is a direct function of the auxiliary equipment such as enclosures, skirts, shrouds and so on in the case of exhaust ventilation systems. The effectiveness of water spray systems depend upon proper water pressure and volume and the proper number of nozzles. The effectiveness of any dust control system is limited if the system is not properly maintained.

Revisions to the Metal and Nonmetal Health and Safety Act will undoubtedly result in more frequent inspections and stronger enforcement procedures. This will require that the metal and nonmetal mining industry use current dust control equipment and methods to their maximum efficiency. This can be done only through proper selection, design and maintenance of the equipment or methods. It is recommended, therefore, that a number of research programs on dust control methods be undertaken, with the objective being to demonstrate to the industry that dust can be controlled.

Specific areas which would warrant R&D studies are:

1. Evaluation of off-the-shelf dust control and collection devices -
The efficiencies of baghouse collectors, wet cyclones and scrubbers, dry cyclones, electrostatic precipitators and so on have been studied and reported by equipment manufacturers. The overall efficiency of these systems is dependent, however, on the auxiliary equipment such as enclosures, skirting, ductwork size, ductwork configuration and air velocities. A demonstration of the effectiveness of existing equipment, when properly designed, installed and maintained should be made. Specific locations where this type of equipment is being used are crushers, dumps, chutes and transfer points.

2. Evaluation of the effectiveness of water sprays at transfer points - Most water spray systems which have been installed in mines have been designed on a trial and error basis. The mining industry has expressed interest in the development of guidelines for water spray systems. Parameters which would affect the number, type and water capacity of the sprays include natural wetness of the ore, belt width and belt speed. A systematic study aimed at the development of guidelines would be valuable to the mining industry.
3. Evaluation of water sprays at crushers, dumps and slushers - Water spray systems which have been installed at these dust generating sites have been designed by trial and error, also. Again, a comprehensive evaluation of water sprays as a function of the cross sectional area of the opening, the height of fall, ore loading rates and so on would benefit the mining industry.
4. Effects of water additives - Little work has been done on the effect of water additives in dust abatement in the non-coal mining industry. A program directed at evaluating the efficiency of dust control with additives could provide an incentive for the mining community to use additives. In addition, it must be shown that these additives have no affect on ore processing, particularly the flotation process.
5. Development of methods to minimize plugging of spray nozzles - The mining industry is plagued with the problem of plugging of spray nozzles. This results in excessive maintenance programs and frequently the sprays become completely inoperable.

Plugging is caused by dirt and corrosion products which are present in the mine water supply. Efforts at developing easily cleaned or self-cleaning filters would provide more effective use of water spray systems.

6. Evaluation of new dust control methods for soft, water soluble minerals - Trona and potash mining are typical examples where the use of water must be limited. Excess water results in slippery conditions in drifts and caking of the product during processing. High expansion foam could provide a means of controlling dust on continuous and longwall mining machines with less water required than with water sprays. Integral scrubbers on continuous mining machines should be considered also since these have shown some degree of effectiveness in controlling dust generated by continuous mining machines in coal mines.
7. Evaluation of belt cleaning systems - Dust adhering to belts is a continuous source of airborne particulates as well as settled dust at idlers and take-up pulleys. Belt scrapers appear to be relatively ineffective. The belt washing systems which were observed not only reduced the respirable dust concentration in belt galleries, but also greatly reduced settled dust at idlers and pulleys. As with sprays, design of belt washing systems has been on a trial and error basis. A study of belt washing system design as a function of belt width and speed would be of value, and the mining industry would likely be interested in such a system since maintenance and clean up problems are greatly reduced.

The recommended programs should demonstrate to the mining industry that dust can be controlled, and should provide guidelines for design of dust control systems.

The metal and nonmetal mining industry should initiate efforts to reduce dust concentrations. Engineering, ventilation and industrial hygiene departments within companies, or outside consultants, can be used to determine dust problem areas and possible means of controlling dust. A bibliography is included herein as a guide to dust measurement and control methods.

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