ASSESSMENT OF DUST CONTROL TECHNOLOGY

FOR

SELECTED CERAMIC PRODUCTION PROCESSES

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ABSTRACT

An assessment of dust control technology for selected ceramic industry production processes was conducted by the National Institute for Occupational Safety and Health. Four ceramic industry sites were evaluated in depth. The primary processes evaluated were the crushing of ball clay, shale and pyrophyllite in the wall and floor tile industry; the grinding of finished quarry tile in the wall and floor tile industry; and the crushing and formulation of raw materials in the refractory industry. Several dust control procedures were found to effectively control exposure levels below the OSHA Standard. These include: (1) isolation of workers from major dust-producing operations; (2) isolation of major dust-producing operations from other plant operations; (3) enclosure and ventilation of processing and material transfer equipment; and (4) design of equipment and facilities to permit the use of centralized ventilation systems and washdown of facilites.

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Executive Summary

Background

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering Control Technology Branch has been given the lead role in this effort and has conducted a number of health hazard control technology assessments on the basis of industry, process or control techniques.

These studies involve a number of phases:

- o preliminary or walk-through surveys are conducted to select sites having effective and potentially transferable control concepts or techniques;
- o in-depth surveys are conducted to determine both the control parameters and the control effectiveness; and
- o findings are reported in technical reports and journal articles to build the data base of publicly available information on hazard control techniques.

Industry Selection

The ceramics industry was selected for this study because:

- o there are approximately 100,000 workers potentially exposed to silica-containing dusts in the production of structural clay and pottery products;
- o a number of NIOSH Health Hazard Evaluations (HHE's) reported the existence of unhealthful dust conditions; and

- the Occupational Safety and Health Administration (OSHA) reported that, over a 5-year period (1975-79), 83% (225 of 270) of the samples collected for crystalline silica exceeded the Permissible Exposure Limit (PEL).

Control Strategy

Control strategy for the ceramics industry is based on the premise that occupational exposures to silica-containing dust can be controlled by the application of a number of well-known principles including engineering measures, work practices, personal protection and monitoring.

Purpose

The purpose of this study was to evaluate and document the health hazard control procedures being used to control dust in the ceramic production industry (including the operating parameters of the exhaust ventilation systems) and to identify gaps in existing control technology.

Scope

Although the potential for hazardous exposures to crystalline silica exists throughout the ceramics industry, the scope of this study was limited to selected production processes having the highest hazard potential. The major emphasis was on the assessment of controls used during:

- the crushing of ball clay, shale and pyrophyllite in the wall and floor tile industry;

- the grinding of finished quarry tile in the wall and floor tile industry; and

- the crushing and formulation of raw materials in the refractory industry.

Methodology

Three types of Total Dust and Respirable Dust samples were collected and analyzed for crystalline silica (quartz):

- o personal (breathing zone) samples to estimate actual personnel exposures;
- o area (background) samples to estimate the contribution of ambient dust to overall dust levels; and
- o source samples to estimate the efficiency of a specific dust control system.

In addition to the collection of the above dust samples, material samples, rafter samples and bulk air samples were collected to determine the composition of airborne dust, qualitatively and quantitatively. Air velocity, air volume and air flow pattern measurements were made to evaluate the effectiveness or efficiency of local exhaust and general ventilation systems.

Results

Dust control procedures in three of the four sites studied were generally effective in maintaining dust exposures below the OSHA Standard.

Site A

Site A involved the crushing and grinding of pyrophyllite ore to production specifications in the wall and floor tile industry. Exposures to airborne dust containing approximately 13% silica were maintained below the OSHA Standard (averaging 22% of the PEL for personal samples and 33% of the PEL for area and source samples) by a combination of control procedures including:

- o isolation of major dust-producing operations, such as bulk transport of ore from stockpiles and the coarse-crushing circuit, from the other grinding plant operations;

- isolation of workers in a filtered, air-conditioned front-end loader and control room;

- enclosure and ventilation of processing and material transfer equipment;

- a good housekeeping program utilizing a permanently installed central air vacuum system;

- a personal protective equipment program; and

- an environmental/medical monitoring program.

Site B

Site B involved the crushing of ball clays and shale to -35 mesh (approximately 300 um) particle size in the quarry wall and floor tile industry. Exposures to airborne dust with a crystalline silica content of approximately 19% Respirable Fraction and 24% of Total Dust exceeded the OSHA Standard. Personal samples averaged 106% of the respirable PEL and 361% of the total dust PEL. Area and source samples averaged 172% of the PEL. Major contributors to these exposures were:

- the ball clay and shale storage areas and movement of these materials were not isolated from the rest of the crushing plant;

- conveyor transfer-points were not enclosed nor equipped with local exhaust ventilation;

- crusher operators were not provided with an isolated control room;

- the additive feeder/vibrating screen area local exhaust hoods were improperly designed and located; and

- the overhead exhaust duct transport velocity was insufficient due to improper operation and maintenance.

Site C

Site C involved the finish grinding of tile in the quarry wall and floor tile industry. Exposures to airborne dust containing approximately 19% silica were maintained below the OSHA Standard (averaging 53% of the PEL for personal samples and 84% of the PEL for area and source samples) by the use of local exhaust ventilation on all grinding machinery. An environmental/medical monitoring program was also observed.

Site D

Site D involved the batching, mixing and packaging of ceramic materials in the refractory industry. Exposures to airborne dust containing approximately 6.7% silica were maintained below the OSHA Standard (averaging 60% of the PEL for personal samples and 50% of the PEL for area and source samples) by a combination of control procedures including:

- design of facility layout to permit efficient use of a centralized local exhaust ventilation system;
- design of equipment and facilities to permit effective washdown of spilled product;
- enclosure and ventilation of all processing and material transfer equipment;
- use of semi-automatic material handling systems to fill containers;
- a good housekeeping program utilizing end-of-shift washdown procedures and a large mobile industrial vacuum sweeper; and
- an effective personal protective equipment program.

Significant Findings

- Materials used in these ceramic industry processes contain significant amounts of crystalline silica.

- State-of-the-art control technology exists to control silica-containing dust in the ceramic industry processes studied.

I. INTRODUCTION

A. Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services (formerly DHEW), it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, ECTB has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. Examples of these completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concepts or techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures.

Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

B. Background for the Ceramic Industry Study

This study of the Ceramics industry was undertaken because there are approximately 100,000[1] workers potentially exposed to silica-containing dusts in the production of structural clay and pottery products. Other NIOSH studies have indicated that the handling of dry material, such as pesticides[2] and silica flour,[3] is an important source of airborne dust generation in the workplace. The latter, silica flour study revealed that as much as one-half of the environmental silica dust exposures may be effectively controlled by good work practices including effective housekeeping practices. The problem of dust dispersion during material handling spans many industries and can be a major source of exposure. Although several industries may have devised successful methods of dust control, our literature review revealed that there is presently no centralized information base making the solutions universally available. The results of this study will help to overcome this shortcoming.

NIOSH Health Hazard Evaluations (HHEs)[4,5,6] of ceramics industry workplaces have shown the importance of effective engineering controls. Three Health Hazard Evaluations attribute the existence of unhealthful dust conditions at the time of the surveys to inadequate ventilation. In all of these studies, where high workroom-air contamination and adverse health effects were documented or suspected, inadequate ventilation was identified as a contributing factor. In addition to improved local exhaust ventilation, other control measures recommended in the reports include modified work practices, better worker education about occupational hazards, and the appropriate use of personal protective equipment. In total, these studies show a need for continuing activity in control technology development.

During the period July 1974 through June 1979, the Occupational Safety and Health Administration (OSHA) reported[7] that 83% (225 of 270) of the samples collected for crystalline silica in the ceramics industry exceeded the Permissible Exposure Limit (PEL). Our preliminary surveys and contacts with industry personnel seem to indicate that there are now controls in place that reduce these excesses. This study will document the existence and usage of these controls.

C. Control Strategy

Occupational exposures can be controlled by the application of a number of well-known principles (Appendix A), including engineering measures, work practices, personal protection, and monitoring. These principles may be applied at or near the hazard source, to the general workplace environment, or at the point of occupational exposure to individuals. Controls applied at the source of the hazard, including engineering measures (material substitution, plant layout and design, process/equipment modification, isolation or automation, local ventilation) and work practices, are the preferred and most effective means of control both in terms of occupational and environmental concerns. Controls which may be applied to hazards that have escaped into the workplace environment include dilution ventilation, dust suppression, and housekeeping. Control measures may also be applied to protect individual workers, including the use of remote control rooms, isolation booths, supplied-air cabs, work practices, and personal protective equipment.

In general, a system comprised of a combination of the above control measures is required to provide worker protection under normal operating conditions as well as under conditions of process upset, failure and/or maintenance. Process and workplace monitoring devices, personal exposure monitoring, and medical monitoring are important mechanisms for providing feedback concerning effectiveness of the controls in use. Ongoing monitoring and maintenance of controls to ensure proper use and operating conditions, and the education and commitment of both workers and management to occupational health are also important elements of a complete, effective, and durable control system.

In any presentation of control strategies, it is necessary to discuss the relationship between effectiveness and efficiency as it relates to the overall control system. In this report, "control effectiveness" is defined as "the capability of the control system to maintain exposures at or below a specific standard or design exposure level." Thus, it is a function of both the control system and of the hazard potential of the material being controlled. For example, a specific control system may be "effective" in controlling one type of dust (eg. a low silica-containing dust) whereas, it may be "ineffective" in controlling a second type of dust (eg. a high silica-containing dust or a toxic pesticide dust).

On the other hand, "control efficiency" of a system may be defined as the fraction of the dust removed from the environment by the control system divided by the dust emitted by the system. Our evaluations of efficiency, normally must be indirect and approximate, since it is usually not feasible to measure the total amount of a potential emission source without major disruption of the control system and/or production. Thus, a control system may be highly "efficient" in controlling a dust source (ie. 95 per cent efficient); yet, it may be at the same time "ineffective" if the 5 per cent emission results in an environmental exposure above the Permissible Exposure Limit (PEL). Conversely, a system may be of low control efficiency (50-80 per cent); yet it could be "effective" if the dust is non-toxic or the potential emission rate is of a low magnitude.

