

AN EVALUATION OF EXPOSURE TO FUNGAL SPORES AND RECOMMENDATIONS
FOR THEIR CONTROL IN A BEET SUGAR REFINERY (SENSOR)

At

Monitor Sugar Company
Bay City, Michigan

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PLANT SURVEYED: Monitor Sugar Company
2600 Euclid Avenue
Bay City, Michigan 48706

SIC CODE: 2063 (Beet Sugar)

SURVEY DATE: January 14-18, 1991 and
June 19-21, 1991

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I. SUMMARY

In 1987, NIOSH initiated the SENSOR (Sentinel Event Notification System for Occupational Risks) program, a cooperative state-federal effort designed to develop local capability for the recognition reporting, follow-up, and prevention of selected occupational disorders. The Michigan Department of Health (MDOH) is participating in the SENSOR program for occupational asthma. The MDOH reported that three workers at the Monitor Sugar Company had developed asthma-like symptoms and were subsequently tested for allergic reactions to moldy beet sugar pulp. One worker tested positive while two others tested negative. The Engineering Control Technology Branch (ECTB) of NIOSH assisted the MDOH in the conduct of surveys to recommend improved controls in this plant. This report describes an in-depth survey of employee exposure to microorganisms in the Monitor Sugar Company beet sugar refinery in Bay City, Michigan. Engineering and bioaerosol evaluations were conducted in January and June of 1991.

The bioaerosol evaluation included the collection of 70 personal and area samples, which were analyzed, using 0.8 μm pore polycarbonate filters and 37 mm cassettes, to identify and quantify exposure to microorganisms present in selected work situations and in areas of the plant. Multiple species of fungi were found in the plant. The pellet silo and the pellet loading operations were identified as areas of high exposure to airborne microorganisms.

Recommendations were made to improve the storage of the pellets, to reduce the growth of the microorganisms, and to install ventilated loading spouts to contain dust generated during pellet loading. Also, several general safety hazards were noted and recommendations were made for their correction.

II. INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is engaged in occupational safety and health research. NIOSH, Centers for Disease Control, is part of the Department of Health and Human Services (formerly the Department of Health, Education, and Welfare). 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 conducted 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, physical, and biological 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 hazard control.

Since 1976, ECTB has conducted a number of assessments of health hazard control technology among industries, common industrial processes, or specific control techniques. The objective of each of these studies has been to document and evaluate effective techniques for the control of 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 techniques.

In 1987, NIOSH initiated the SENSOR program (Sentinel Event Notification System for Occupational Risks), a cooperative state-federal effort designed to develop local capability for the recognition, reporting, and prevention of selected occupational disorders. Under this program, the state health department (or other agency) launches three types of actions upon notification of a case of occupational disease: first, disease management guidelines will be made available to the health care provider; second, medical evaluations of coworkers who may be at risk of developing similar disorders will be conducted; and finally, action directed to reduce work site exposures will be considered. To assist the states in developing intervention plans for exposure reduction, ECTB is conducting a pilot engineering assistance project with selected states participating in SENSOR. This assistance may include specific control recommendations for an individual plant, or the recommendations may address an entire industry or a single process which may be used in different industries. The intent is to develop guidelines for the elimination of occupational disease associated with the entire industry/process.

In 1989, the Michigan Department of Health conducted a survey of employees at the Monitor Sugar Company, Bay City, Michigan plant to assess the extent of asthma and other allergic reactions related to their employment. There appeared to be a number of employees of Monitor Sugar Company suspected to be sensitive to the fungus A. niger and other Aspergillus species or its culture fluid protein extracts.¹ In that investigation, questionnaires prepared by Michigan State University were administered to the 350 to 400 workers on the payroll at the Monitor Sugar Company. Responses were received from 73 workers that revealed a variety of health problems.¹ Health effects reported were daily nasal stuffiness, runny nose, tearing and burning of the eyes, redness of the eyes, sore throat, cough, wheezing, and shortness of breath. Only one worker consented to sensitization testing provided by the Michigan State University. That worker reacted to moldy sugar beet pulp (skin test, and specific serum IgE), had specific IgG to A. niger, specific IgE to Aspergillus, and reacted on challenge testing to the moldy but not the fresh sugar beet pulp.¹ IgG and IgE are classes of immunoglobulin (Ig) involved in the immune process which form antibodies.² Two other workers at Monitor Sugar Company with asthma-like symptoms were tested by their private physicians and did not have specific IgE to moldy sugar beet pulp.¹ Other workers who might have been at risk of exposure to these microorganisms declined to be tested. The pulp silo was suspected to be the source of exposure to Aspergillus niger.³ Potential exposure of maintenance and production workers to microorganisms as a result of entering areas of the plant where dust has settled was also noted. Since the entire plant and grounds are "well seeded" with fungal spores,³ any settled dust is a potential source of fungal growth. The objective in this study was to identify and quantify exposure to airborne microorganisms at the Monitor Sugar Company, and to recommend engineering controls to minimize this exposure.

The activity at the plant from March until early September is centered about shipping of siloed pellets and seasonal maintenance. Since maintenance

operations involve considerable welding, previous studies of hypersensitivity pneumonitis have focused on nickel sulfates produced during welding operations.⁴ In those studies, no evaluation was made to test those affected for sensitivity to fungal spores or other biological material. Since the plant is "well seeded" with spores, maintenance workers may be exposed to A. niger from residual pulp from previous operations.⁵

This project was undertaken by ECTB in response to a request in November 1990 under the SENSOR program from the Michigan Department of Health, Division of Occupational Health. A previous investigation by MDOH, indicated the existence of an asthma-like condition existing in employees, which was thought to be due to exposure to microorganisms. As a result of that investigation, the Michigan Department of Health requested assistance from ECTB in performing a survey at the Monitor Sugar Company, Bay City, Michigan plant to make an evaluation of airborne concentrations of fungal spores and to make recommendations for engineering controls in the plant.

III. PLANT PROCESS

Monitor Sugar Company is located in the state of Michigan where sugar beets are harvested from the fields from September to mid-October, before the first frost. This plant employed 336 personnel during the 1990/1991 "campaign," 70 of whom are hourly workers, 261 are temporary workers and 5 are security. The plant average throughput was 410 tons of sugar per day.⁶ The beets are transported by truck to the plant, where the beets are screened and placed in piles, 17 to 23 feet in height. The cleaning screens cause bruising as beets are dropped over rollers, which rotate in the opposite direction to the flow of beets. This bruising is tolerated to obtain clean beets, since dirt and trash impede air movement through the piles.⁷ The piles have a base of approximately 120 feet and a top of approximately 80 feet wide. Piles of these dimensions can contain 40 tons of beets per lineal foot. The cross-section dimensions are important to allow ventilation of the piles to reduce spoilage. These piles of sugar beets can develop "hot spots" due to growth of microorganisms, which generate heat by metabolism. The beets also generate heat due to respiration. Some plants ventilate the beet piles with forced air; however, this plant does not. Beets are trucked from the storage piles to the refinery yard. There, front-end loaders dump the beets into a wet hopper from which the beets are transported by a water flume to the plant. Since fungal growth is related to beet temperature, rapid cooling of beet piles and maintenance of temperatures below 60°F reduces storage rot.⁸ Figure 1. is a diagram of the refining process.

The refining process begins when the sugar beets are thoroughly washed and rinsed. The first process step is to slice the beets into cossettes (slender strips of beets) which are charged into the diffuser where the sugar is leached counter currently to form "raw juice." After processing the cossettes in the diffuser, a pulp residue remains which is dried, pressed, pelletized, siloed, and sold to animal feed producers. Bacteria in the diffuser is controlled with biocides such as formaldehyde so that the raw juice is not contaminated as it enters the carbonation steps.

BEET SUGAR REFINING PROCESS

MONITOR SUGAR, BAY CITY, MICHIGAN

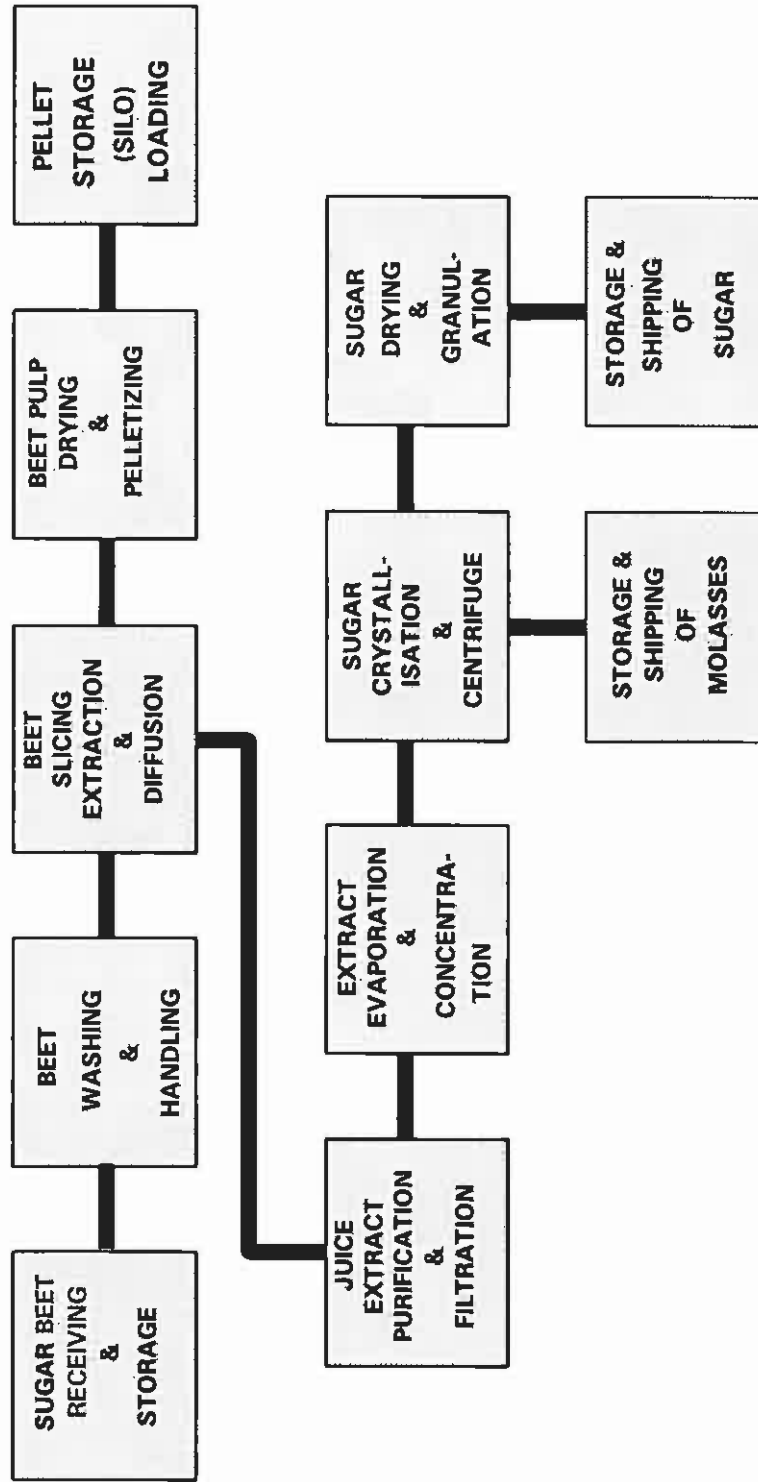


FIGURE 1.

The raw juice purification begins in the precarbonation step with the addition of milk of lime ($\text{Ca}(\text{OH})_2$) to begin precipitation of impurities. This is followed by two stages of carbonation using CO_2 generated in the lime kiln to complete the recrystallization of CaCO_3 with its entrapped non-sugars. The calcium carbonate is then filtered from the juice. Sulfur dioxide may be added to the raw juice after the second carbonation to control the pH. The sulfur dioxide, received as a pressurized liquid, is introduced in the gas phase, directly to the raw juice. The thin juice is light amber colored and clear. Through evaporation, its density is more than quadrupled - 15% to 65%. This is done in steam fed multiple effect evaporators. To this "thick juice" is added the sugar that comes from the lower purity or "raw" vacuum pans. All is heated, melted and filtered again. It is now "standard liquor".⁹

The pulp resulting from the initial diffusion step is pressed to reduce the moisture content from about 95 percent to between 72 percent. The pressed pulp is kiln-dried to a moisture content of about 10 percent. The hot pulp is transported to one of several pelletizers, screened to remove fragmented pellets, air cooled then transported to the silo. About 400 tons/day of pulp pellets are produced. The storage silo is 100 feet in diameter, has a wall height of 30 feet, then tapers an additional 34 feet to an apex, where pellets enter the silo. The total volume is over 280,000 cubic feet and, when full, will hold over 4,900 tons of pellets. A more detailed description of the sugar beet refining process may be found in Beet-Sugar Technology.¹⁰

IV. HEALTH EFFECTS ASSOCIATED WITH BEET SUGAR REFINING

Health problems in the sugar beet refining industry are not well documented in the literature. Several NIOSH Health Hazard Evaluations have been conducted in the sugar beet refining industry. These studies focused on welding and other maintenance operations conducted during the off season.^{4, 11-15} An occupational health problem not extensively evaluated in the sugar beet refining industry is the exposure to microorganisms. Forster¹⁶ performed an industrial hygiene investigation of a sugar beet plant in England to determine the nature of organisms which were apparently causing respiratory problems with workers. The investigation centered on the beet slicing machines and the cossette conveyor. She identified mesophilic bacteria, actinomycetes, gram-negative bacteria, and fungi as potential health problems. Workers showed a reduction in IgG titer to beet extract after a ventilation system was installed.

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff normally employ occupational exposure limit criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. There are no such criteria for exposure to microorganisms. The exposure level to microorganisms that will cause symptoms is difficult to define since the degree of immune response varies from person to person. Once an individual is sensitized, the individual may have an extremely low tolerance level for exposure.