D. Purpose of Study

As mentioned above, the major health hazard in the ceramics industry is exposure to silica-containing dusts. The purpose of this study was to evaluate the effectiveness of the health hazard control procedures which are presently being used to control silica-containing dust in this industry. The specific objectives were:

1. To evaluate and document the effectiveness of the individual health hazard control technology methods in use.

2. To evaluate and document the operating parameters of the exhaust ventilation systems in use.

3. To identify gaps in existing control technology, which may be resolved by appropriate research and development programs.

E. Scope of Study

The potential for hazardous exposures to silica dust exists throughout the ceramic industry. These exposures may occur during mining, crushing, milling, forming, drying, firing, and grinding of raw materials, intermediates, or finished products. The major emphasis of this assessment, however, was limited to exposure control during: (1) the crushing of ball clay, shale and pyrophyllite in the wall and floor tile industry[8,9]; (2) the grinding of finished quarry tile in the wall and floor tile industry[8]; and (3) crushing and formulation of raw materials in the refractory industry[10]. The various aspects of hazard control technology, including engineering, environmental monitoring, work practices, and use of personal protective equipment, were evaluated either quantitatively or qualitatively.* The primary evaluation was directed toward engineering controls. Preliminary surveys were conducted in 22 plants in the structural clay and pottery products part of the ceramic industry. Four sites were selected for in-depth evaluation. Management at each of these sites demonstrated a commitment to improved worker health; and recent company and/or OSHA environmental data supported this commitment.

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* Quantitative evaluations involved measurements of environmental dust exposures or control systems; whereas, qualitative evaluations involved professional judgments of the effectiveness of the control parameters.

II. METHODOLOGY

A. Health Hazards Investigated

Several minerals are encountered in the ceramics industry as raw materials, intermediates, and final products. The minerals found in this survey include: ball clays, pyrophyllite, shales, flint, zircon, alumina, liquid silicates and phosphates. The major components of these minerals are "combined" silicates and carbonates of aluminum and magnesium, which are generally considered to be "nuisance dusts" from a health hazard view point. However, many of these minerals contain significant quantities of crystalline free silica or quartz as shown in Table I.

Table I. Silica Content of Selected Mineral Dusts

	% Silica (as Quartz)	
Mineral	Respirable Dust	Total Dust
Ball Clay	19	24
Shale	19	24
Pyrophyllite	13	39
Refractory Raw Materials	7	7

Exposure to quartz dust, by inhalation, can produce a pulmonary disease, silicosis, which is both debilitating and irreversible[11]. The onset and severity of this disease is determined by the amount of dust inhaled (airborne concentration), the length of exposure (in years), the percentage of silica (quartz) in the dust and the particle size range (respirability) of the dust. The OSHA standards for Permissible Exposure Limits (PEL's)[12] for the mineral dusts encountered in the ceramics industry are based on the quartz content of the airborne (inhaled) dust according to the following formulae:

$$\text{PEL (respirable dust)} = \frac{10}{\% \ SiO_2 + 2} \text{ milligrams per cubic meter of air, } (mg/m^3)$$

and

$$\text{PEL (total dust)} = \frac{30}{\% \ SiO_2 + 2} \ mg/m^3$$

Table 1a. presents examples of calculated PELs for Respirable Dust and Total Dust, based on the above formulae at increasing levels of quartz:

Table 1a. PELs for
Silica-Containing Mineral Dusts

% Silica (as quartz)	PEL mg/m^3 Respirable Dust	Total Dust
0	5.0	15.00
5	1.43	4.29
10	0.83	2.50
15	0.59	1.76
20	0.45	1.36
40	0.24	0.71
50	0.19	0.58
75	0.13	0.39
100 (pure silica)	0.10	0.29

Although the above PELs refer specifically to the 8-hour, time-weighted average (TWA) exposure, "to which nearly all workers may be exposed day after day without adverse effect"[7], in this research, the PEL's are used as environmental criteria to evaluate the effectiveness of the control systems in use. NIOSH has recommended that exposures to all forms of crystalline silica, including quartz, be reduced to 0.05 mg/m^3[11].

B. Environmental Evaluation Procedures

1. Environmental Dust Measurements

Three types of Total Dust and Respirable Dust samples were collected and analyzed for crystalline silica (quartz) by Methods listed in Appendix B. These samples were collected for the duration of a workshift, usually on three consecutive days of work operations.

(a) Personal (breathing zone) samples were collected on employees.

(b) Source samples were collected near sources, such as conveyor transfer points; and by operator stations, bag packing stations and other points where dust emissions were possible.

(c) Area (background) samples were collected in general work areas and outside plant buildings (upwind and downwind).

Personal samples were collected to estimate actual exposures of personnel to atmospheric dust as they moved from station to station throughout the work day. Source samples were collected to estimate the efficiency of a specific dust control system by assuming that the magnitude of uncontrolled dust from a potential source was a function of the difference between the total dust level at that source and the background/room dust level. Area and background dust samples were collected to estimate the contribution of ambient dust to overall dust levels at work stations and to personal exposure levels.

In addition to the collection of atmospheric dust samples, material samples, rafter samples, and bulk air samples were collected to determine the composition of airborne dust, qualitatively and quantitatively. All sampling equipment was calibrated in NIOSH's Engineering Control Technology Branch (ECTB) industrial hygiene laboratory prior to use. Air and material samples were analyzed for Total Dust, Respirable Dust and silica content at the Utah Biomedical Test Laboratory (UBTL), Salt Lake City, Utah[13,14].

2. Ventilation Control Measurements

Air velocity, volume and flow pattern measurements were made to evaluate the effectiveness or efficiency of local exhaust ventilation and general ventilation systems[15].

(a) Quantitative air velocity measurements were made at local exhaust hoods, through transport ducts and at the exhaust of fans and air filters. These measurements were made with a calibrated Pitot-static tube or with calibrated thermal anemometers, listed in Appendix C.

(b) Qualitative air flow patterns were defined around capture hoods and other controlled emission sources using Gastec Smoke Tester tubes.

The effectiveness of other dust control procedures was also evaluated qualitatively. These included vacuum cleaning and other housekeeping equipment and procedures; enclosures of product-handling equipment; maintenance schedules; work practices and environmental-medical monitoring programs.

III. CONTROL TECHNOLOGY EVALUATION

A. Crushing and Grinding of Pyrophyllite in the Ceramic Tile Industry (Site A)[9]

1. Process Description

At one site, ball clay, flint, and pyrophyllite are processed to make glazed floor and wall tiles. Pyrophyllite ore is crushed and ground in a grinding plant and transported pneumatically through a 6-inch pipe to a separate production building approximately 350 feet away.

The grinding plant is divided into two main buildings, a pyrophyllite raw materials storage building (RMSB) and a processing building (PB), which are physically separated by a wall (Figure 1).

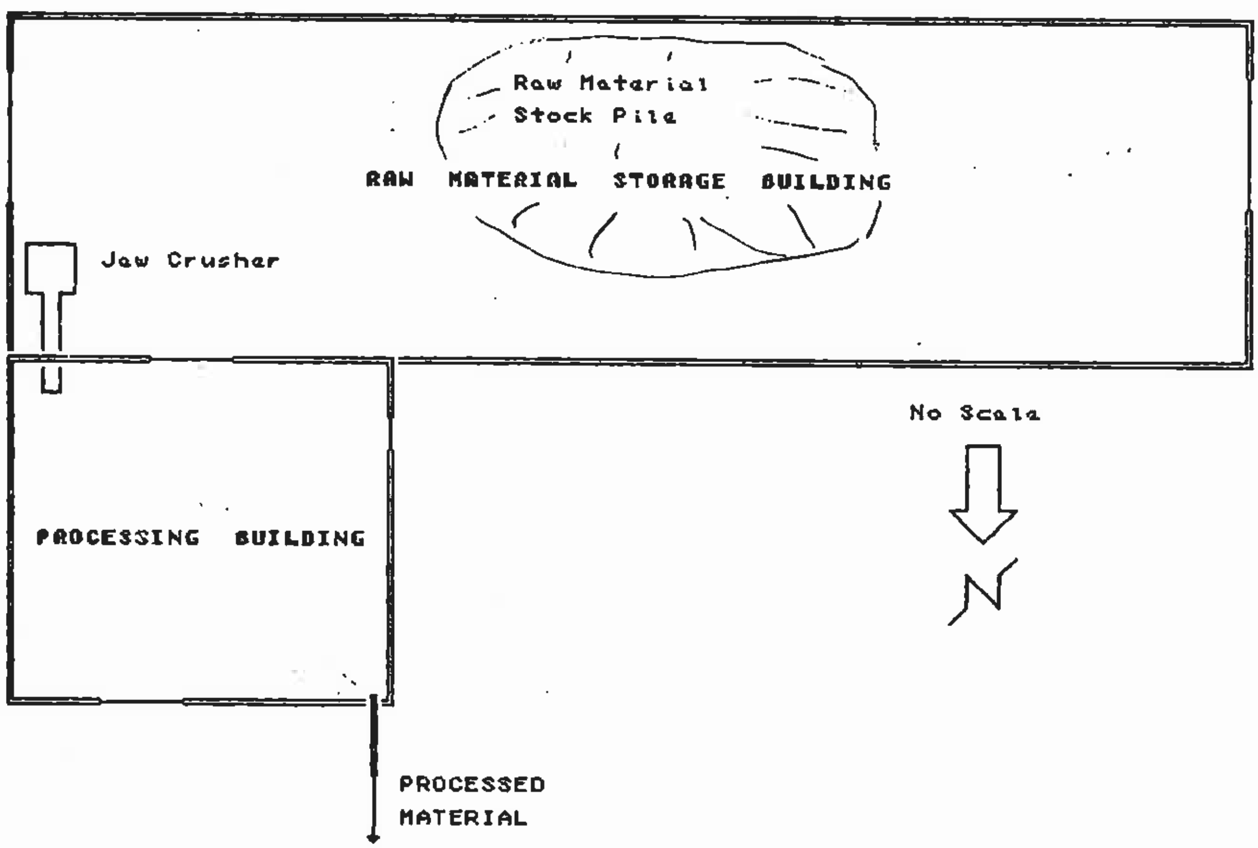


Figure 1. Storage and Processing Buildings

Bulk Newfoundland pyrophyllite, with a moisture content of approximately 5% and a crystalline silica (quartz) content of approximately 13%, is transported by truck to a bulk storage pile in the storage area. It is moved periodically from the bulk storage pile to the loading hopper of a coarse crusher (12" x 24" jaw crusher) in the storage area by means of a cab-enclosed, filtered, air-conditioned front-end loader. The coarse-crushed material is then transported, via an 18" troughing conveyor, through an opening in the wall, to the processing area of the grinding plant.

The damp, coarsely-crushed pyrophyllite is then conveyed through a series of surge tanks, a rotary drier, vibrating screens, a cone crusher for fine crushing, blending silos, and fine grinding in a ball mill. The finely ground material, dried to essentially 0% moisture, is discharged from the ball mill to a classifier, where properly-sized material passes to a product collector, and oversized material is returned to the ball mill for further grinding. Production-size pyrophyllite, as a final product, is then conveyed pneumatically (under low positive pressure) to the adjacent tile production building. Transport to and from the processing equipment is accomplished by a series of enclosed troughing conveyors, bucket elevators and shuttle conveyors.

2. Controls

Exposures to airborne dust are maintained below the OSHA Standard by a combination of procedures including:

- Engineering controls, including plant layout and equipment design; enclosure and ventilation of processing and material transfer equipment; and isolation of potentially dusty areas.

- Good work practices, including housekeeping procedures and scheduled maintenance of equipment and facilities.

- o Availability and proper use of personal protective equipment, including hard hats and dust respirators.

- o Environmental monitoring of worker exposures to dust and medical monitoring of potential physiological effects of excessive exposures.

a. Engineering controls

Plant layout and equipment design

The major potential dust-producing operations, such as bulk transport of pyrophyllite ore from stock piles and coarse ore crushing, are performed in one building. This building is separated physically from the grinding plant by a floor-to-ceiling wall. A small opening in one corner of the wall provides access for transfer of damp, coarsely-ground material to the processing building via a trough conveyor.

A front-end loader is used to move the bulk pyrophyllite from the storage pile to the coarse crusher system. The operator is isolated from excessive dust in this area, by performing most of his work in an enclosed, filtered, air-conditioned cab of the front-end loader. Similarly, in the grinding plant, the operator performs most of his tasks either in a filtered air-conditioned office/control room or at the operator's control desk where atmospheric dust levels are low.

All product handling and movement through the plant is automated, except for loading of the primary jaw crusher in the storage area. Potential airborne dust sources are contained or controlled by enclosure and ventilation of material processing and transfer equipment.

Ventilation systems

All material conveying systems are either of a trough or enclosed design to minimize dust emission. Local exhaust ventilation systems are used to capture and contain potential point sources of dust, such as open transfer points, between conveyors or between conveyors and bucket elevators. Thirteen open material transfer points are provided with local exhaust ventilation hoods. In addition, exhaust ducts are connected to three enclosed transfer points and to three enclosed processes, to minimize dust dispersion to the general work atmosphere.

Airborne dust, captured at these operational control points, is transported via ventilation ducts to a baghouse, where the dust is separated from the air stream and returned to a main product storage bin. The baghouse system contains 120 12-foot, polyester felt collecting tubes. It is designed to operate at 15,000 cubic feet per minute (cfm).

b. Work Practices

Effective workroom housekeeping, including cleanup of spilled product, is accomplished by the use of a permanently installed central air vacuum system. The system contains forty 1-1/2-inch inlet valves, strategically located throughout the plant. Operators and helpers are trained in the correct methods for cleaning up spills and other dust accumulations as rapidly as possible. This reduces the potential for re-entrainment of dust into the work atmosphere.

c. Personal Protective Equipment

Head protection is required in both the Processing Building and the Storage Building of the grinding plant. Since airborne dust levels are generally low throughout the grinding plant, respirator use is not required. However, NIOSH/MSHA-approved dust respirators are provided to workers on an "as needed" basis.

d. Environmental/Medical Monitoring

Annually, the company's industrial hygienist conducts atmospheric dust evaluations at strategic locations in the Storage and Processing Buildings. Personnel exposure evaluations are also made among the grinding plant operators. Additionally, annual physical examinations, including chest x-rays and pulmonary function tests are conducted by a Company contract physician.

3. Sampling Results and Control Effectiveness

The Newfoundland pyrophyllite, processed in this crushing plant, is essentially an aluminum silicate mineral, which contains approximately 13% crystalline silica as quartz (ranging from 12 to 18%). The calculated Permissible Exposure Limit (PEL), established by OSHA for this Respirable Dust is 0.67 mg/m^3 (ranging from 0.50 to 0.71 mg/m^3).

Overall Control Effectiveness

The overall effectiveness of the dust control system at this plant is judged to be excellent, as demonstrated by evaluation of both personal exposures and area exposures to atmospheric dust (see Table 2).

Personal Exposures

Personal exposure samples (up to 8 hours per day) were collected on two operators in the crushing plant on three consecutive work days.

Table 2. Average Respirable Dust Exposures in Crushing Plant - Site A

Location (sample numbers)	Type sample	% Quartz	PEL mg/m^3	Dust Conc. mg/m^3	Fraction of PEL	Work activity
A. Raw Product Storage Building						
1. At jaw crusher (#1)	SOURCE	18	.51	.71	1.40	high
2. General room area (#20 and 21)	AREA	12	.71	.11	.15	high
3. Loader operator (# P2)	PERSONAL	14	.63	.24	.38	normal
B. Process Building						
1. Near blenders 1 to 5 (#2, 3, 4, 5, 6)	SOURCE	13 (12 to 14)	.67	.32 (.15 to .73)	.48	low to medium
2. Near drier surge bin (#7, 8, 9)	SOURCE	17 (16 to 18)	.53	.20 (.15 to .23)	.38	med. to high
3. Ball mill surge tank (#10)	SOURCE	12	.71	.12	.17	high
4. After cone crusher (#11, 12, 13)	SOURCE	15 (13 to 17)	.59	.32 (.20 to .48)	.54	medium
5. Office/control room (#25)	AREA	12	.71	.13	.18	low
6. Operator's desk (#23)	AREA	12	.71	.07	.10	low
7. General room - ground floor (#22, 24, 26, 27, 28)	AREA	12	.71	.11 (.03 to .12)	.15	low
8. General room - above ground level (14, 15, 16, 17, 18, 19)	AREA	12 (12 to 14)	.71	.14 .01 to .19)	.20	medium
9. Process room operator (P1)	PERSONAL	12	.71	.05	.07	normal
Average: (area and source samples		13	.67	.22	.33	
(personal samples)		13	.67	.15	.22	

As shown in Figure 2, the distribution of personal exposures appear to be normally distributed. The average exposure was 22% of the PEL. In the process plant, the worker's exposure averaged approximately 0.05 mg/m^3 (PEL = 0.71 mg/m^3) or less than 10% of the PEL (Table 2). His exposures were low because he spent a major portion of his work day either in the air-filtered office/control room, where dust levels averaged approximately 0.13 mg/m^3; or at the operator's control desk, where dust levels averaged approximately 0.07 mg/m^3.

In the storage area, the loader operator's exposure averaged approximately 0.24 mg/m^3 (PEL = .63 mg/m^3) or approximately 38% of the PEL (Table 2). His exposure was also low because he spent most of his time either in the filtered, air-conditioned cab of the front-end loader or in other work areas away from the jaw crusher area.

Effectiveness of Engineering Controls

Plant Layout and Design

Good planning in the design of this plant has resulted in a highly effective dust control system. Major potential sources of uncontrollable dust, such as storage and movement of bulk pyrophyllite and coarse crushing of the ore, were physically isolated from the remainder of the plant by a solid wall partition. All transfer of material throughout the plant is automated; and enclosure of dust sources is used as much as possible. Plant operators spend a major portion of their time in dust-controlled environments, such as in the filtered, air-conditioned cab of the front-end loader and in a filtered, air-conditioned control/office room.

Local Exhaust Ventilation Systems

Thirteen open transfer points (between conveyor belts or between conveyors and bucket elevators) were evaluated for effectiveness of their ventilation control hoods. Twelve of the 13 hoods were found to