Several genera of fungi were identified in air samples collected in this plant. These include Alternaria, Aspergillus, Beauveria, Botrytis, Cladosporium, Drechslera, Monilia, Mucorales, Penicillium, Rhizopus, and Trichoderma. Alternaria is noted to cause hypersensitivity pneumonitis, conjunctivitis, and skin and nail infections.¹⁷ There are several species of Aspergillus that are reported to cause allergic health problems, as well as the opportunistic infection aspergillosis.¹⁷⁻¹⁸ Members of the genera Botrytis, Drechslera, Monilia, and Trichoderma are identified as allergens.¹⁹

V. STUDY METHODOLOGY

Air samples were collected on persons working in different job categories in the plant and in selected plant areas. A Real-time Aerosol Monitor (RAM) (MIE, Inc., Bedford, Massachusetts) was used to determine areas of high dust concentration to further identify workers potentially at risk. The selection of sampling sites was aided by information supplied by the Michigan Department of Health.

Sampling was performed in two phases of plant operation: during the sugar production campaign (January) by NIOSH and during the cleanup/maintenance phase (June) by the Michigan Department of Health. The purpose was to determine when the workers have the highest exposure to microorganisms. In the January survey, sampling focused on pellet loaders, beet loaders, beet washer operators, pellet mill operators, and maintenance workers in the plant. Area samples were collected in the factory office, the vacuum pans area, the trash catcher area, the pulp drier area, and the pellet conveyor area. Special attention was given to the pellet loaders who off-loaded pulp pellets from the pellet silo to truck and rail cars. Two cassette samples per day per worker were taken. Most jobs and areas were sampled for three days. A total of 49 cassette samples were collected, both area and personal. In addition, during the January survey, one Burkard Spore Trap was operated for 3 days on the roof of the Plant Office to obtain a continuous record of airborne dust and organisms in the ambient air. The Burkard Spore Trap produced one sample strip representing a continuous analysis for three days.

The June follow-up survey performed by the Michigan Department of Health focused upon the pellet loaders who off-loaded pulp pellets from the pellet silo to truck and rail cars, workers who were operating front-end loaders in the silo, and maintenance personnel working in the pellet mill/warehouse area. A total of 21 cassette samples were obtained.

Sampling and Analytical Methods

The sampling emphasized locating areas of high dust to qualitatively and quantitatively identify the presence of microorganisms in the air. The assessment of microorganisms was accomplished by counting and identifying organisms captured on a sterile polycarbonate membrane filter, sticky surface, agar plate, or in a high velocity liquid impinger.

Filter cassettes with a polycarbonate membrane filter (0.8 micrometer pore size) were used in personal and area sampling. This method allows flexibility in dealing with unpredictable levels of spores by permitting a direct count of the spores on the filter or a serial dilution. A portion of the filter was scanned with a microscope to observe and count the spores. Another portion of the filter was washed with a buffer solution (0.02 percent Tween 20®) in water with agitation. A portion of the recovered wash volume was serially diluted (full strength, 1:10, 1:100, 1:1000) and 0.1 ml of each was inoculated onto duplicate malt extract agar plates. Residual spores on the filter were counted by placing the filter on a nutrient culture to allow growth of colonies.

As part of a project collateral to this survey, a comparison was undertaken of the sampling efficiency of seven bioaerosol sampling devices when challenged with aerosols of different size distributions. The sampling devices studied included: Andersen Six stage Viable Particle Sizing Sampler (6-STG), Andersen Two-stage (2-STG), Andersen Single-stage (1-STG), PBI Surface Air System (SAS), Mattson-Garvin Slit-to-Agar (STA), Gelman 47 mm Membrane Filter (MF), and the ACE Glass All Glass Impinger-30 (AGI-30). All of these samplers (except the AGI-30) require a culture medium as the collecting surface; the medium is selective to fungi so as to screen out bacteria. For this study, Malt Extract Agar (MEA)²⁰ was used with the antibiotic streptomycin added to inhibit the growth of bacteria. The results of this collateral project are explained in Appendix A.

Airborne exposures to formaldehyde (used periodically along with other process biocides) were evaluated by use of detector tubes (National Dräger Company, Pittsburgh, Pennsylvania).

VI. RESULTS AND DISCUSSION

Microbiological evaluation

Fungi identified in this beet sugar plant during the two survey periods are identified in Table I. They were found in varying numbers at different times and locations in the plant but certain genera were frequently present in significant concentrations.

The data from the cassette samples were first analyzed to determine which of the 18 genera identified in Table I were predominant. These predominant fungi taxa were Penicillium, Cladosporium, Aspergillus, Monilia, Trichoderma and Rhizopus. Because of the predominance of one Aspergillus species, Aspergillus was subdivided into A. glaucus and A. species (other Aspergillus).

TABLE I. Fungi Identified in Airborne Samples.	
Fungi Most Observed.	
Penicillium Aspergillus glaucus †Aspergillus flavus group *Monilia *Rhizopus	Cladosporium †Aspergillus vericolor †Aspergillus fumigatus *Trichoderma
† Reported as Aspergillus species (A. spp.) * Frequently overgrew the culture plate.	
Present But Reported As "Other".	
Alternaria Ascospores Basidiospores Botrytis Fusarium Paecilomyces Wallemia	Aureobasidium Aspergillus flavus colum Beauveria-like Drechslera Mucorales Pithomyces

Results of the air sampling for each job classification and plant areas for these eight fungi classifications are listed in Table II. Graphical representations are shown in Appendix B. Because many organisms are not easily identified they were classified as unknown or unknown-nonsporating.

Previous medical tests indicated a sensitivity of a maintenance worker to A. niger. Therefore, one prime object of the study was the identification of A. niger. Sampling results did not indicate the presence of A. niger in January. It had been assumed that during the winter months, there would be sufficient warmth in the pellet silo to support the growth of A. niger, which is thermophilic. Several other A. species were detected in the January samples: A. glaucus, A. fumigatus, A. flavus colum, A. flavus, and A. versicolor.

In January, the pellet loaders had the highest average personal exposures to fungal spores, 30,000 CFU/m³ (n=6). Exposure was principally to Penicillium (16,000 CFU/m³), A. species (6,900 CFU/m³), and A. glaucus (2,300 CFU/m³). The pellet conveyor area had the highest spore concentration measured in the plant, 69,000 CFU/m³, which is an order of magnitude higher than the next highest area, the plant roof. The pellet loaders' jobs require them to periodically enter the pellet conveyor area.

The beet loaders had an average exposure to all fungi (excluding yeasts) of 2,200 CFU/m³ (primarily to Penicillium), the lowest of all the job categories sampled. The average exposure of the pellet mill operators to fungi was 2,400 CFU/m³. The maintenance workers, pellet foreman and the beet washer operators were exposed primarily to Penicillium and lower concentrations of Cladosporium and A. glaucus.

Table II. Average microorganism concentration/exposure (CFU/m³).

AREA SAMPLES - JANUARY 1991						
FUNGI	ROOF	OFFICE (FACTORY)	PELLET CONVEYOR	PULP DRYER	TRASH CATCHER	VACUUM PANS
No. of Samples	3	3	3	3	2	3
Penicillium	1000	90	340	460	330	130
Cladosporium	430	15	20	56	25	20
A. glaucus	0	0	0	0	0	0
A. species	1300	14	25000	85	300	9
Monilia	5	9	450	37	0	9
Trichoderma	0	0	0	0	7	0
Rhizopus	5	0	9300	20	0	9
Other (non yeast)	1700	20	34000	30	58	53
Total Fungi	4400	150	69000	690	720	230
PERSONAL SAMPLES - JANUARY 1991						
FUNGI	MAINT.	BEEET LOADER	PELLET LOADER	PELLET MILL OP.	PELLET FOREMAN	BEEET WASH OPERATOR
No. of Samples	6	6	6	3	3	3
Penicillium	2000	1600	16000	480	2300	670
Cladosporium	730	100	130	310	450	20
A. glaucus	360	0	4600	0	300	0
A. species	20	40	4600	250	0	40
Monilia	0	160	12	500	600	10
Trichoderma	0	0	0	510	0	0
Rhizopus	0	0	6	5	10	0
Other (non yeast)	270	260	4800	310	5	210
Total Fungi	3400	2200	30000	2400	3700	950
PERSONAL SAMPLES - JUNE 1991						
FUNGI	SILO UNLOADER	PELLET MILL OP.	PELLET LOADER			
No. of Samples	7	4	10			
Penicillium	400000	43000	800000			
Cladosporium	0	12000	20000			
A. glaucus	0	1000	0			
A. species	300000	26000	490000			
Monilia	64000	0	42000			
Trichoderma	39000	2000	43000			
Rhizopus	67000	0	53000			
Other (non yeast)	410000	12000	77000			
Total Fungi	1300000	96000	1500000			

* Column totals are reported to 2 significant figures.

The results of all January area samples are reported in Table II. They represent six sample points: pellet conveyor, plant roof, factory office, trash catcher, vacuum pans, and the pulp drier. The factory office, located away from production areas, had the lowest spore count of all the areas sampled; the average concentration of fungi was 150 CFU/m³. The highest average spore count for area samples was for A. species at 25,000 CFU/m³ (n=3) and Rhizopus at 9,300 CFU/m³ (n=3).

It should be noted that, in work areas sampled, Penicillium was the predominant fungi except at the pellet conveyor, situated under the silo, where A. species were the most predominant. The Penicillium concentration there was below 400 CFU/m³, which is surprising since the average exposure of the pellet loaders to Penicillium was 16,000 CFU/m³. The pellets are presumably the same in both cases. One reason could be that the workers spend very little time in pellet conveyor tunnel. Another possible explanation is that there is an inherent weakness in dilution analysis: high analytical dilutions can exclude taxa present in the air sample at low concentrations. The dilution technique therefor favors the predominant fungi at the expense of excluding minor populations. It is important to note that higher dilutions also increase the variance of the data.

The sampling by the Michigan Department of Health, during the June 1991 clean-up/maintenance phase of plant operation, concentrated on the pellet silo, pellet loaders and on the pellet mill/warehouse operators. The analyses were performed by the same laboratory that performed the analyses for the January survey.

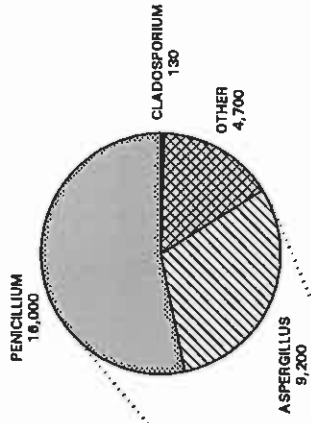
The comparison of the January and June results indicate a great increase of exposure levels in June for each job tested. The pellet silo, closed during the January survey, was open in June so that the pellet loaders could enter the silo with a front-end loader to move residual pellets from the silo floor. The residual pellets were overgrown with fungi growth, and high spore levels were encountered. The pellet loaders also performed rail car and truck loading as they had in January. The average exposure to fungi of the pellet loaders increased five-fold from the January survey. A comparison of the January/June spore exposure levels of the pellet loaders is shown in Figure 2. The pellet mill operators ran the pellet mills in January; in June they performed maintenance work and were exposed to moldy pulp dust. Their average exposure to fungi increased about 35 times from the January survey. A comparison of the exposure of the pellet mill operators is shown in Figure 3.

Real-time aerosol measurements

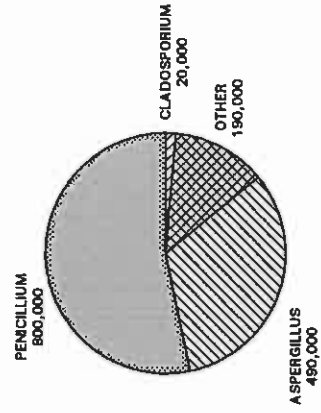
The Real Time Aerosol Monitor (RAM) was used during the walk-through survey to identify individuals or areas for subsequent sampling for microorganisms. This instrument is a light-scattering device and its response is dependent upon the optical density, size and shape of the dust particles being measured. The sample air entering the RAM has been passed through a cyclone to remove particles greater than 10 microns. Measurements of airborne dusts and mists obtained using the RAM are reported in Table III. The RAM does not differentiate chemically between types of dusts. For these reasons, concentrations reported are not indicative of any particular material but are relative to the factory calibration using Arizona Road Dust, a standard reference dust. The high concentrations recorded in the beet washing and pulp pressing areas may be due to the presence of water mist, which could potentially contain microorganisms. The truck loading area, a visibly dusty operation, was sampled with the RAM during pellet loading at selective points. It was noticed that compressed air is used to clear dust from this area; no aerosol

MONITOR SUGAR COMPANY, COMPARISON OF DATA, JANUARY/JUNE

JANUARY 1991



JUNE 1991



**PELLET LOADERS
JANUARY & JUNE 1991**

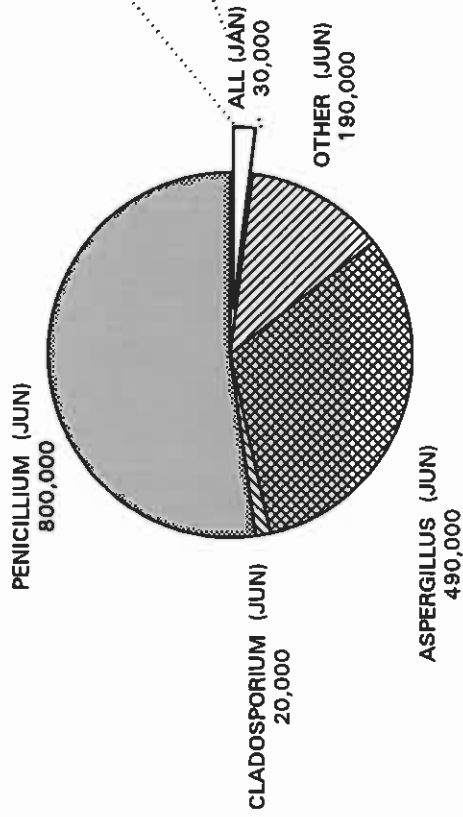
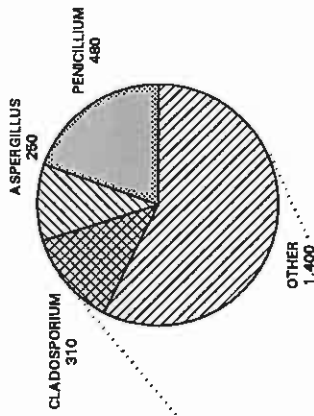


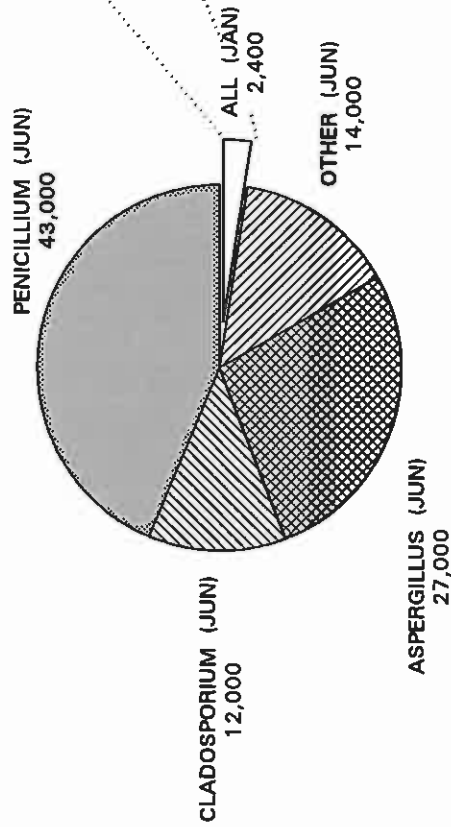
FIGURE 2.