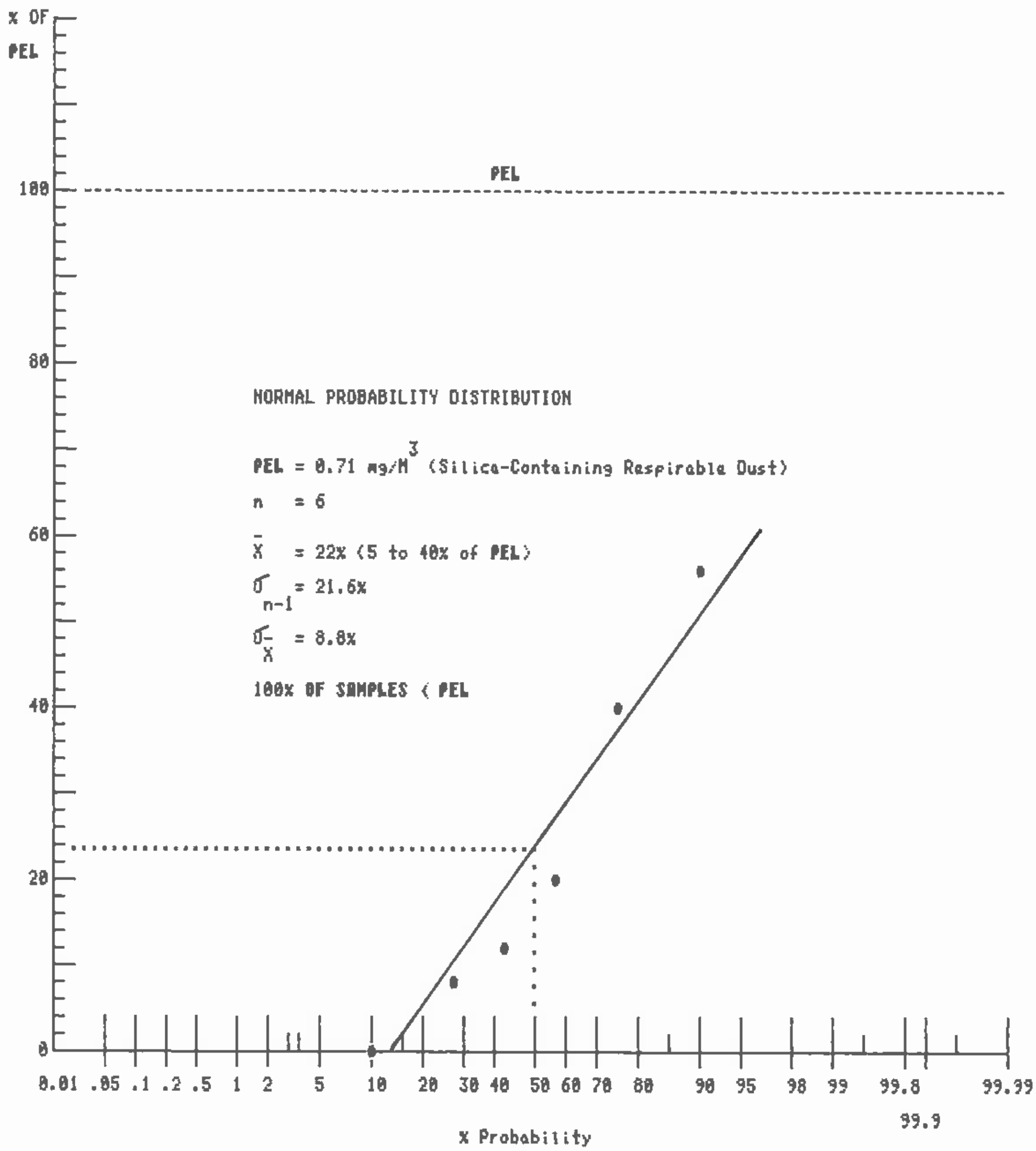


FIGURE 2: PERSONAL EXPOSURES TO RESPIRABLE DUST, SITE A - PYROPHYLLITE CRUSHING and GRINDING

be effective in controlling dust levels to or below their applicable PEL (Table 3). At one location, the jaw crusher transfer point in the storage building, respirable dust concentrations averaged 0.71 mg/m^3 or approximately 142% of the calculated PEL (Table 3). Since this location is not a normal work station, the dust source did not contribute significantly to the operator's overall dust exposure. Although the material handled at this transfer point was damp and the air velocity patterns of the hood enclosure were high, averaging approximately 365 fpm, dust levels were still high. Excessive dust apparently was emitted from multiple sources around the transfer point, such as the top of the hopper; the discharge from the hopper to the crusher feed belt; and the open feed belt to the crusher.

Conversely, at the other 12 transfer points, highly effective dust control was probably due to a combination of several factors, such as: high degree of enclosure of transfer points, effective airflow patterns and velocities; and absence of other uncontrolled dust sources in the vicinity of the transfer points. Atmospheric dust levels at these 12 potential dust sources averaged 0.27 mg/m^3 (range 0.12 to 0.73 mg/m^3) or approximately 43% of their PEL.

When dry milled product was handled at eight open transfer points, good correlation (-.71) was observed between excess dust generation (dust level at a hood minus background dust level) and average hood face velocity (see Figure 3). As this plot indicates, an average hood face velocity of approximately 100 fpm was sufficient to maintain excess dust levels at the PEL of 0.67 mg/m^3. However, if a more toxic dust, such as pure quartz, (with a PEL of .1 mg/m^3) were being processed in this type of transfer system, the required hood velocity would be approximately 300 fpm.

Table 3. Effectiveness of Local Exhaust Ventilation Hoods - Site A

Hood location	Type hood	Average Velocity fpm	PEL* mg/m^3	Face dust conc mg/m^3	Fraction of PEL
1. Jaw crusher, transfer from belt to elevator	lateral exhaust	365	.50	.71	1.42
2. CFW #1 hood	"	154	.67	.29	.43
3. CFW #2 hood	"	100	.67	.73	1.09
4. CFW #3 hood	"	134	.67	.24	.36
5. CFW #4 hood	"	125	.67	.17	.25
6. CFW #5 hood	"	143	.67	.15	.22
7. Elevator A transfer point	canopy	330	.59	.23	.39
8. Elevator B transfer to drier surge bin	side draft	97	.59	.15	.25
9. Discharge port from drier surge bin	lateral exhaust	70	.71	.21	.30
10. Ball mill surge tank discharge	slot exhaust	700	.71	.12	.17
11. Elevator C discharge port	lateral hood	310	.63	.28	.44
12. Elevator C transfer to shuttle conveyor	side slots	230	.67	.20	.30
13. Shuttle conveyor discharge to blending silos	down draft		.67	.48	.72

* Silica-containing dust.

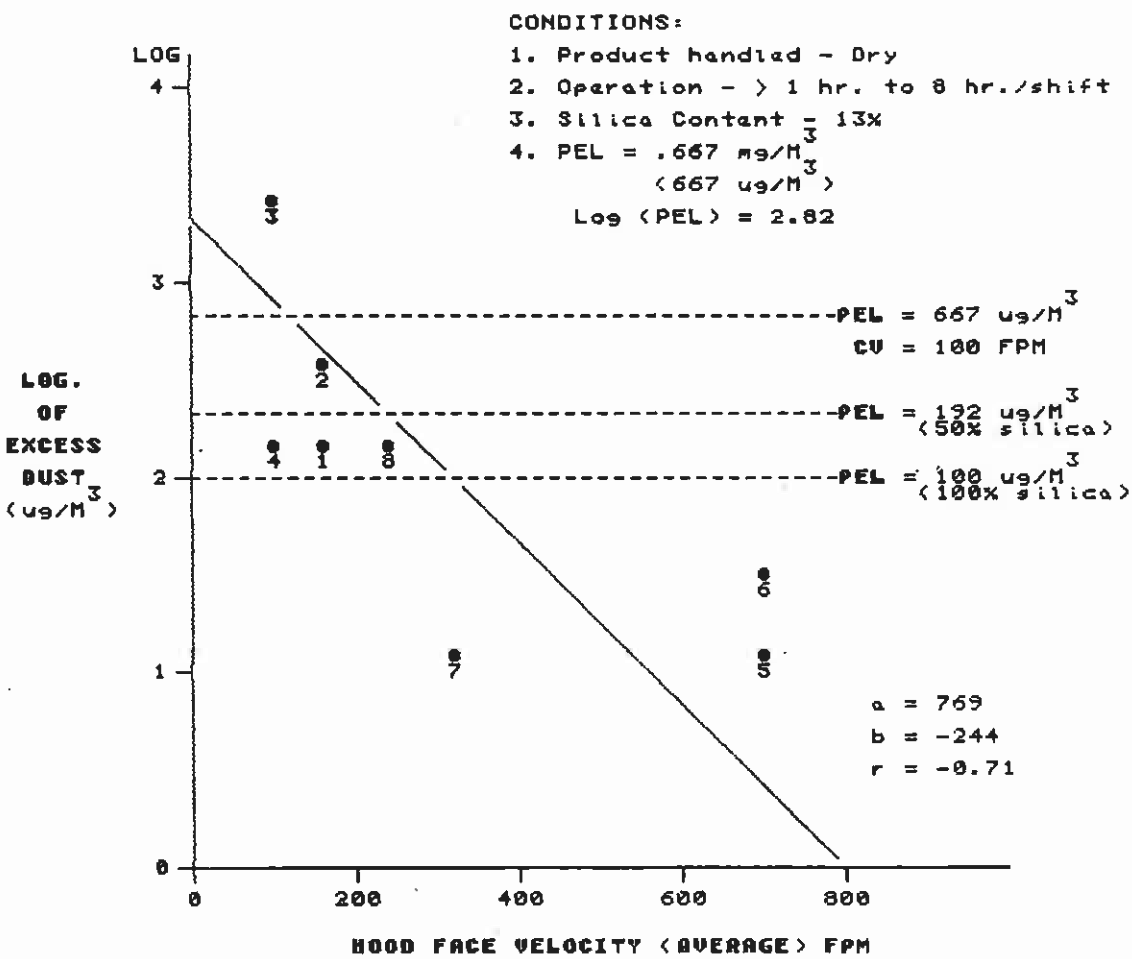


Figure 3. Correlation of Excess Dust from Hoods and Hood Face Velocities

Major Ventilation Ducts

The transport of mineral dusts, such as pyrophyllite (density 2.8 gms/cc), through a ventilation duct system requires air transport velocities in the order of 3500 to 4000 fpm. Velocities through five major ducts in this plant were measured. The average velocity through these ducts was 3220 fpm (ranging from 2775 to 3530 fpm). Sufficient transport velocity was found in four of the five ducts. One duct, however, a vertical riser, moved air upward at approximately 2800 fpm. This lower velocity was probably responsible for the relatively low face velocity (100 fpm) and the relatively high dust concentration (1.95 mg/m^3) at one of its associated dust control hoods. Low transport velocities may also result in partial plugging of ducts, particularly in vertical risers, in addition to developing low hood velocity patterns. Therefore, duct systems should be inspected, on a regular basis, to repair holes, to locate discontinuities, to unplug accumulations, and to compare actual dust velocities with design velocities.

B. Crushing of Ball Clays and Shale in the Quarry Tile Industry (Site B)[8]

1. Process Description

At a second site, Kentucky ball clay, shale, and other additives are processed to produce quarry floor and wall tile. The ball clay and shale are crushed in a crushing plant and transported by conveyor to the production building where they are milled, formed, dried, fired and the finished product ground to production specifications. The crushing plant is separated from the production building by a continuous floor-to-ceiling wall and is open to the outside on one side. This open-side is under roof and contains the clay and shale storage bins (Figure 4).