MONITOR SUGAR COMPANY, COMPARISON OF DATA, JANUARY/JUNE

JANUARY 1991



**PELLET MILL OPERATORS
JANUARY & JUNE 1991**



JUNE 1991

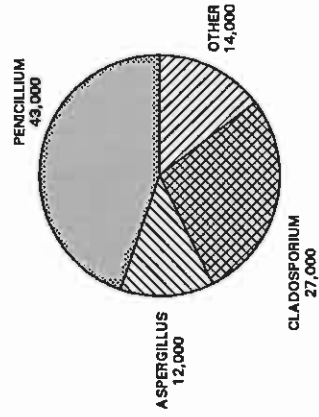


FIGURE 3.

III. Total Aerosol Measurements Using the RAM	
Beet washer (upper plant)	15.0 mg/m ³
Beet washer (behind washer)	5.0 mg/m ³
Flume pump to beet washer	4.0 mg/m ³
Pulp presses	2.0 mg/m ³
Pellet Conveyor	0.1-0.2 mg/m ³
Truck loading (general area)	0.5-2.0 mg/m ³
Truck loading:	
First Loading Port	0.4-1.0 mg/m ³
First Loading Port	1.5 mg/m ³
Second Loading Port	1.5 mg/m ³
Second Loading Port (downwind)	1.0 mg/m ³
Third Loading Port	2.0 mg/m ³
Third Loading Port	7.0 mg/m ³
Third Loading Port	0.2 mg/m ³

measurements were made with the RAM during compressed air use. This use of compressed air may produce high levels of organic dusts, spores or nonviable fungi fragments.

Observational evaluations

Chlorine dioxide (ClO₂), used as a bactericide in the diffusion process, is generated on site from the reaction of sodium chlorite with chlorine gas. The chlorine gas is contained in one ton capacity cylinders. The cylinders and generator are located on the ground floor beneath the pulp presses in the main plant building. Reserve cylinders of chlorine are stored outside. Leakage of chlorine from the cylinder could present a major hazard, requiring evacuation of the plant. (This company reports that they no longer use chlorine gas.⁹)

Formaldehyde along with other biocides was used in the process to control bacterial growth in the diffuser. Formaldehyde is only used when pH is observed to drop due to the production of lactic acid from bacterial activity. No formaldehyde was used during this study. No airborne formaldehyde was detected in the formaldehyde drum storage area. At the bung of an "empty" but open drum of formaldehyde, a reading in excess of 50 ppm was detected.

One-ton cylinders of sulfur dioxide, used as a Ph control agent in the refining process, are stored in a separate building. Warm water is used to vaporize the sulfur dioxide. Supplied air respirators are stored near the tanks, but not routinely worn during cylinder changes. Respirator air lines are located near the tanks, which may not be connectable in case of leaks or spills. The air supply source for the breathing air is located on the other side of the wall from the tank. A major leak could potentially contaminate the air inside the building and render the respirator air supply unusable. The sulfur dioxide lines running through the plant could present a hazard to the entire plant in the event of leakage.

VII. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Although no Aspergillus niger was found, this study demonstrated high exposure of pellet loaders and pellet silo workers to other Aspergillus species. Other fungal species were detected in the survey which pose a potential health hazard. The exposures to fungi in June were much higher than those measured in January. This was not unexpected since the original worker complaints occurred in the month of June when the silo was opened for removal of the residual pellets. The comparison of the exposure of pellet loaders in the two sampling periods indicates that the general spectrum of taxa is similar but the concentration of fungal spores in June was over 50 times greater. This may be attributed to the higher temperature in June plus the long period of time that the pellets had been trapped in the bottom of the silo.

The exposure of the pellet loaders and pellet silo workers was due to three factors: 1) a silo design which fails to provide for product turnover, creating conditions favorable for microbial growth; 2) pellet spillage and inadequate ventilation of the pellet conveyor area; and 3) no dust control during the loading of trucks and railroad cars.

The design of the pellet silo is a factor in spore exposure during and after the campaign due to fungal growth in the immobile pellets on the flat floor of the silo. The four pellet discharge ports in line along a diameter of the silo leaves a large area of the floor that does not feed pellets into the ports. These four in-line discharge outlets above the conveyor belt draw pellets from directly above the port, to create channels or rat-holes. This situation is depicted in Figure 4. With continuous operation, the incoming pellets will periodically collapse to fill these rat-holes and will tend to pass directly through the silo. Pellets along side these channels will have a longer residence time; some near the bottom and by the walls will remain until the silo is emptied at the end of the campaign. This situation contributes to fungal growth in the stored pellets and subsequent exposure of workers to spores.

The pellet conveyor area had high concentrations of airborne spores. These high concentrations of spores can be attributed to the fungal growth in the pellet silo described above, clogging of the discharge openings with aging clumps of pellets (which must be manually removed), pellet spillage from the conveyor belt, and inadequate ventilation of the pellet conveyor area. An exhaust duct is present at each of the points where the silo discharges onto the conveyor belt, but the duct inlets are located several duct diameters from the point of dust generation, a distance which is too great to effectively capture dust. A large duct with fan discharges to the outdoors. This duct would appear to do little for evacuation of dust in the conveyor tunnel. Some operating mechanisms for clamshell discharge doors were inoperable, requiring the operator to wedge the doors open with a stick. This resulted in poor control of pellet flow and subsequent spillage.

Pellet Loaders are exposed to high levels of pellet dust during the loading of trucks and railroad cars. Pellets, which fall a considerable distance through chutes and into the trucks or railroad cars, induce a flow of air, which becomes laden with pellet debris. This debris will contain fungal spores when moldy pellets are being loaded.

PELLET STORAGE SILO, MONITOR SUGAR COMPANY, BAY CITY, MI.

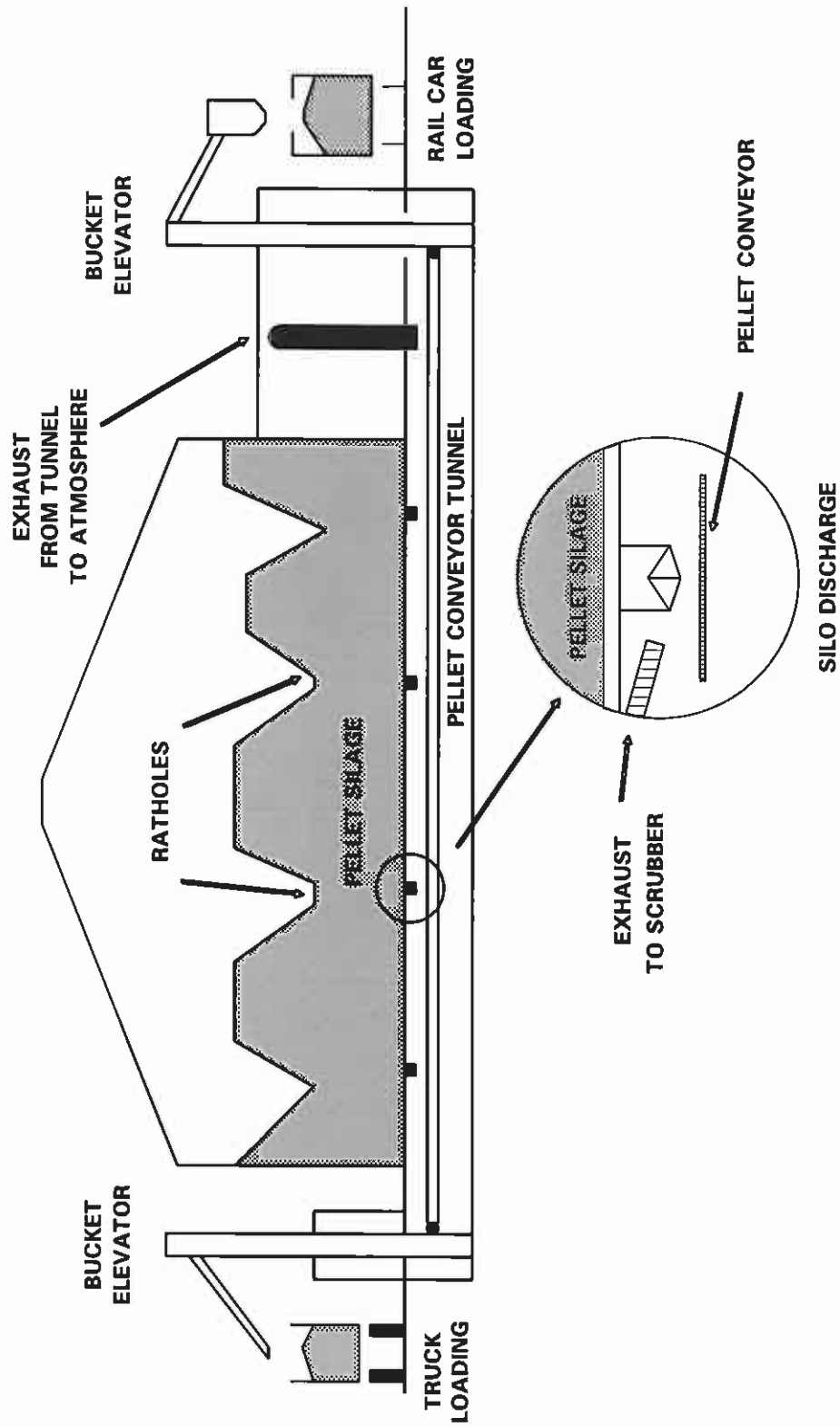


FIGURE 4.

Recommendations

The exposure of the pellet loaders and pellet silo workers can be minimized by the following actions: 1) improving silo design to improve pellet flow; 2) minimizing entry into the pellet conveyor area; 3) improvement of conveyor ventilation, and 4) addition of dust controls during the loading of trucks and railroad cars.

Improving the silo design is the single most important element in the reduction of exposure to the fungal spores. By preventing the accumulation and subsequent rotting of pellets, production of fungal spores would be minimized, and exposures in subsequent transport and loading would be reduced. The flat-floored design of the silo is responsible for the accumulation and subsequent deterioration of the pellets through microbial action. Two alternatives exist for improved pellet flow. The first alternative would be to install a sloped metal floor in the silo. The geometry of the existing silo would limit the slope to a maximum of 30 degrees. Dead spots would still exist along the line of the discharge ports; installation of a screw conveyor(s) in the "vee" formed by the sloped floor could eliminate all dead spots. A second alternative would be to replace the existing silo with a series of smaller diameter silos, each with a conical hopper.

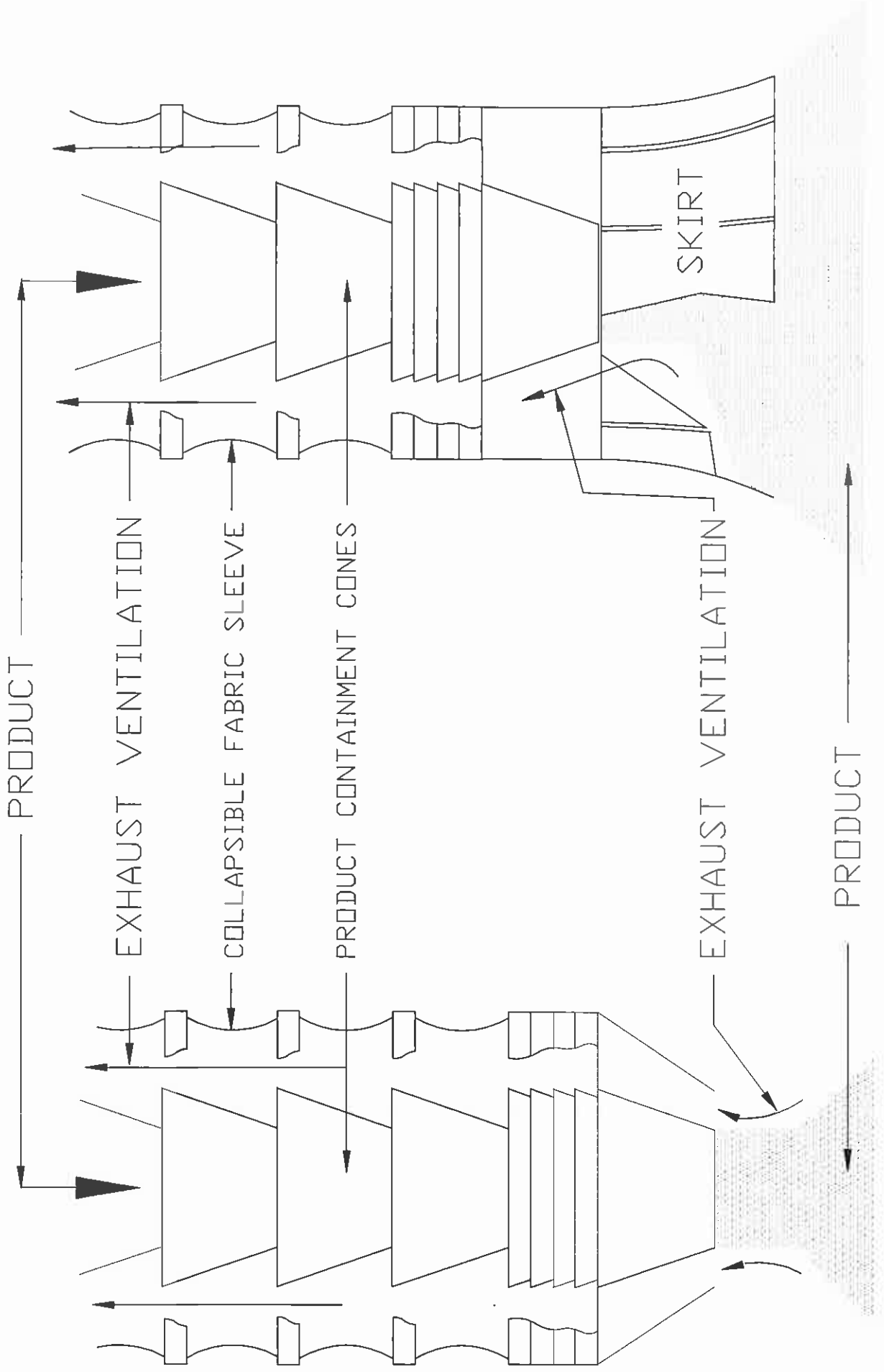
Entry into the pellet conveyor tunnel should be minimized by repairing and motorizing the existing clamshell discharge ports. This operation can then be accomplished from outside of the conveyor area; a television camera can be installed in the conveyor pit so that operation can be remotely monitored.

Ventilation can be improved in the pellet conveyor area. Since the existing exhaust ducts at the conveyor pellet discharge points are too far away to be effective, they should be connected to sheet metal enclosures built around the discharge openings, with rubber skirts above the conveyor belt. Installation of side-boards along the conveyor should be considered to reduce the spillage of pellets onto the floor of the conveyor tunnel. A vacuum cleaner (preferably one with HEPA filters) for use in the pellet conveyor area would be helpful in cleaning up spilled pellets.

Dust exposure during the loading of trucks and railroad cars can be reduced by the installation of ventilated loading spouts. An example of such a system is shown in Figure 5. These systems were originally developed for grain loading operations and are available from several sources.²¹ These systems typically consist of two concentric tubes. Product material is discharged through the inner tube. Dust and displaced air from the container being filled are exhausted through the outer tube, countercurrent to the solids flow.

Until the above measures can be implemented and the degree of control ascertained, a respiratory protection program must be implemented. The pellet mill operator, the silo unloader, and the pellet loaders should be required to wear NIOSH/Mine Safety and Health Administration (MSHA) approved respirators. Respirators should be fitted and used in accordance with OSHA requirements for an acceptable respiratory protection program as described in 29 Code of Federal Regulations, Part 1910.134.

After implementation of a respiratory protection program, sampling for airborne fungi should be performed to ensure that the respirator selected is adequate. Such sampling should be conducted periodically, because of the observed seasonal variation of fungi exposure.



Handling of toxic/flammable compressed gases needs to be improved. Propane and chlorine gas storage was in very large containers inside the process building. These containers would present less of a hazard if they were moved into a separate building. Consideration should also be given to installation of pipe within a pipe system for sulfur dioxide lines, with the outer pipe continuously purged and monitored. It is also recommended that multi-point monitoring systems be installed which will warn workers of a hazardous level of sulfur dioxide. Respiratory protection should be used during cylinder changes. The type of respiratory protection used should be based upon the concentration expected to be encountered. Guidelines should be posted for storing all compressed gases, as many cylinders were observed to be not secured.

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IX. APPENDICES

Appendix A Sampler comparison.

A comparison was undertaken of sampling efficiencies of seven bioaerosol sampling devices when challenged with aerosols of different size distributions. The sampling devices studied included: Andersen Six stage Viable Particle Sizing Sampler (6-STG), Andersen Two-stage (2-STG), Andersen Single-stage (1-STG), PBI Surface Air System (SAS), Mattson-Garvin Slit-to-Agar(STA), Gelman 47 mm Membrane Filter (MF), and the ACE Glass All Glass Impinger-30 (AGI-30). Two data sets were obtained during the industrial hygiene evaluation of Monitor Sugar Company Refinery. Large, polydisperse aerosols of fungi were collected at two different locations within the refinery. The size distributions are presented in Figure A-3. The Milling area aerosol was characterized as having a Count Median Aerodynamic Diameter (CMAD) of 4.4 μm with a Geometric Standard Deviation (GSD) of 1.67. The silo area aerosol was characterized as having a CMAD of greater than 6.8 μm with a GSD of 2.52. The sampler results (CFU/m³) for each area are presented in Figures A-1 and A-2. The SAS demonstrated a significant reduction in collection efficiency (compared to the other six samplers) for the aerosol of fungi spores with CMAD of 4.4 μm . There was no significant difference in collection efficiencies of the samplers for the aerosol of fungi spores with CMAD of $\geq 6.8 \mu\text{m}$. These results indicate the possible underestimation of microbial contamination if a sampler is used in an environment containing a viable particle size distribution with a CMAD near of less than the cut-diameter of the sampler used.

Legend for Figures A-1 to A-3:

MF	Mean frequency for all samplers
SAS	SAS single stage sampler
2-STG	Andersen 2 stage sampler
STA	Slit to Agar Sampler
1-STG	Andersen Single Stage Sampler
AGI-30	All Glass Impinger
6-STG	Andersen 6 Stage Sampler

Titles of Illustrations A-1 through A-3:

Illustrations:

A-1.	Silo Area - Individual Sampler Results
A-2.	Mill Area - Individual Sampler Results
A-3.	Size Distribution For Milling and Silo Areas