Locally-mined ball clays and shale, with a moisture content of approximately 6.5 per cent and a crystalline silica (quartz) content

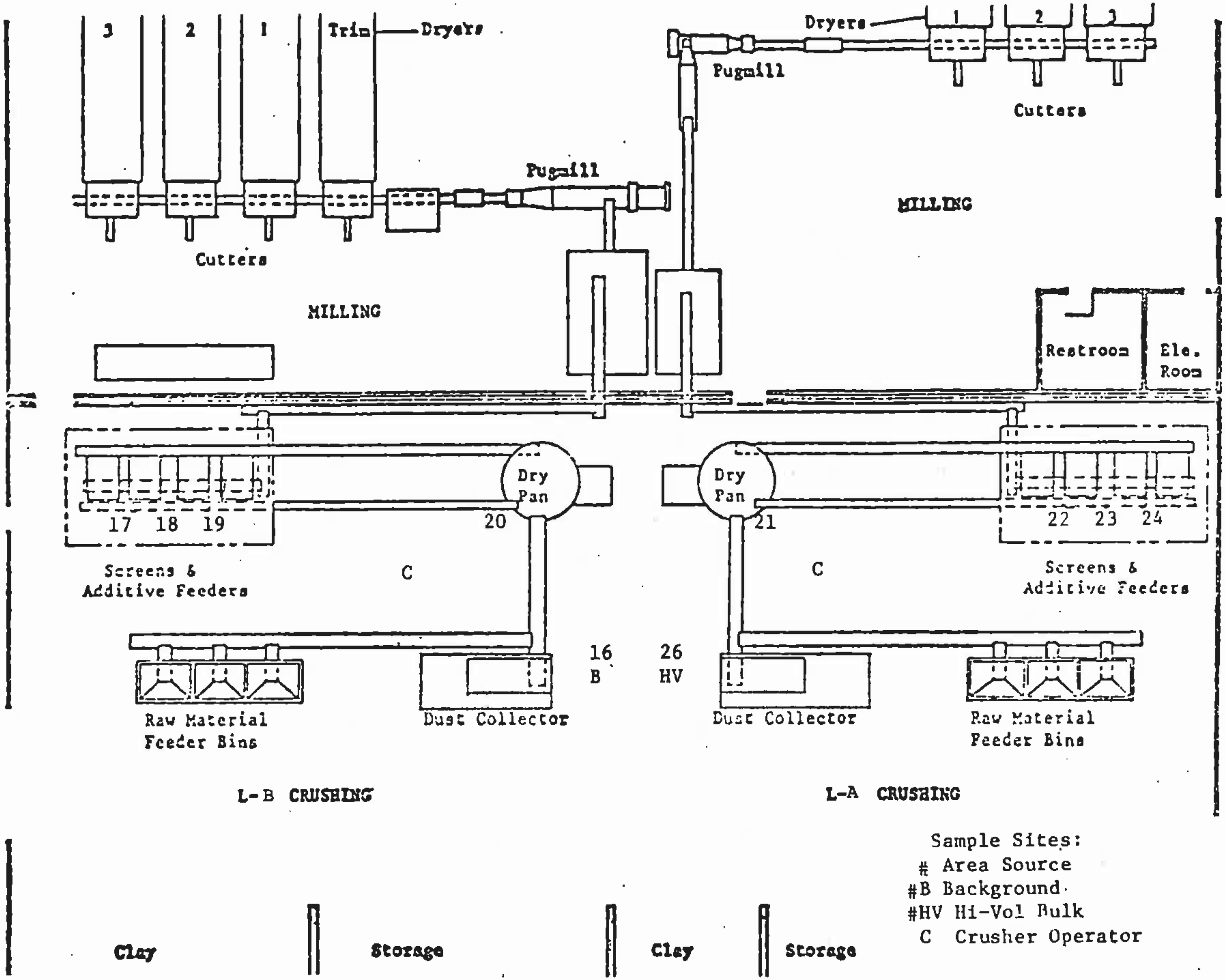


Figure 4 - Crushing Plant

of approximately 19 per cent (respirable fraction) and 24 per cent (total dust) are transported by truck to bulk storage bins in the crushing plant. The operation has two crushing lines, consisting of clay and shale storage bins, raw material feeder bins, dry pans, vibrating screens, and additive feeders. Two crusher operators are involved in the operation, one on each line. The raw materials are stored and handled in an area open to and contiguous to both crushing lines. These raw materials are transported from the storage bins by cab-enclosed, filtered, air-conditioned front-end loaders and dumped into feeder bins. They are fed from the feeder bins onto conveyors in proportioned amounts to produce the desired shade of tile. The conveyors transport the blended raw material mixture to dry pans for crushing to -35 mesh (approximately 300 um) particle size. The crushed material is discharged from the dry pan onto a conveyor for transport up to vibrating screens, for classifying and to additive feeders for the introduction of other materials. The properly-sized particles pass through the screen onto another conveyor and the over-sized material returns to the dry pan for further size reduction. The crusher operators manually add 50-pound bags of additive materials to the vibrating feeder hoppers. These materials (to precipitate naturally-occurring salts, to lower the melting point, and to act as a coloring agent) are fed from the vibrating hoppers onto the conveyor for blending with the ground clay body material. The blended body material is transported by conveyor to storage bins in the mill area of the production building.

2. Controls

A combination of control procedures is used in an effort to reduce exposures below the OSHA Standard:

- Engineering Controls - including plant layout and design and ventilation of processing equipment.

- Use of personal Protective Equipment - including hard hats and dust respirators.

- Environmental and Medical Monitoring - including atmospheric dust sampling and physical examinations.

a. Engineering controls

The crushing plant was designed with an open end on the bulk storage bin side so that trucks bringing clay and shale from the mines could unload into the storage bins without traversing the crushing plant. Theoretically, dust generated by truck movement would be dispersed to the outside without entering the building. Product movement through the processing plant is automated with the exception of the manual handling of the additive materials and the movement of the bulk clay and shale from the storage bins to the feeder bins by cab-enclosed, filtered, air-conditioned front-end loaders. Potential airborne dust sources at major processing equipment is enclosed and ventilated (Figure 5). A local exhaust ventilation system is used to capture potential point sources of dust at the additive feeders. In addition, exhaust ducts are connected to the enclosed raw material feeder bins, dry pans, and vibrating screens on both crushing lines to minimize dust dispersion to the general work atmosphere. Airborne dust, captured at these operational control points, is transported via ventilation ducts to baghouses where the dust is separated from the airstream (Figure 6). The baghouse system on crushing Line A contains a cloth area of 3670 square feet and is designed to operate at 10,000 cubic feet per minute (cfm). The baghouse system on crushing Line B contains a cloth area of 5360 square feet and is designed to operate at 16,500 cfm.