SILO AREA

TOTAL FUNGI

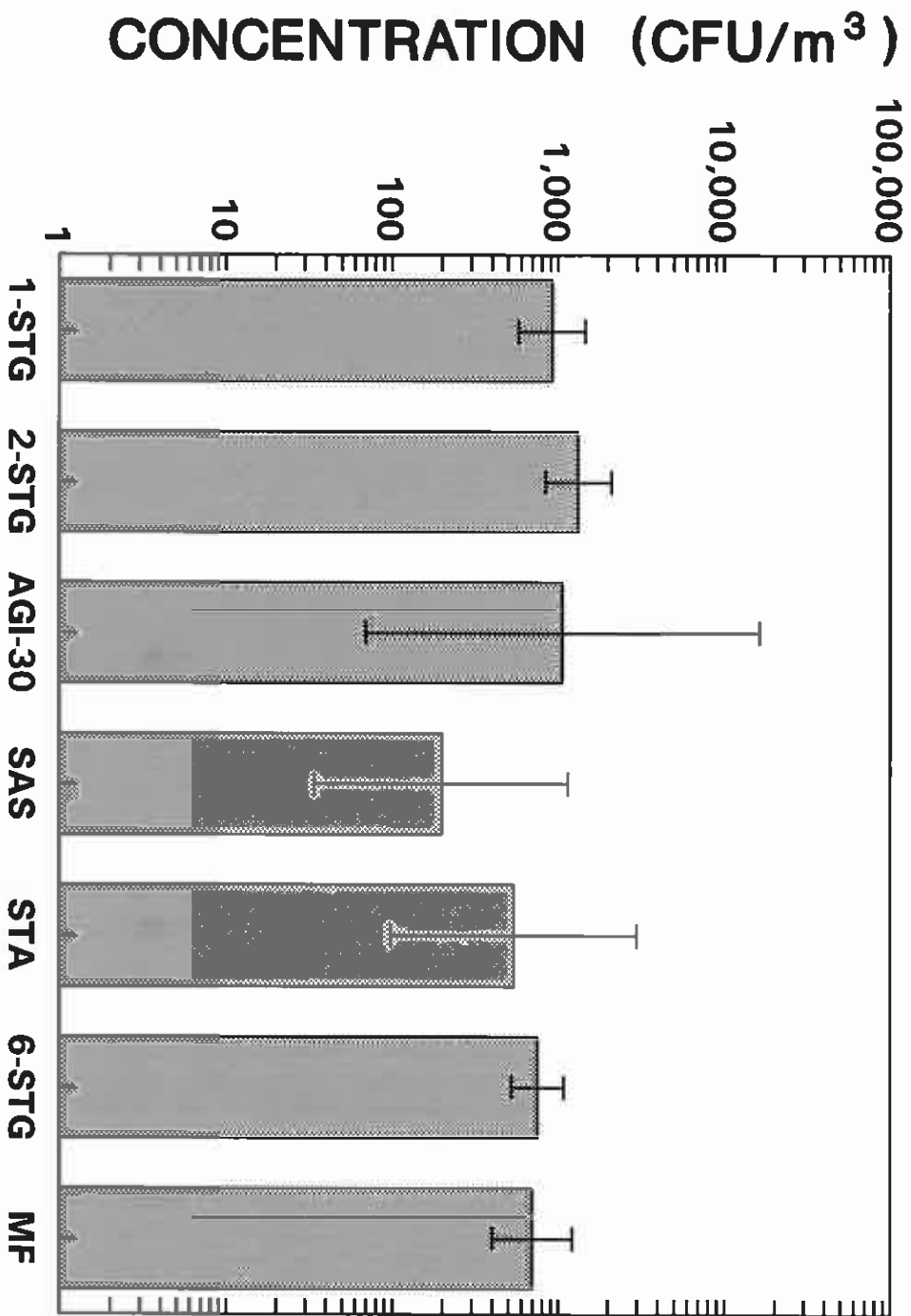


FIGURE A-1

BIOAEROSOL SAMPLER

MILLING AREA

TOTAL FUNGI

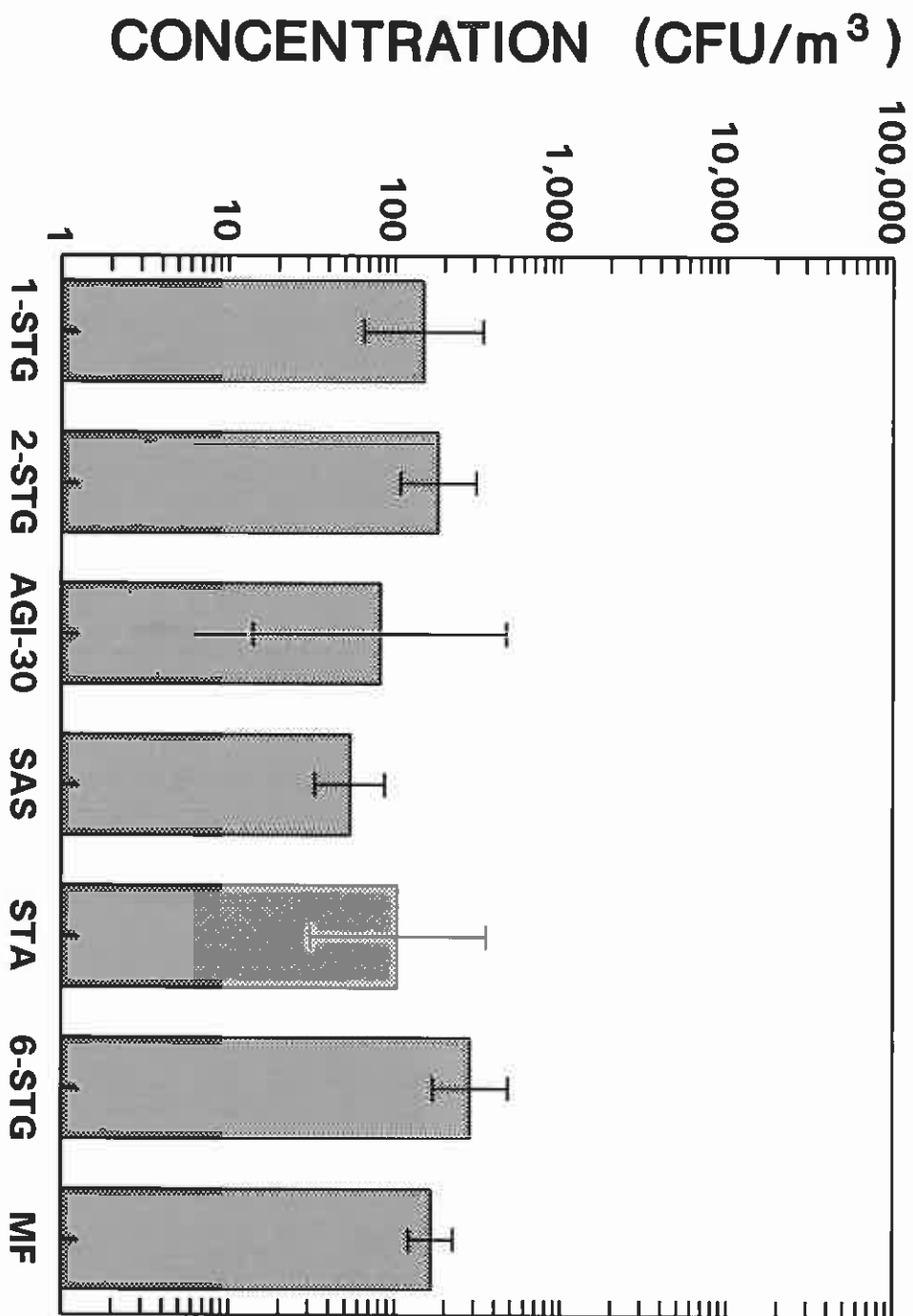


FIGURE A-2

BIOAEROSOL SAMPLER

SIZE DISTRIBUTION

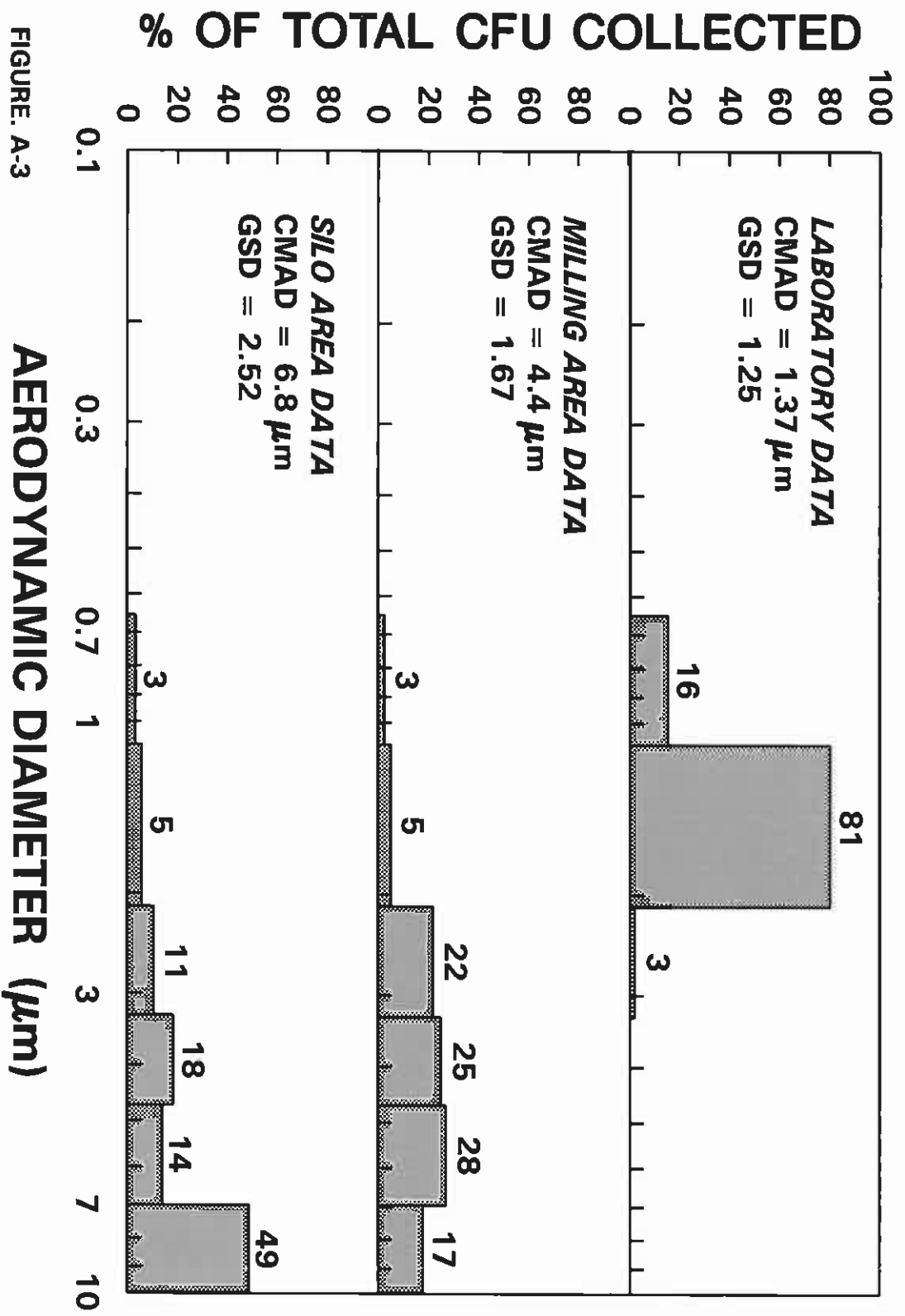


FIGURE. A-3

AERODYNAMIC DIAMETER (μm)

Appendix B. Graphical presentation of bioaerosol sampling results for selected jobs and work areas.

Titles of Illustrations B-1 through B-15:

Illustrations:

- B-1. Average Exposure, Pellet Loaders January 1991
- B-2. Average Exposure, Beet Loaders, January, 1991
- B-3. Average Exposure, Pellet Mill Operators, January, 1991
- B-4. Average Exposure, Maintenance Workers, January 1991
- B-5. Average Exposure, Pellet Foreman, January, 1991
- B-6. Average Exposure, Beet Washer Operator, January, 1991
- B-7. Average Exposure, Pellet Conveyor, January 1991
- B-8. Average Exposure, Roof Area, January, 1991
- B-9. Average Exposure, Factory Office, January, 1991
- B-10. Average Exposure, Trash Catcher, January 1991
- B-11. Average Exposure, Vacuum Pans, January, 1991
- B-12. Average Exposure, Pulp Drier, January, 1991
- B-13. Average Exposure, Pellet Loaders, June, 1991
- B-14. Average Exposure, Pellet Silo Workers, June, 1991
- B-15. Average Exposure, Pellet Mill/Warehouse Workers, June, 1991

AVERAGE EXPOSURE, PELLET LOADERS MONITOR SUGAR COMPANY, JANUARY, 1991

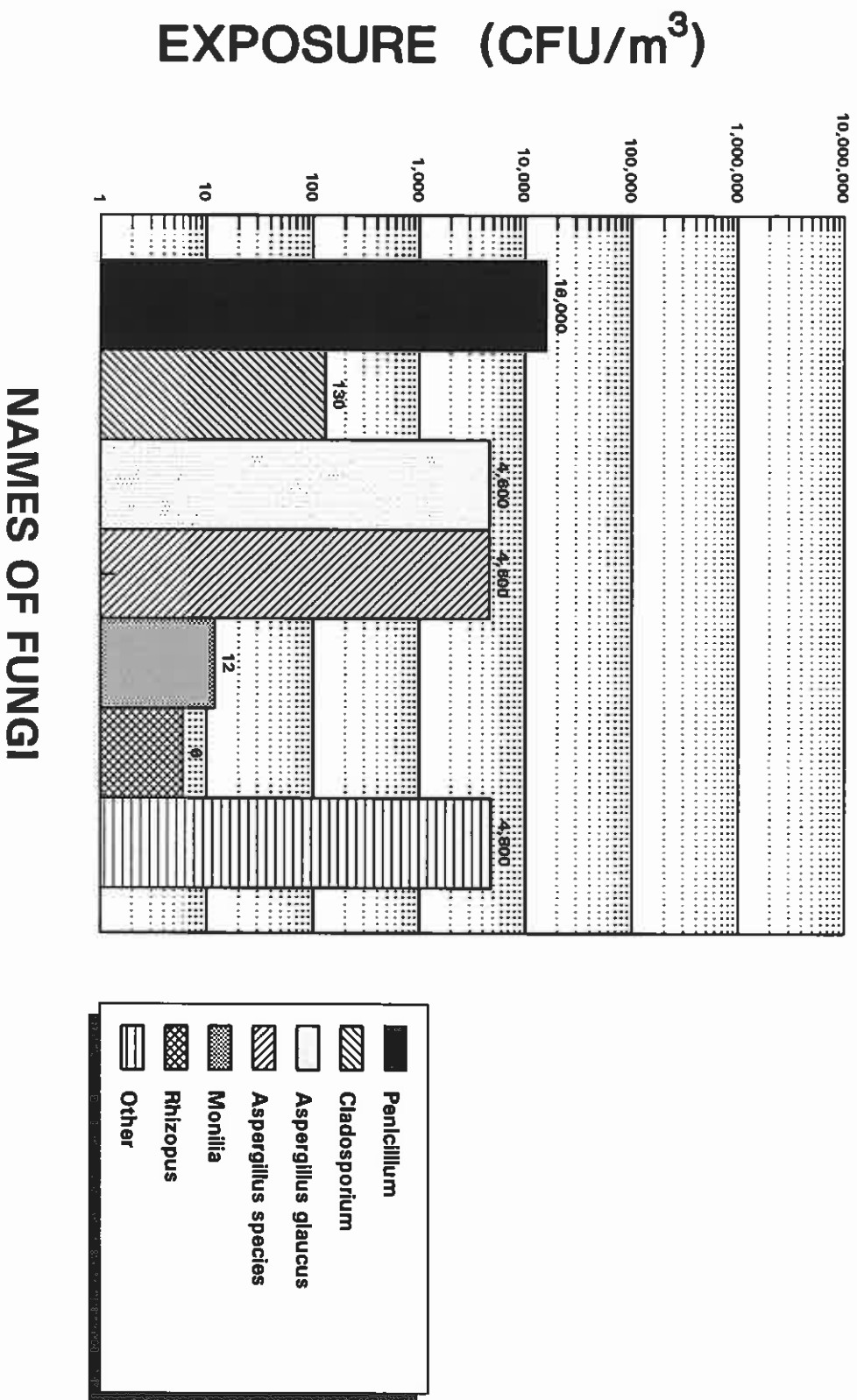


FIGURE B-1.

AVERAGE EXPOSURE, BEET LOADERS MONITOR SUGAR COMPANY, JANUARY, 1991

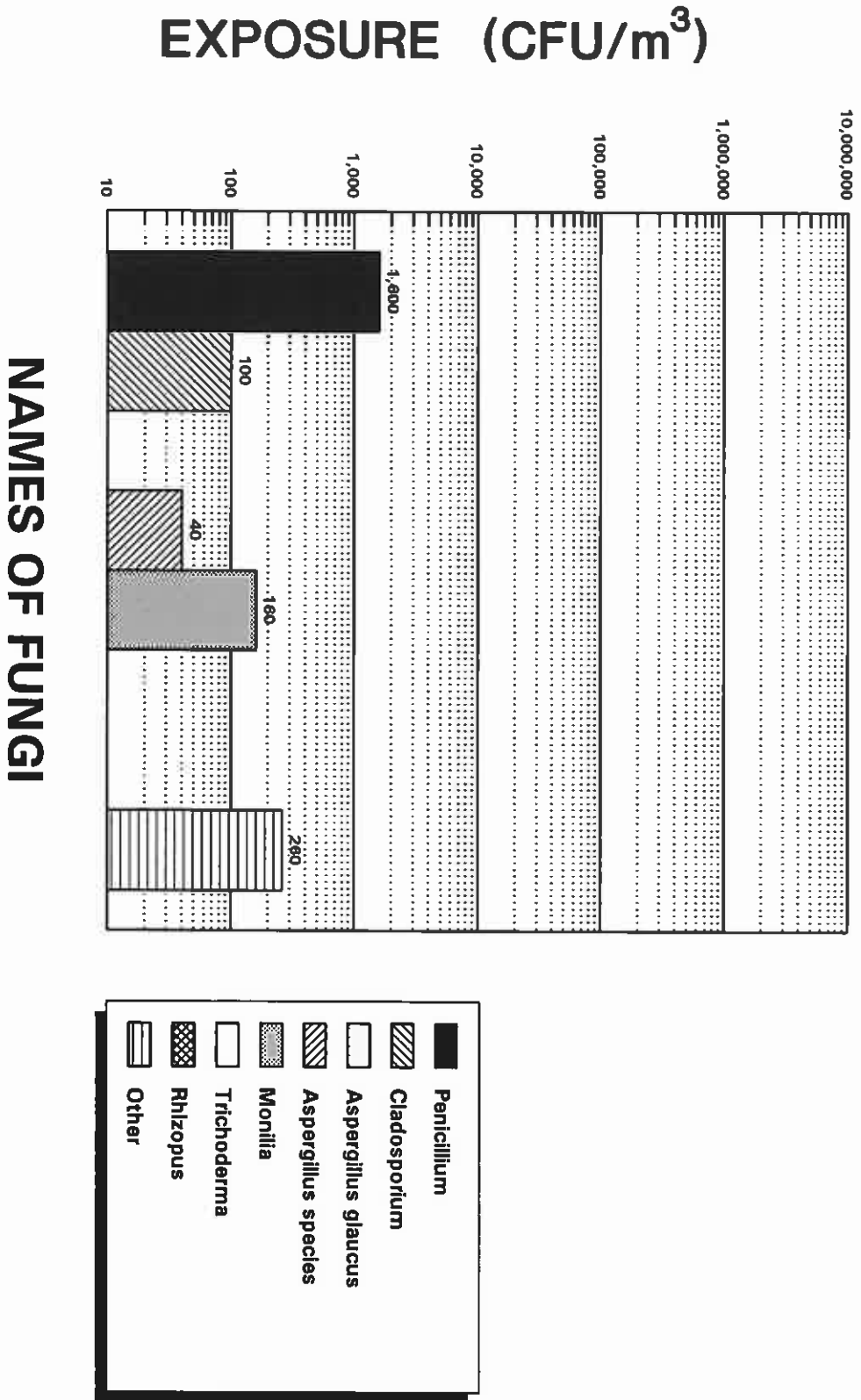


FIGURE B-2.

AVERAGE EXPOSURE, PELLET MILL OPERATORS MONITOR SUGAR COMPANY, JANUARY, 1991

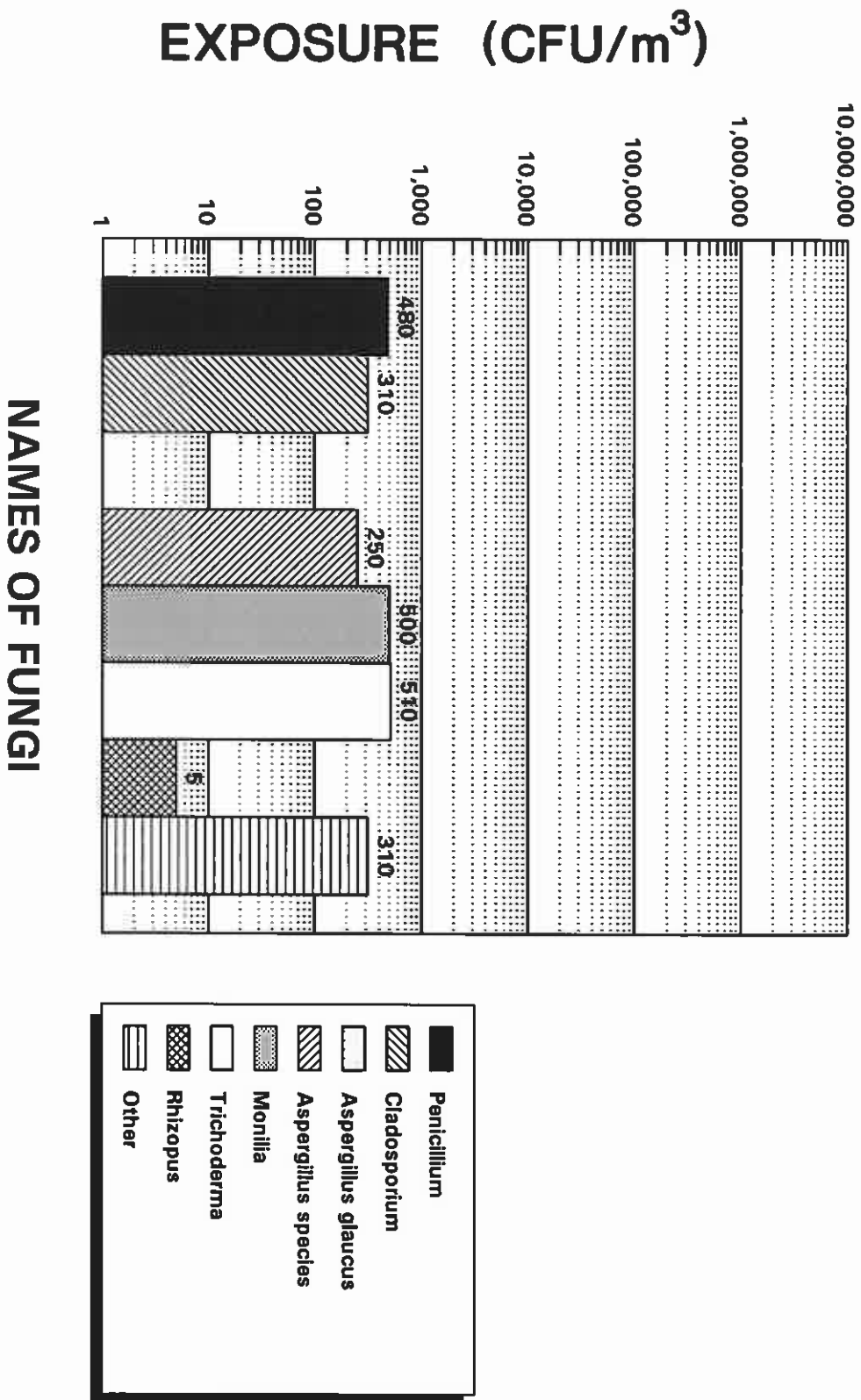


FIGURE B-3.

AVERAGE EXPOSURE, MAINTENANCE WORKERS MONITOR SUGAR COMPANY, JANUARY, 1991

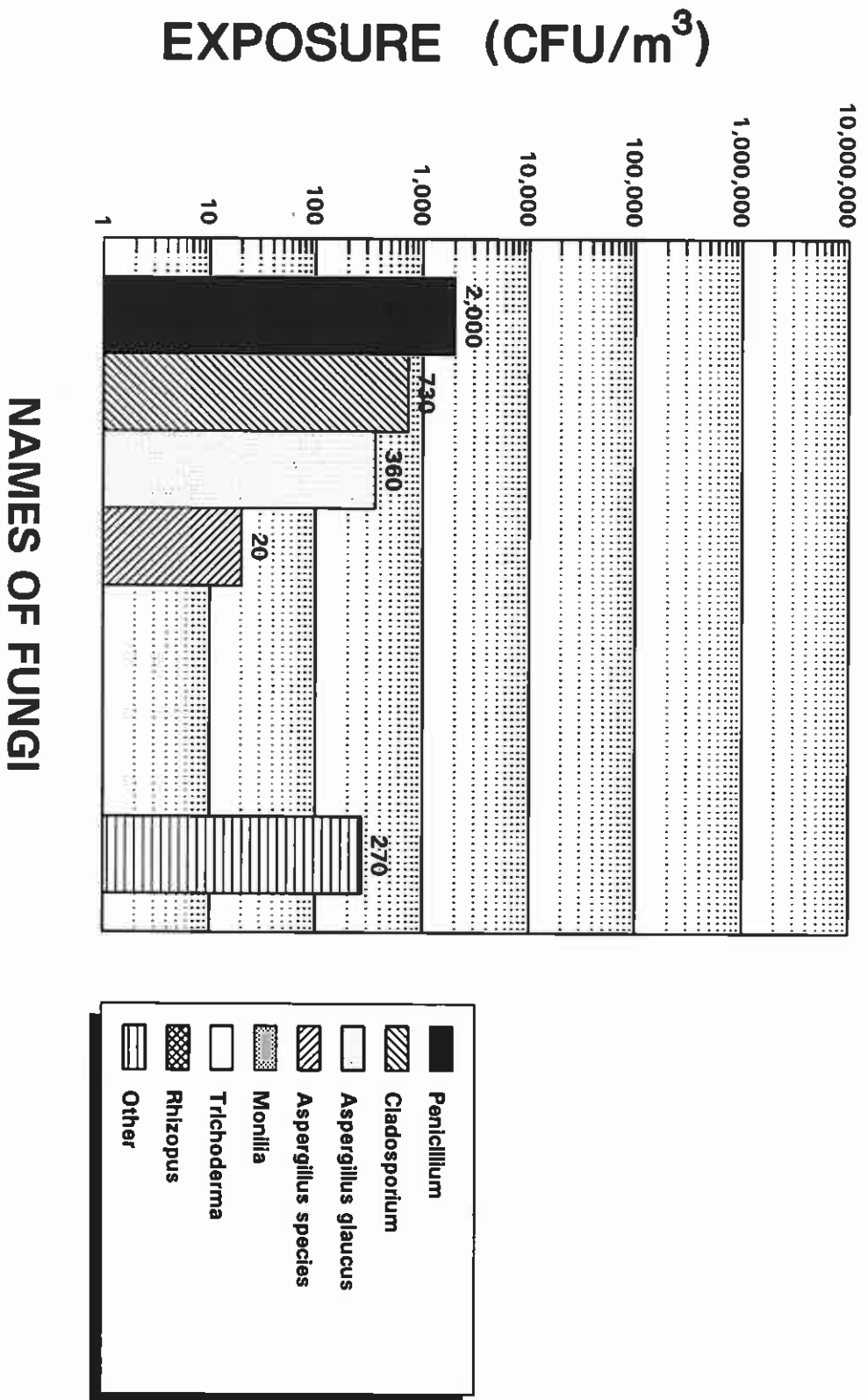


FIGURE B-4.

AVERAGE EXPOSURE, PELLET FOREMAN MONITOR SUGAR COMPANY, JANUARY, 1991

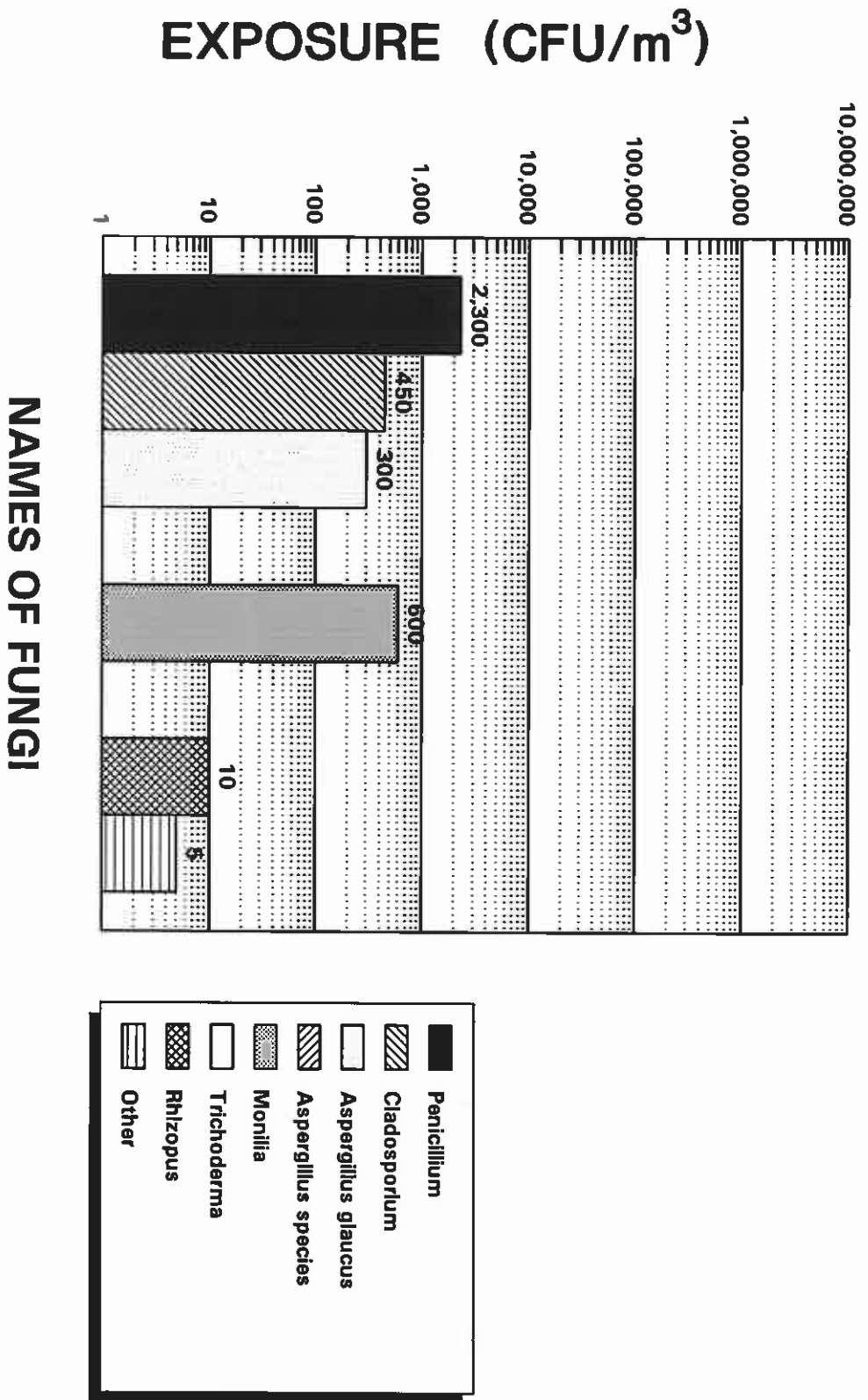


FIGURE B-5.

AVERAGE EXPOSURE, BEET WASHER OPERATOR MONITOR SUGAR COMPANY, JANUARY, 1991

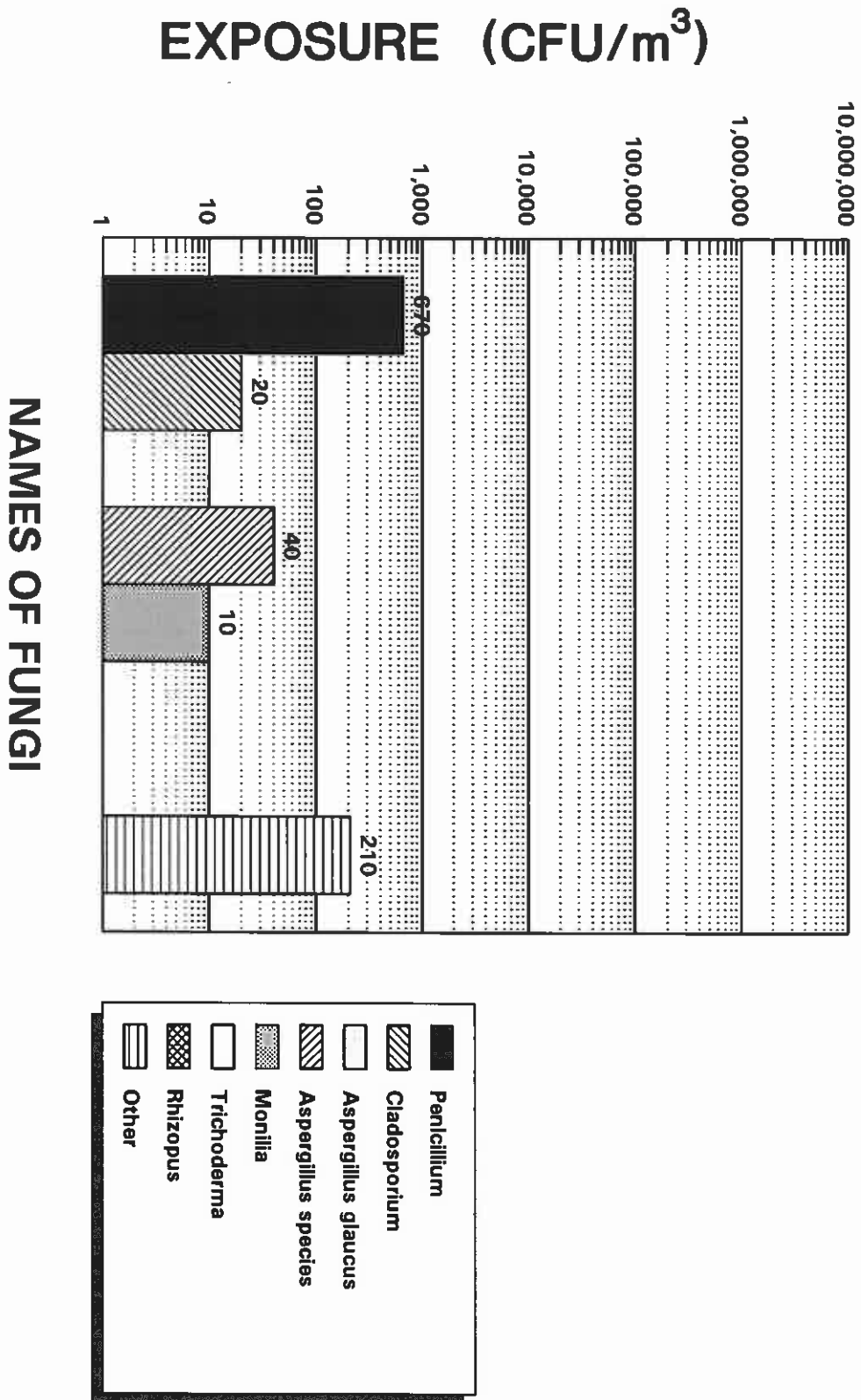


FIGURE B-6.