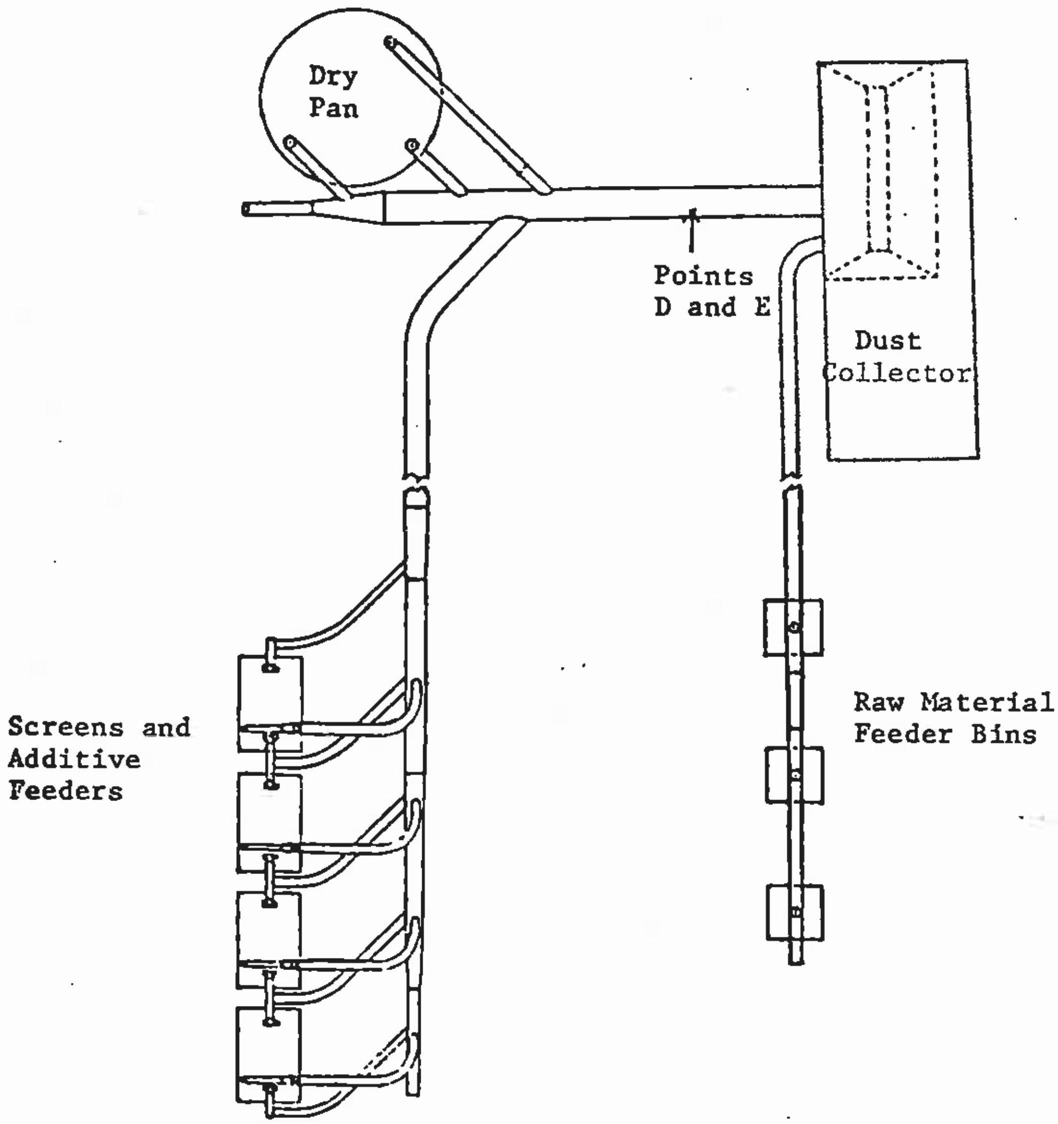


Figure 5 - Crushing Line Exhaust Ventilation System

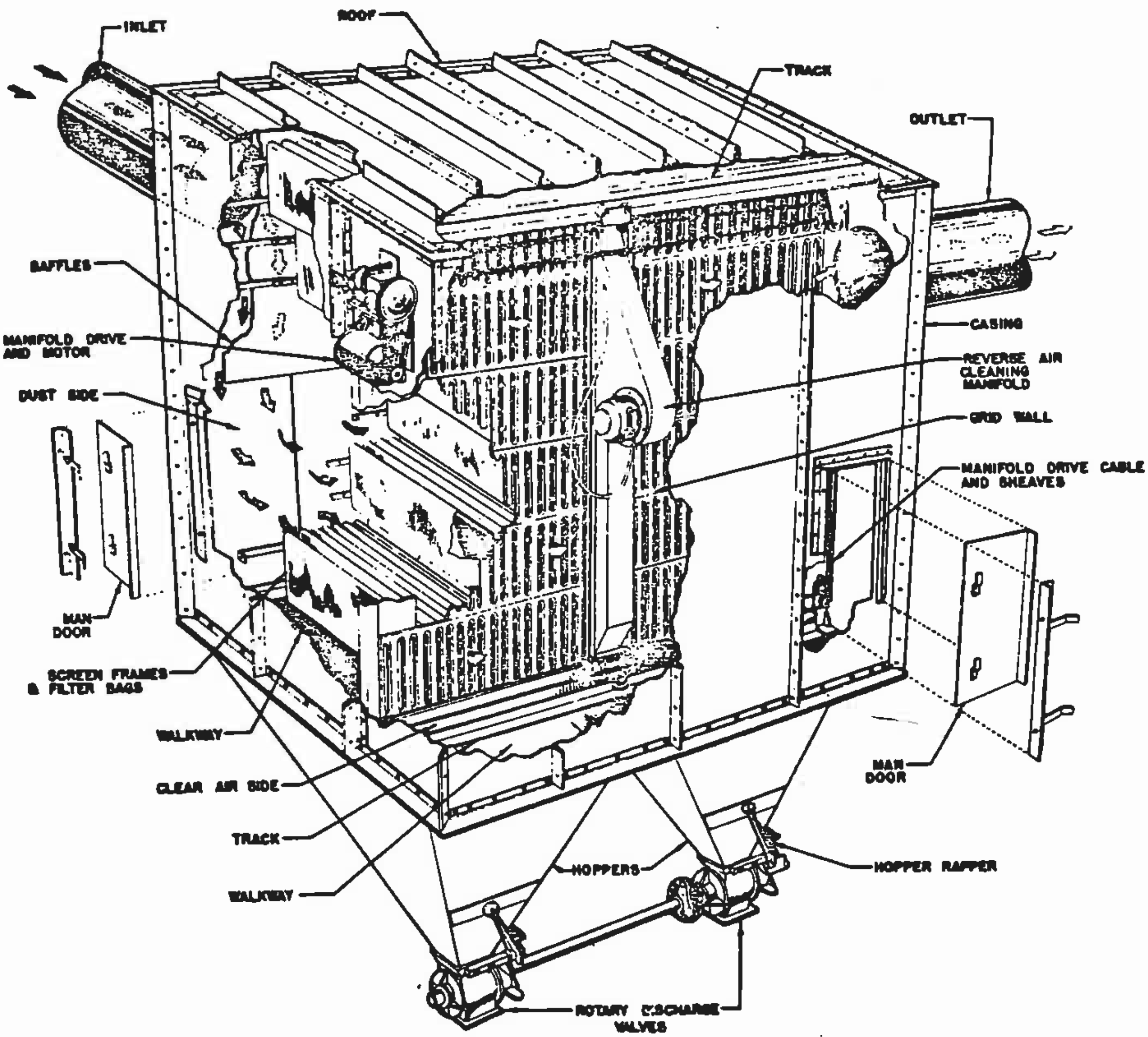


Figure 6 - Dust Collector

b. Personal Protective Equipment

Head protection is required throughout the crushing plant. Since this plant's records indicate the atmospheric dust sampling results have been generally low, respirator use is not required except when the crusher operator manually adds the additive materials to the vibrating feeder hoppers.

c. Environmental/Medical Monitoring

Annually, the Company's industrial hygienist conducts atmospheric dust evaluations at strategic locations throughout the crushing plant and personnel exposure evaluations among the crusher operators. Additionally, annual physical examinations, including chest x-rays and pulmonary function tests are conducted by the Company's contract physician.

3. Sampling Results and Control Effectiveness

The ball clays and shale, processed in this crushing plant, contain approximately 19 per cent crystalline silica (quartz) in the Respirable Dust fraction and 24 per cent in the Total Dust. The calculated PEL established by OSHA for this silica-containing dust, is 0.48 mg/m^3 Respirable Dust fraction and 1.15 mg/m^3 for Total Dust.

The overall effectiveness of the dust control system in this crushing plant is determined to be inadequate as demonstrated by evaluation of both personal, source and area exposures to atmospheric dust (Table 4).

Table 4. Crushing Plant Mean TWA Personal, Source and Area Concentrations - Site B

Grouping	Respirable Dust Conc. mg/m^3	Respirable Dust % of PEL*	Total Dust Conc. mg/m^3	Total Dust % of PEL*
Crusher Oper. Line A	0.48	100	5.04	438
Crusher Line A	-	-	2.13	199
Crusher Oper. Line B	0.51	113	3.36	292
Crusher Line B	-	-	1.62	151
Gen. Crushing Area	-	-	1.40	187

* Silica-containing dust.

Personal exposure samples were collected on two crusher operators for 8 hours each day for three consecutive days. As shown in Figure 7, the distribution of personal exposures appear to be normally distributed. The average exposure of the crusher operators was 361% of the PEL. Line A Crusher Operator's exposure level averaged approximately 100 per cent of the PEL for Respirable Dust and approximately 438 per cent of the PEL for the Total Dust. Line A Crusher Operator's average Total Dust exposure level was 220 per cent of Line A concentration and 234 per cent of the general crushing background concentration. Line B Crusher Operator's exposure level averaged approximately 113 per cent of the PEL for Respirable Dust and approximately 292 per cent of the PEL for the Total Dust. Line B Crusher Operator's average Total Dust exposure level was 193 per cent of Line B concentration and 156 per cent of the general crushing background concentration. Thus, both operators' personal exposures were approximately twice as high as general area exposure levels without any observed evidence to explain the difference.

Inadequate planning in the design and/or maintenance of this crushing plant has resulted in an ineffective dust control system. Major

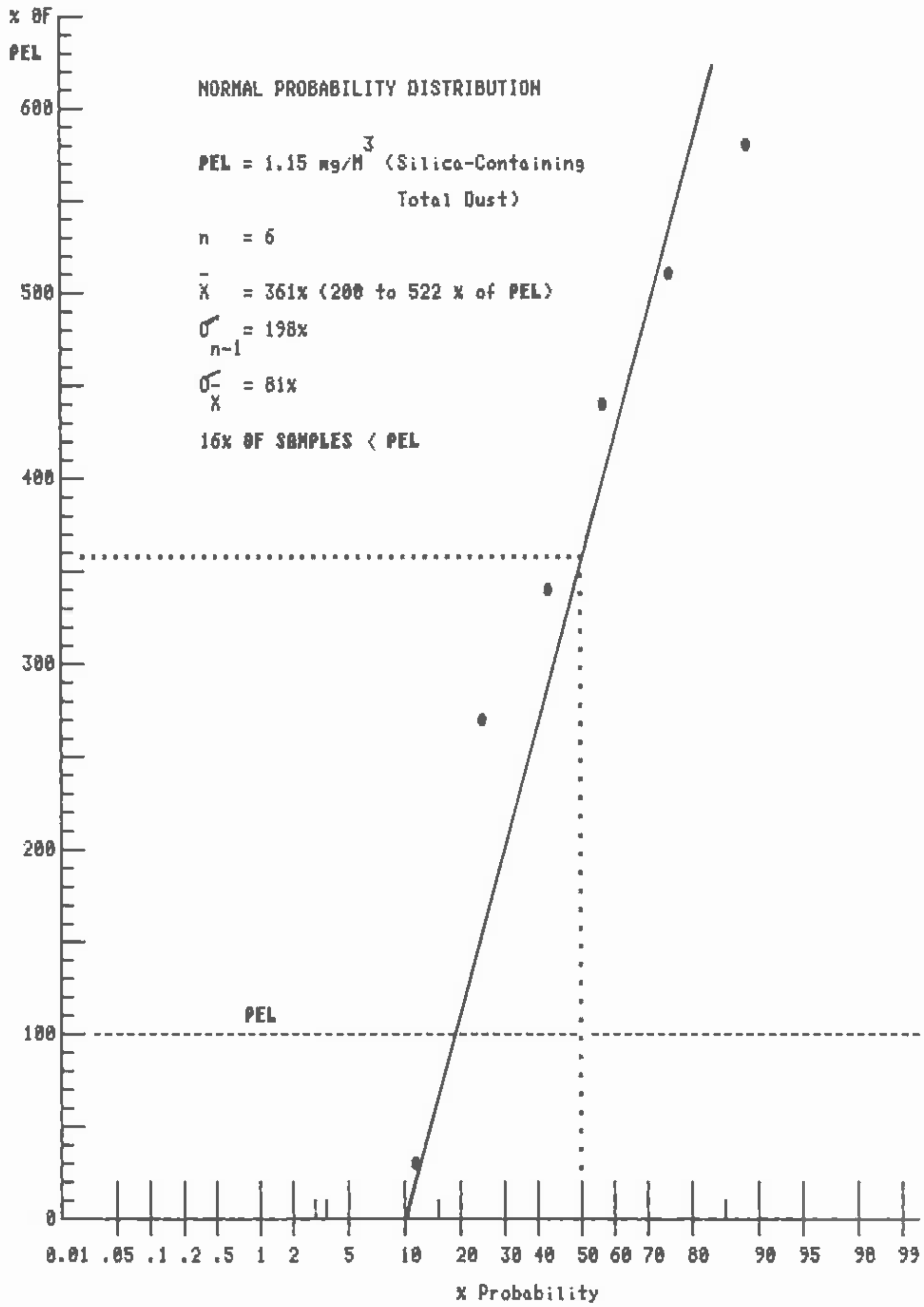


FIGURE 7: PERSONAL EXPOSURES TO TOTAL DUST, SITE B - BALL CLAYS and SHALE CRUSHING

potential sources of uncontrollable dust, such as the ball clays and shale storage area and movement of these materials to the crushing operation, are not isolated from the rest of the crushing plant. Conveyor transfer points are not enclosed or equipped with local exhaust ventilation. Crusher operators are not provided with an isolated control room and must spend essentially 8 hours each day in the crushing area where the Total Dust area concentration ranges from 151 to 438 per cent of the PEL. The additive feeder/vibrating screen area, on each line, is equipped with three 7-inch diameter plain opening exhaust ducts that are not adequately designed or located to capture escaping dust emissions effectively. The overhead exhaust duct transport velocity on Line A was ineffective due to improper operation and maintenance of the equipment. Measurements taken at Point D (Figure 5) averaged 2701 fpm (ACGIH recommends 3500 fpm)[13]. The overhead exhaust transport velocity on Line B was effective. Measurements taken at Point E (Figure 5) averaged 3797 fpm (ACGIH recommends 3500 fpm).

C. Grinding of Tile in the Quarry Tile Industry (Site C)[8]

1. Process Description

At the third site, ball clay, shale, and other additives are processed to produce quarry floor and wall tile. These raw materials are crushed, milled, formed, dried, fired and the finished product ground to production specifications. The tile grinding area is located in an open area of the production building adjacent to the storage and shipping areas.

The finished tile is essentially free of any moisture content. The silica content varies from approximately 21% (range 20 to 22%) in the hand and corner grinding area, to approximately 17% (range 13 to 21%) in the automatic grinding area. Finished tile is transported by forklift truck and placed in stacks adjacent to the grinders. The operation consists of two hand grinders, a corner grinder, and four automatic grinders, two in each line, operating in tandem. The hand and corner grinders are located on a North/South line near the East side of the grinding area and the automatic grinders in two parallel North/South lines near the West boundary (Figure 8). Nine employees are directly involved in the operation; two hand grinder operators, one corner grinder operator, two automatic grinder feeders, and four inspector/packers. The inspector/packers rotate between the automatic grinder and hand grinder stations every two hours. Two inspector/packers are located in each area at any one time.

Finished quarry tile is transported to the grinding area by forklift trucks and placed in stacks at the head of each automatic grinder line and adjacent to the hand and corner grinders. Flat tile edges are ground on the automatic and hand grinders; curved tiles are ground on the corner grinder.

The automatic grinder feeder, positioned at the head of each line, manually loads the quarry tile into a chute that feeds by gravity onto a vertical ferris wheel. A belt holds the tile in place on the ferris wheel while it is being ground. The tile passes between two grinding wheels in the first grinder where two sides are ground. It then drops onto a conveyor belt where it is rotated 90 degrees and transported between another set of tandem grinding wheels in the second grinder that grinds the other sides. The ground tile is transported by conveyor belt under a hooded air brush to the inspector/packer station.

The hand grinder operator manually loads a single tile into a shuttle and feeds the tile between two grinding wheels. The tile is withdrawn, rotated 90 degrees, and fed back into the machine for finish grinding of the other two sides.

The corner grinder operator manually loads a single tile into a shuttle and feeds the edge of the tile onto a single grinding wheel. The tile is withdrawn, rotated, and fed back into the grinder until

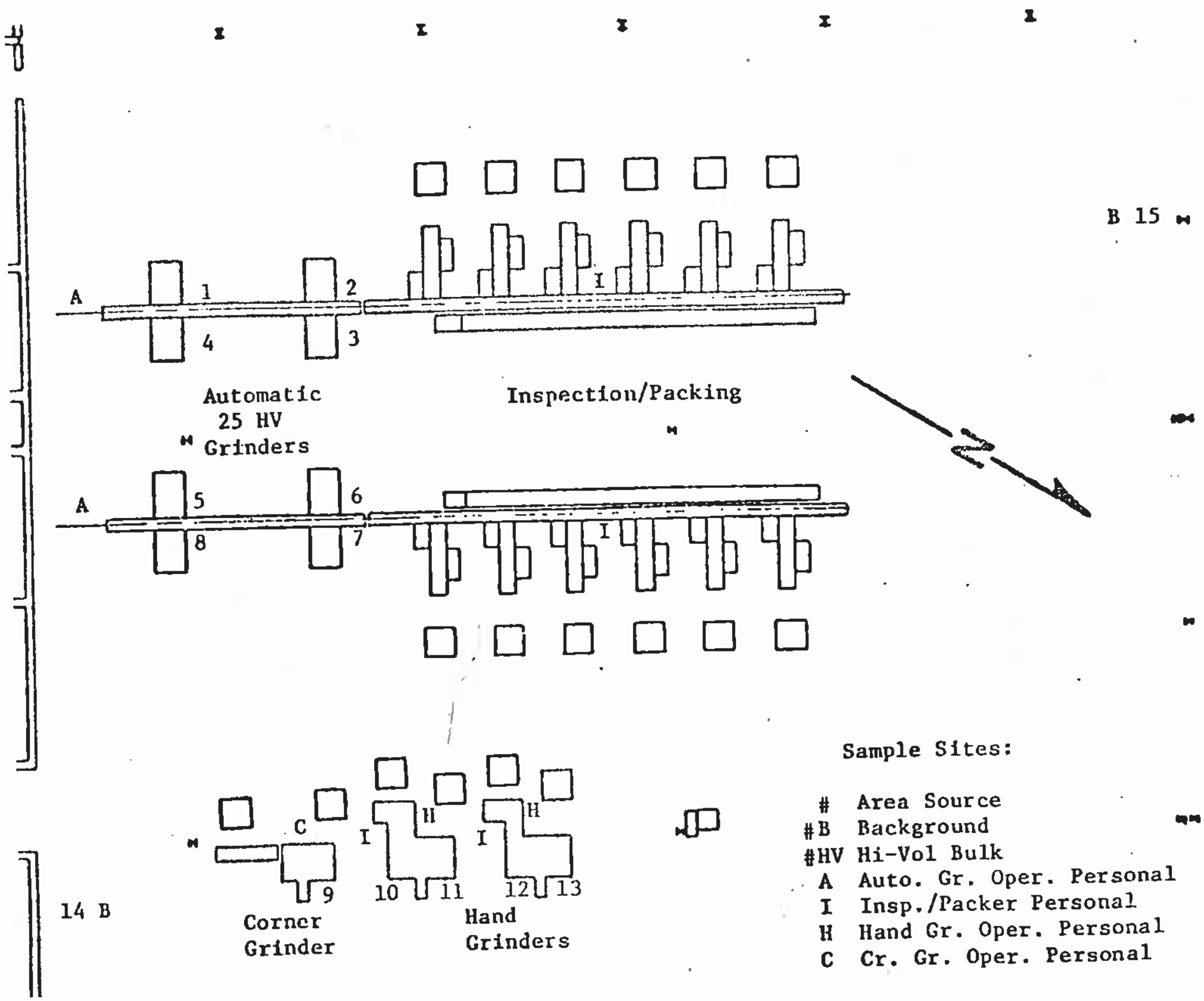


Figure 8 - Grinding and Packing Area

all desired sides are finished ground. The ground tile is inspected, packed in boxes, and transported by forklift truck to the storage area.

2. Controls

Exposure to levels below the OSHA Standard is accomplished by a combination of procedures including:

- Engineering Controls - including ventilation of processing equipment.

- Environmental and Medical Monitoring - including atmospheric dust sampling and physical examinations.

a. Engineering Controls

Potential airborne dust sources at the automatic, hand, and corner grinders are equipped with local exhaust ventilation systems (Figure 9). The automatic grinders are equipped with local exhaust enclosure hoods to capture potential point sources of dust (Figure 10). The largest particles from the tandem grinding wheels either drop into paper bags connected to the hoods or into a pit beneath the grinders. The smaller particles are drawn into 6-by 12-inch hoods located on each side of the ferris wheels. The hoods discharge into 6-inch vertical ducts. After the second ferris wheel on each line, there is a hooded air brush for brushing dust from the tiles that discharges into a 3-inch vertical riser duct. The hand and corner grinders are equipped with local exhaust enclosure hoods around the grinding wheel and shuttle at the point of operation (Figure 11). These enclosures exhaust into 4-inch rectangular ducts that exhaust into round 6-inch vertical ducts. The 4-inch ducts are equipped with cleanout openings. There is an adjustable shield between the operator and the point of operation. Airborne dust captured at these operational control points is transported via ventilation ducts to a baghouse, located outside the building, where the dust is separated from the airstream (Figure 5). The dust collector for the grinding area is designed to operate at 10,000 cfm at 8-inches Standard Pressure with an air-to-cloth ratio of 2.72 cfm per square foot.

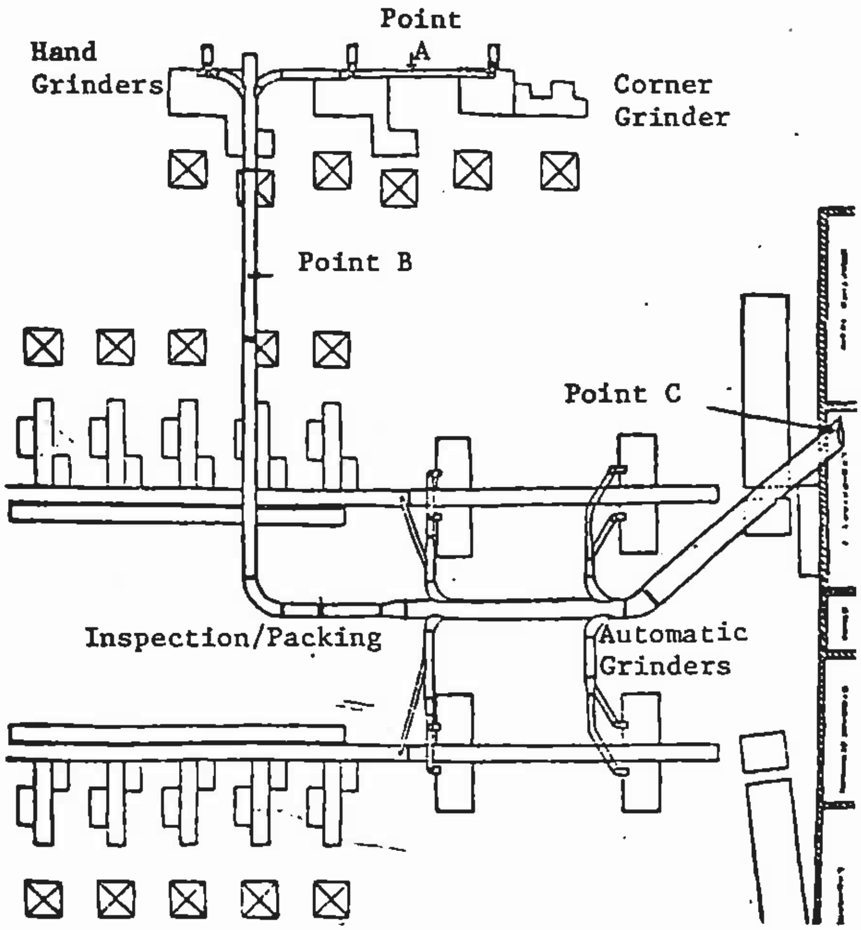


Figure 9 - Grinding Area Exhaust Ventilation System

b. Environmental/Medical Monitoring

Annually, the Company's industrial hygienist conducts atmospheric dust evaluations at strategic locations throughout the grinding area and personnel exposure evaluations among the grinding operators and inspector/ packers. Additionally, annual physical