AVERAGE SPORE CONC., PELLET CONVEYOR MONITOR SUGAR COMPANY, JANUARY, 1991

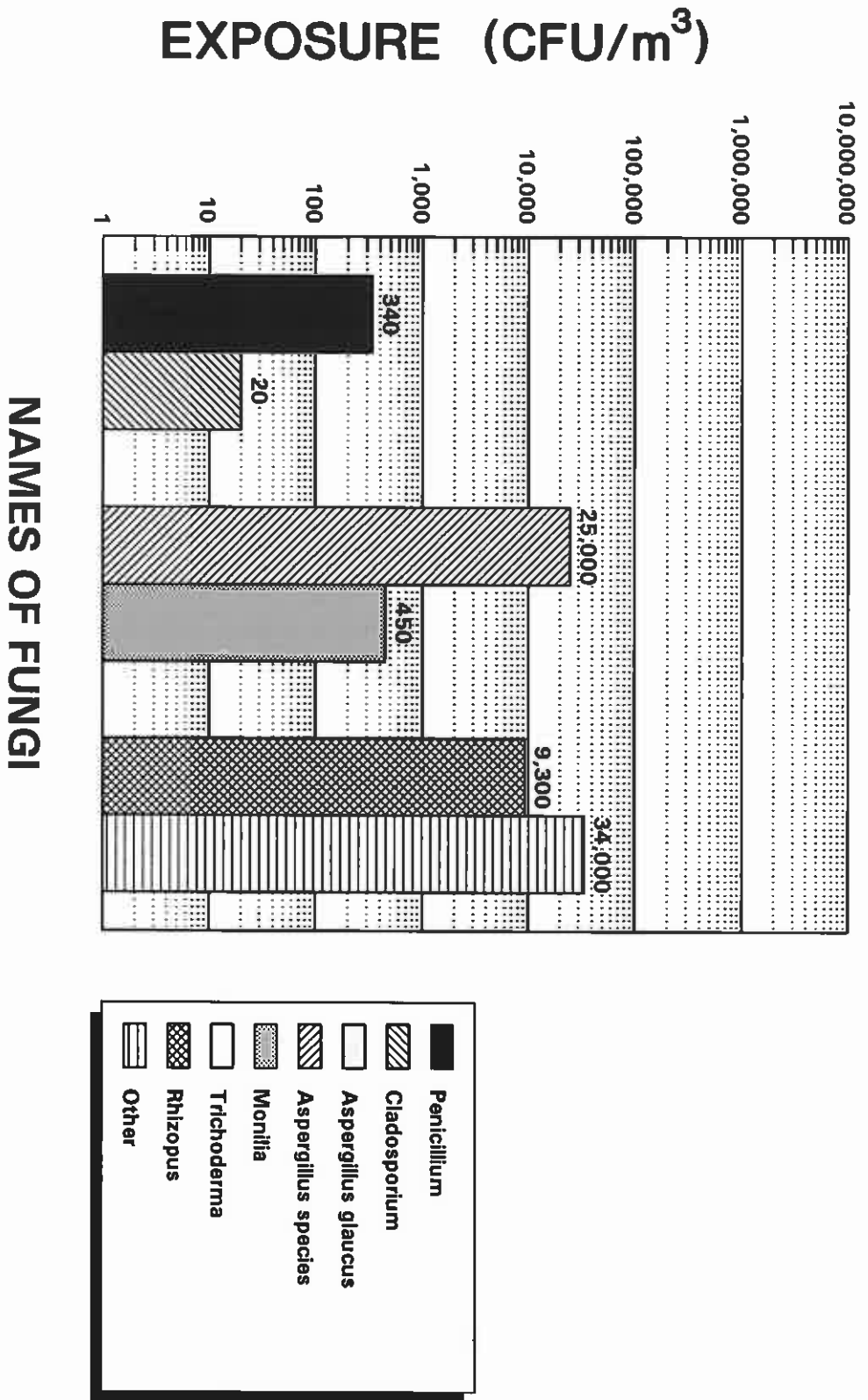


FIGURE B-7.

AVERAGE SPORE CONCENTRATION, ROOF AREA MONITOR SUGAR COMPANY, JANUARY, 1991

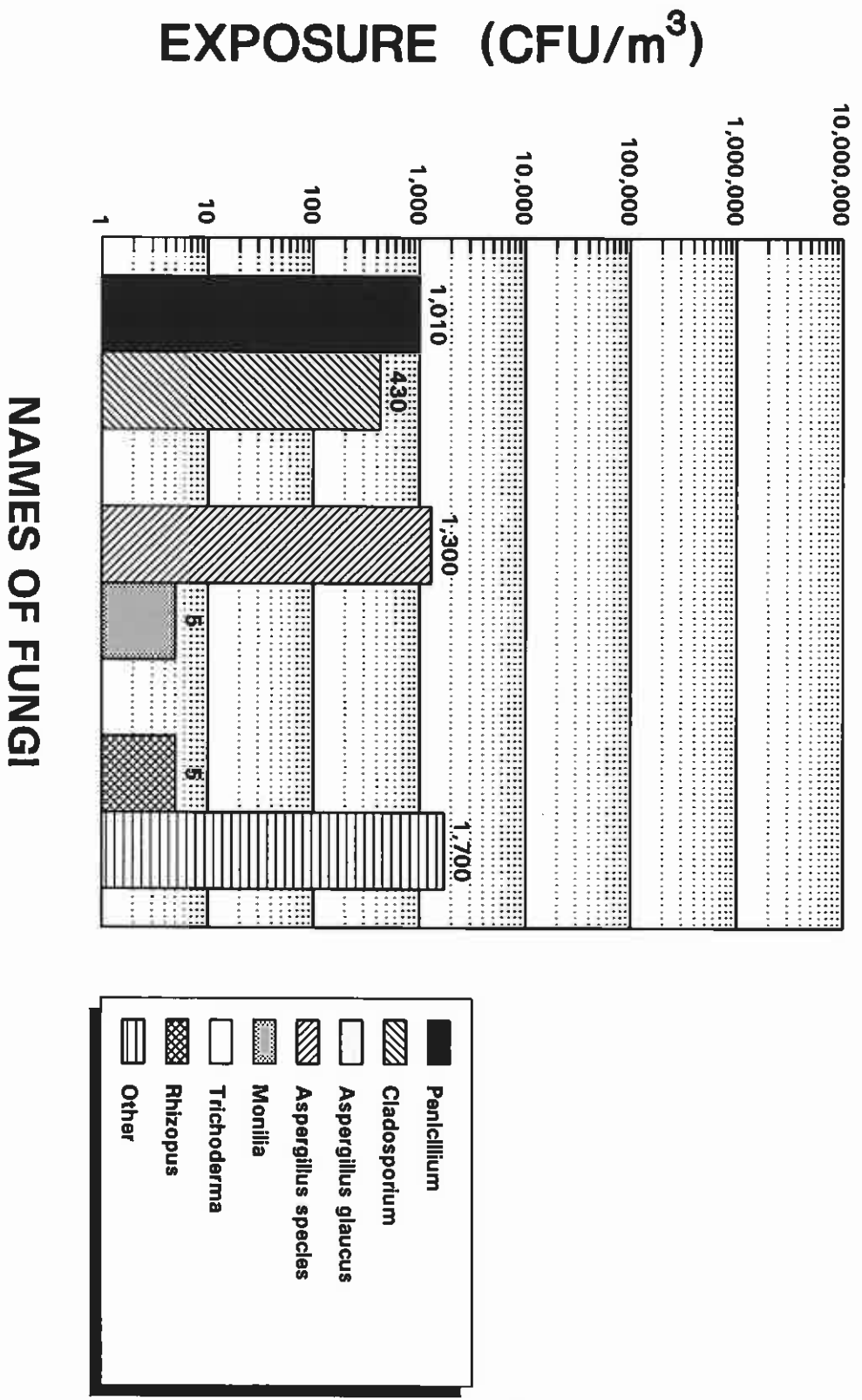


FIGURE B-8.

AVERAGE SPORE CONC., FACTORY OFFICE MONITOR SUGAR COMPANY, JANUARY, 1991

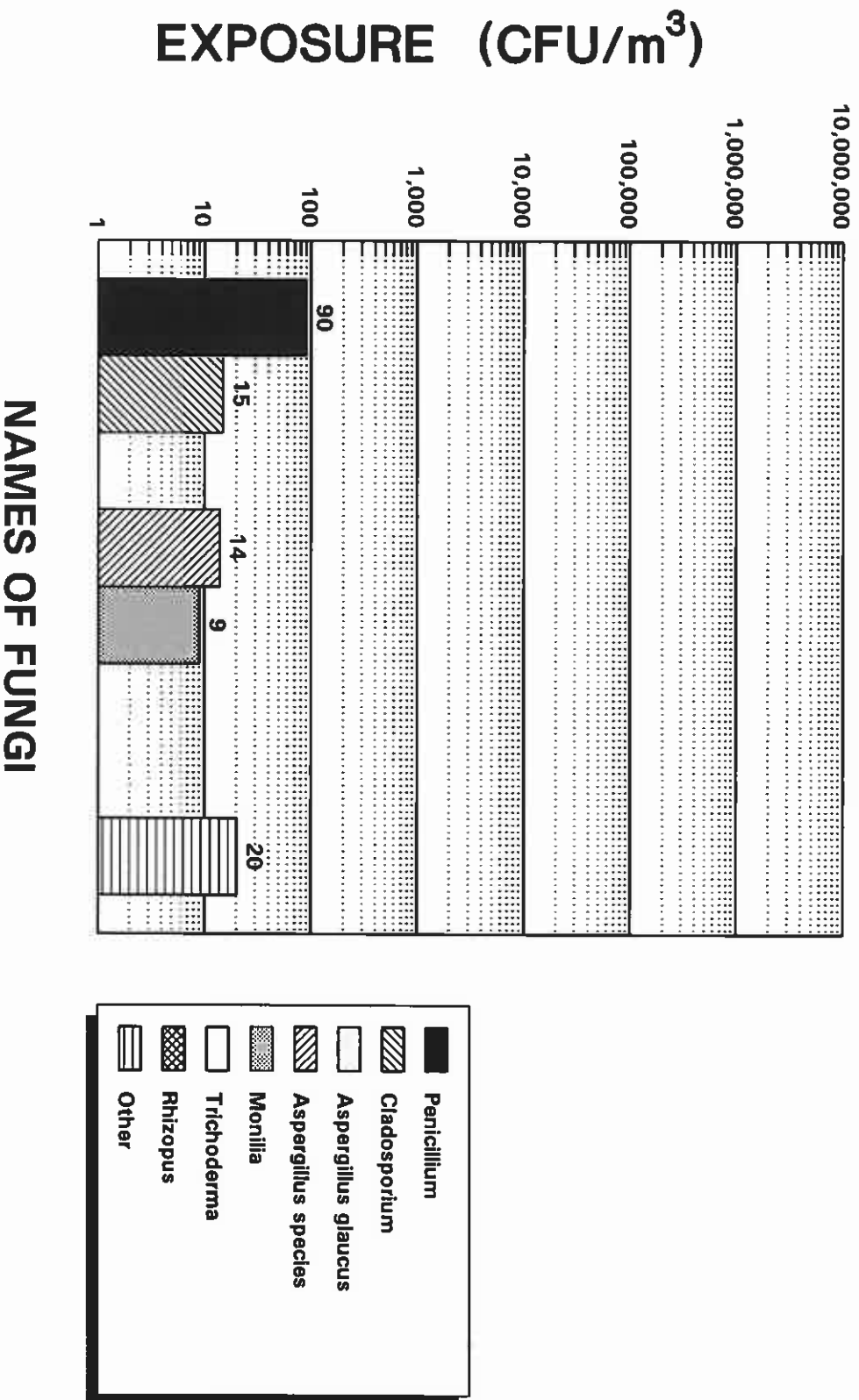


FIGURE B-9.