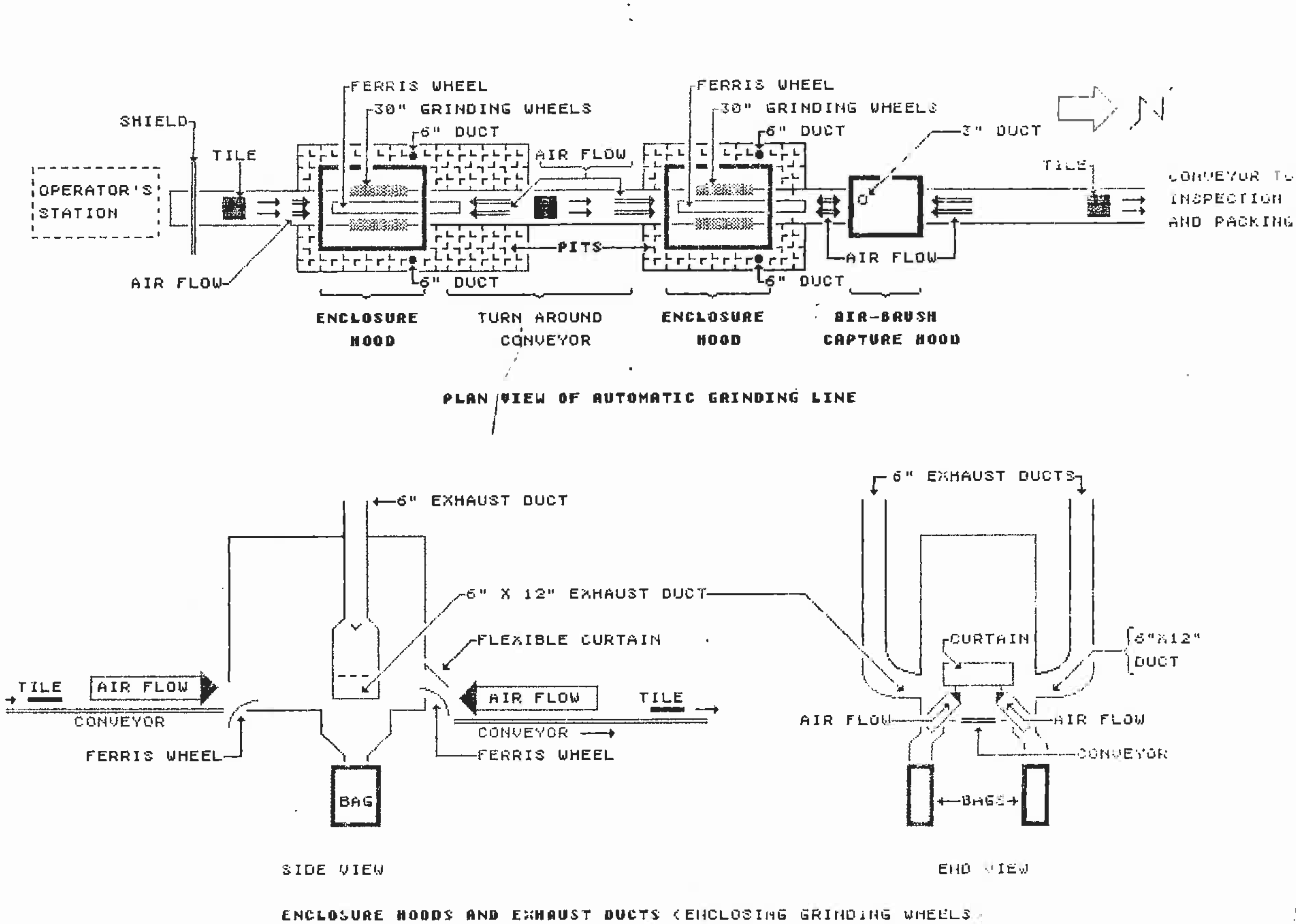
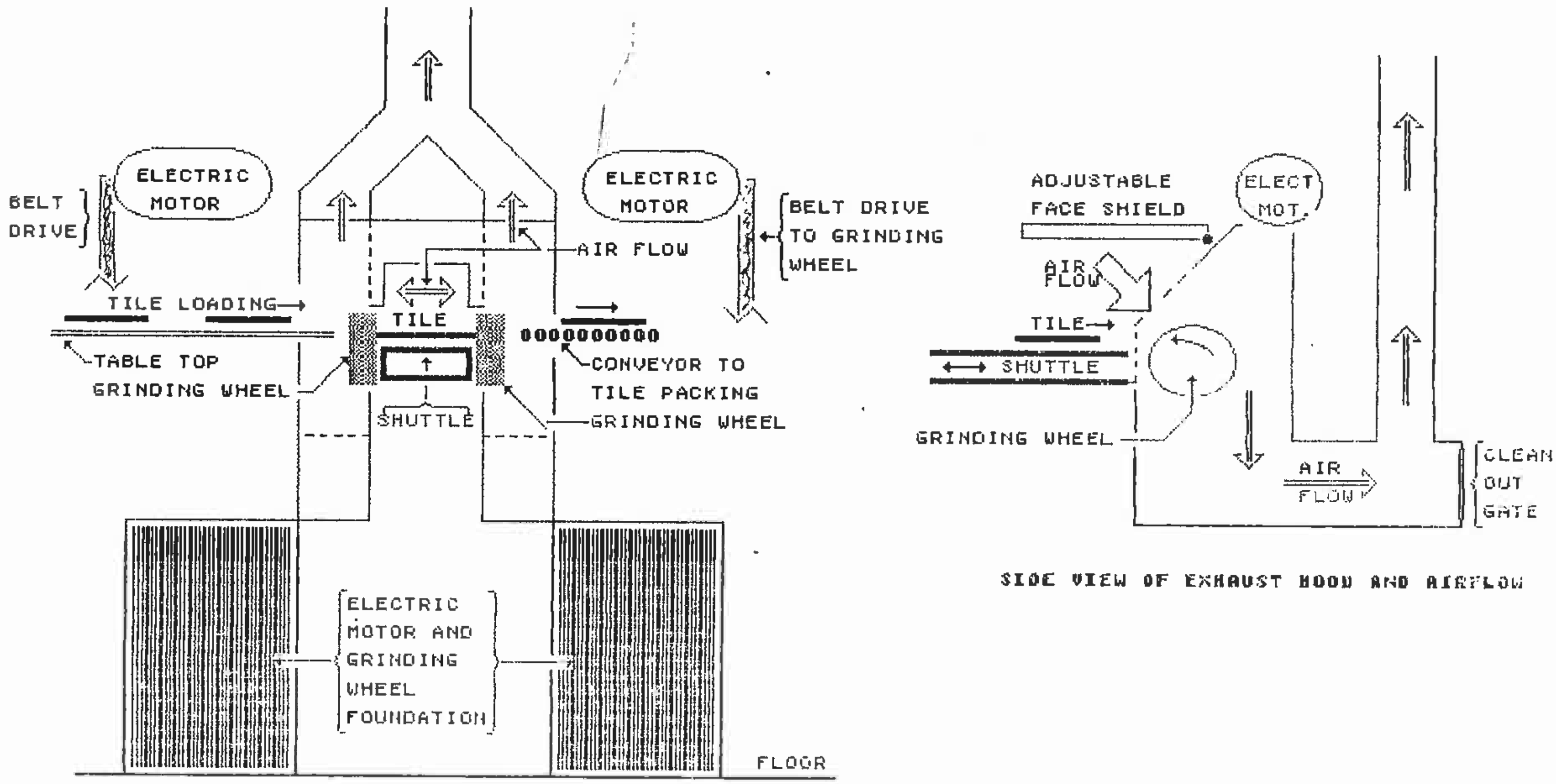


Figure 10 - Automatic Grinder Local Exhaust Hoods



HAND GRINDING STATION

SIDE VIEW OF EXHAUST HOOD AND AIRFLOW

Figure 11 - Hand and Corner Grinder Local Exhaust Hoods

examinations, including chest x-rays and pulmonary function tests are conducted by the Company's contract physician.

3. Sampling Results and Control Effectiveness

The quarry wall and floor tiles ground in the automatic grinding area of this operation contain crystalline silica (quartz) of approximately 13 per cent respirable fraction and 21 per cent of total dust. In the hand and corner grinding area, the dust contains approximately 20 per cent in the respirable fraction and 22 per cent in the total dust. The calculated Permissible Exposure Limits, established by OSHA for these silica-containing dusts, are 0.67 and 0.45 mg/m^3 respirable fraction and 1.30 and 1.25 mg/m^3 for total particulates, respectively.

The overall effectiveness of the dust control system in this grinding area is determined to adequately control dust levels below the OSHA Standard as demonstrated by evaluation of both personal and area exposures to atmospheric dust (Tables 5 and 6).

Table 5. Automatic Grinding Mean TWA
Personal, Source and Area Concentrations - Site C

Grouping	Respirable Dust Conc. mg/m^3	Respirable Dust % of PEL*	Total Dust Conc. mg/m^3	Total Dust % of PEL*
Auto. Gr. 1 & 2 feeder	0.15	19	0.26	26
Auto. Gr. 1	-	-	1.40	144
Auto. Gr. 2	-	-	0.94	94
Auto. Gr. 3 & 4 Feeder	0.16	26	1.06	78
Auto. Gr. 3	-	-	1.07	96
Auto. Gr. 4	-	-	2.28	168
Inspectors/Packers	0.21	46	0.86	66
Gen. Grinding Area	-	-	0.39	35

* Silica-containing dust

Table 6. Hand and Corner Grinding Mean TWA
Personal, Source and Area Concentrations - Site C

Grouping	Respirable Dust conc. mg/m^3	Respirable Dust % of PEL*	Total Dust conc. mg/m^3	Total Dust % of PEL*
Hand Grinder Operators	0.23	51	0.17	57
Hand Grinders	-	-	0.43	37
Corner Grinder Operator	0.19	42	-	-
Corner Grinder	-	-	0.39	36
Inspectors/Packers	0.21	46	0.86	66
General Grinding Area	-	-	0.39	35

* Silica-containing dust