AVERAGE SPORE CONC., TRASH CATCHER MONITOR SUGAR COMPANY, JANUARY, 1991

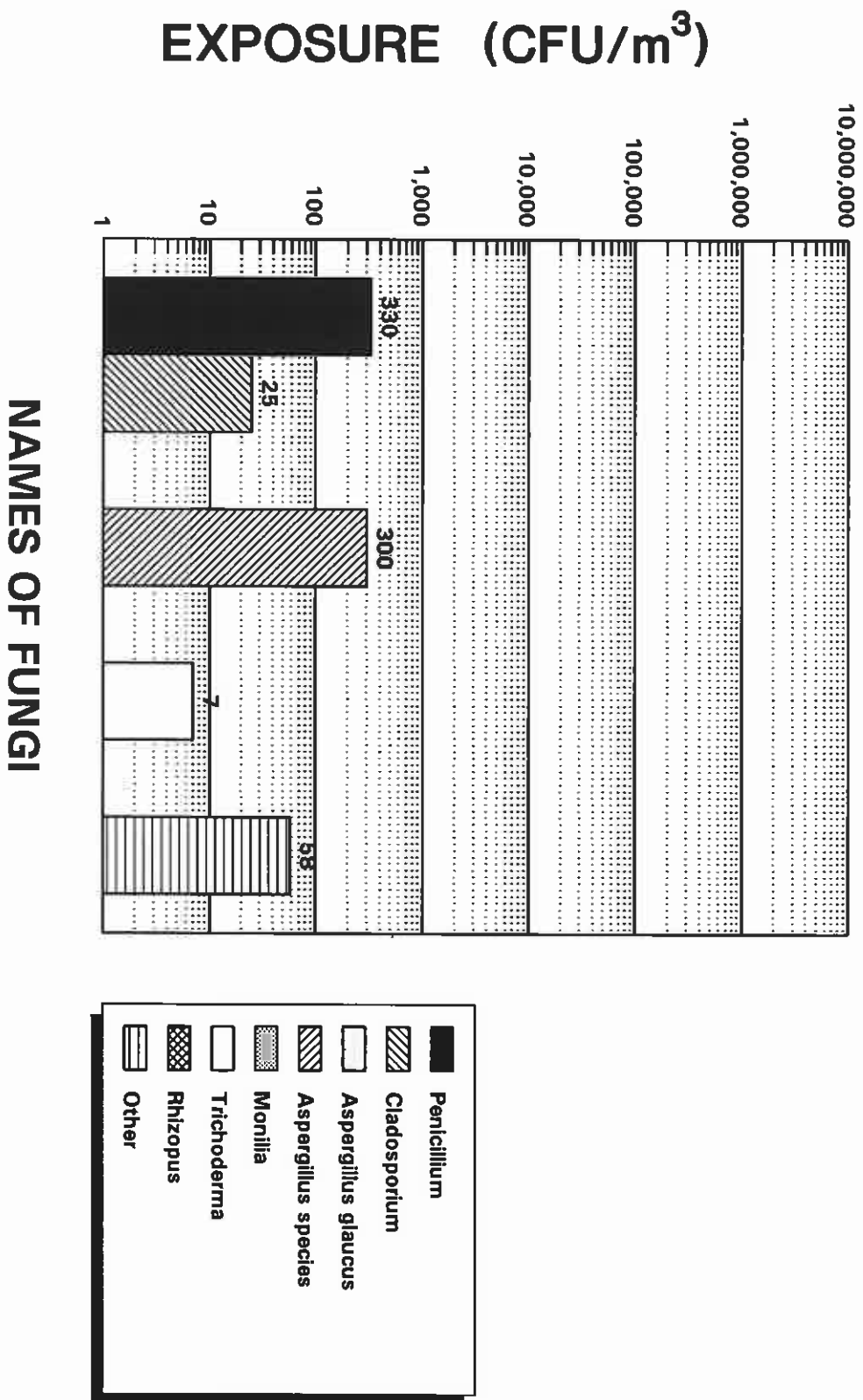


FIGURE B-10.

AVERAGE SPORE CONCENTRATION, VACUUM PANS MONITOR SUGAR COMPANY, JANUARY, 1991

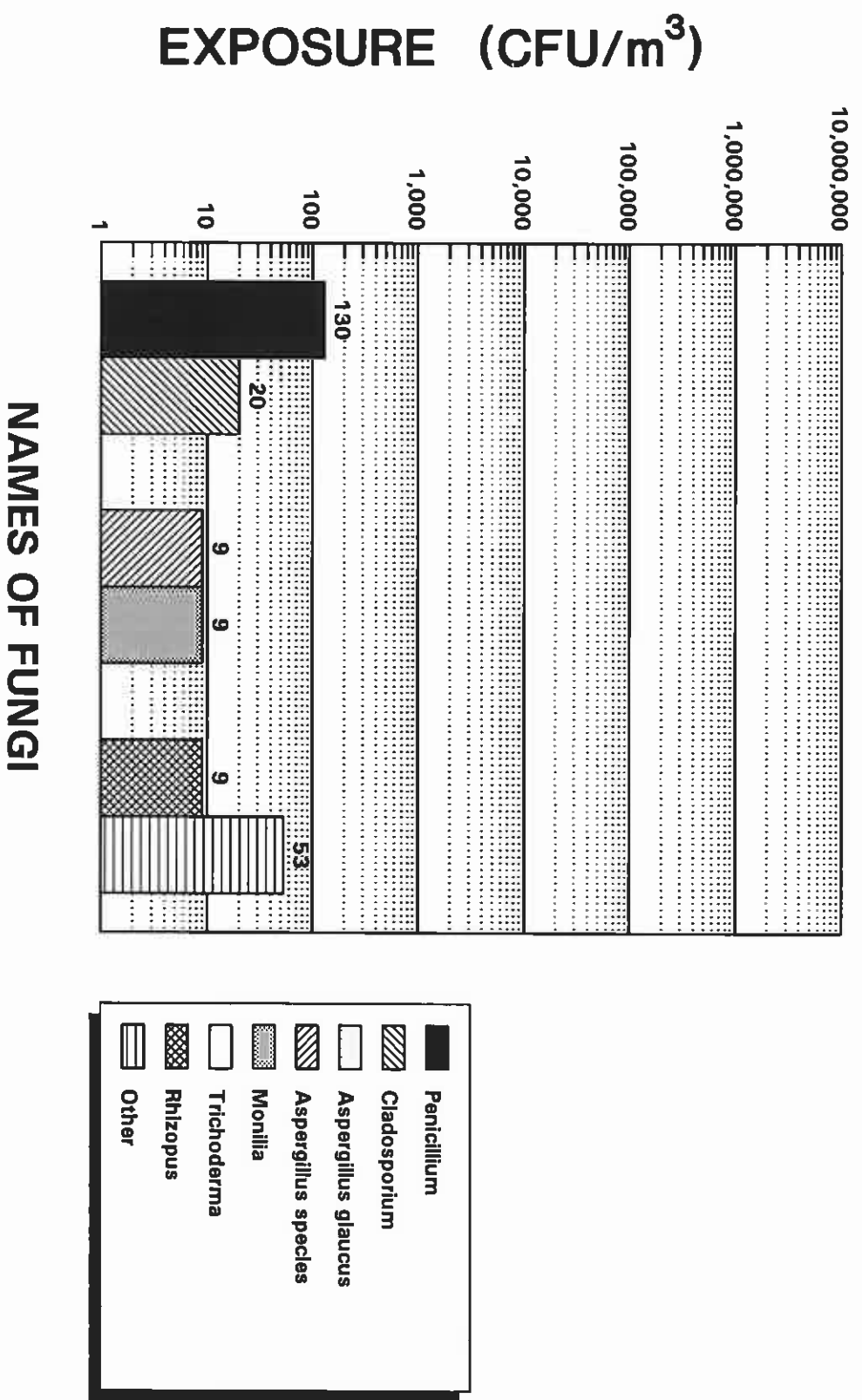


FIGURE B-11.

AVERAGE SPORE CONCENTRATION, PULP DRIER MONITOR SUGAR COMPANY, JANUARY, 1991

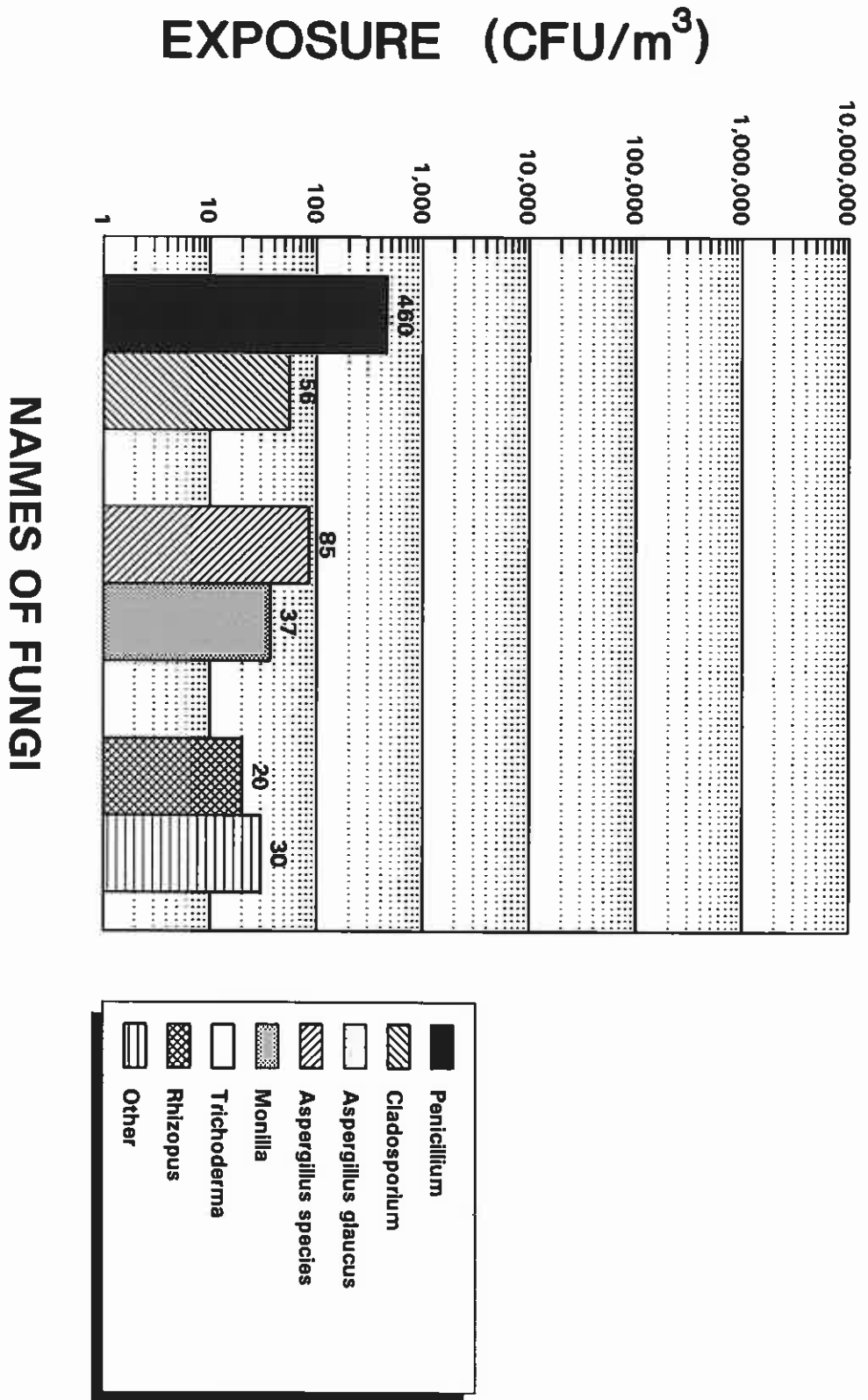


FIGURE B-12.

AVERAGE EXPOSURE, PELLET LOADERS MONITOR SUGAR COMPANY, JUNE, 1991

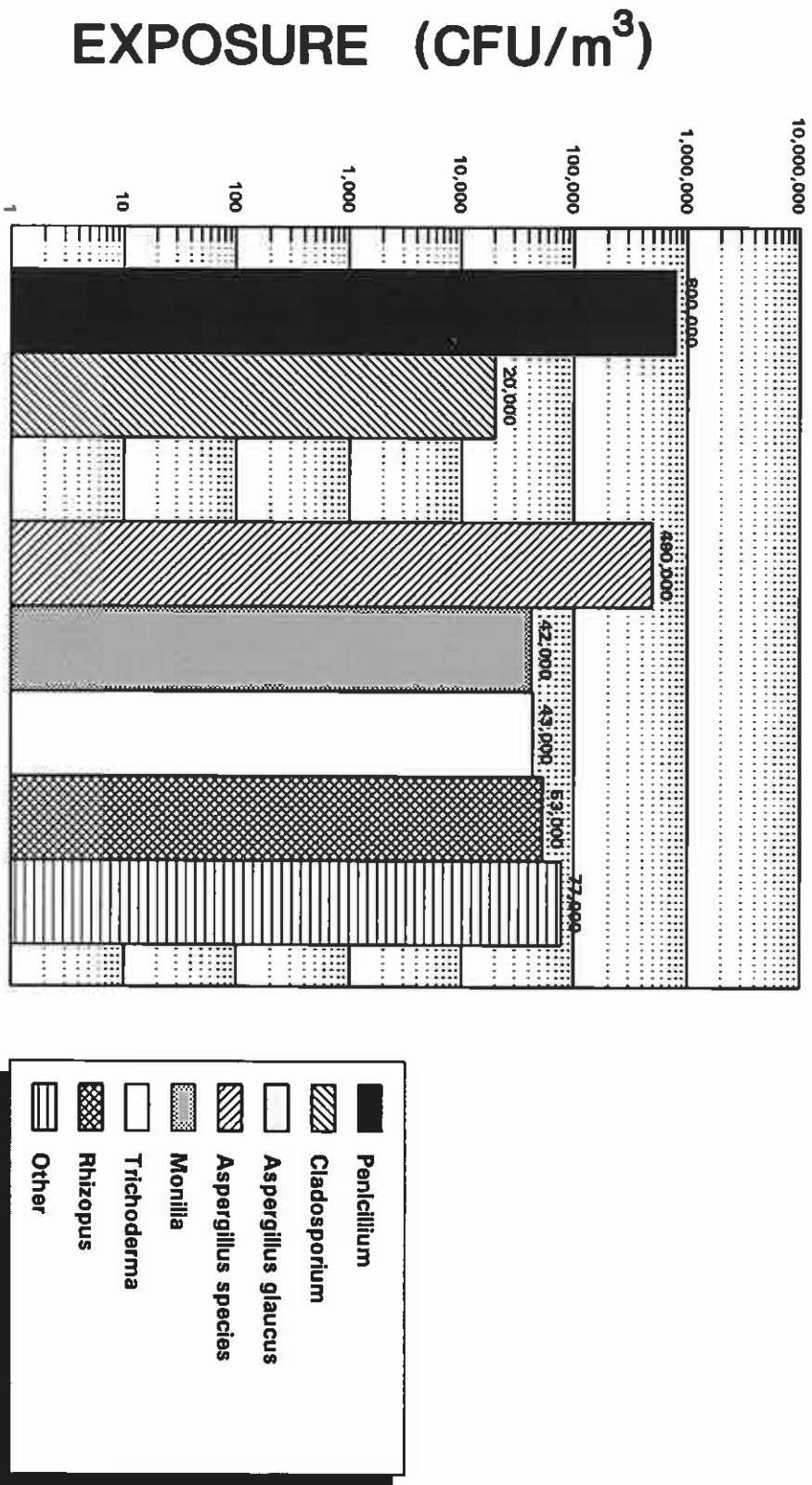


FIGURE B-13.

AVERAGE EXPOSURE, PELLET SILO WORKERS MONITOR SUGAR COMPANY, JUNE, 1991

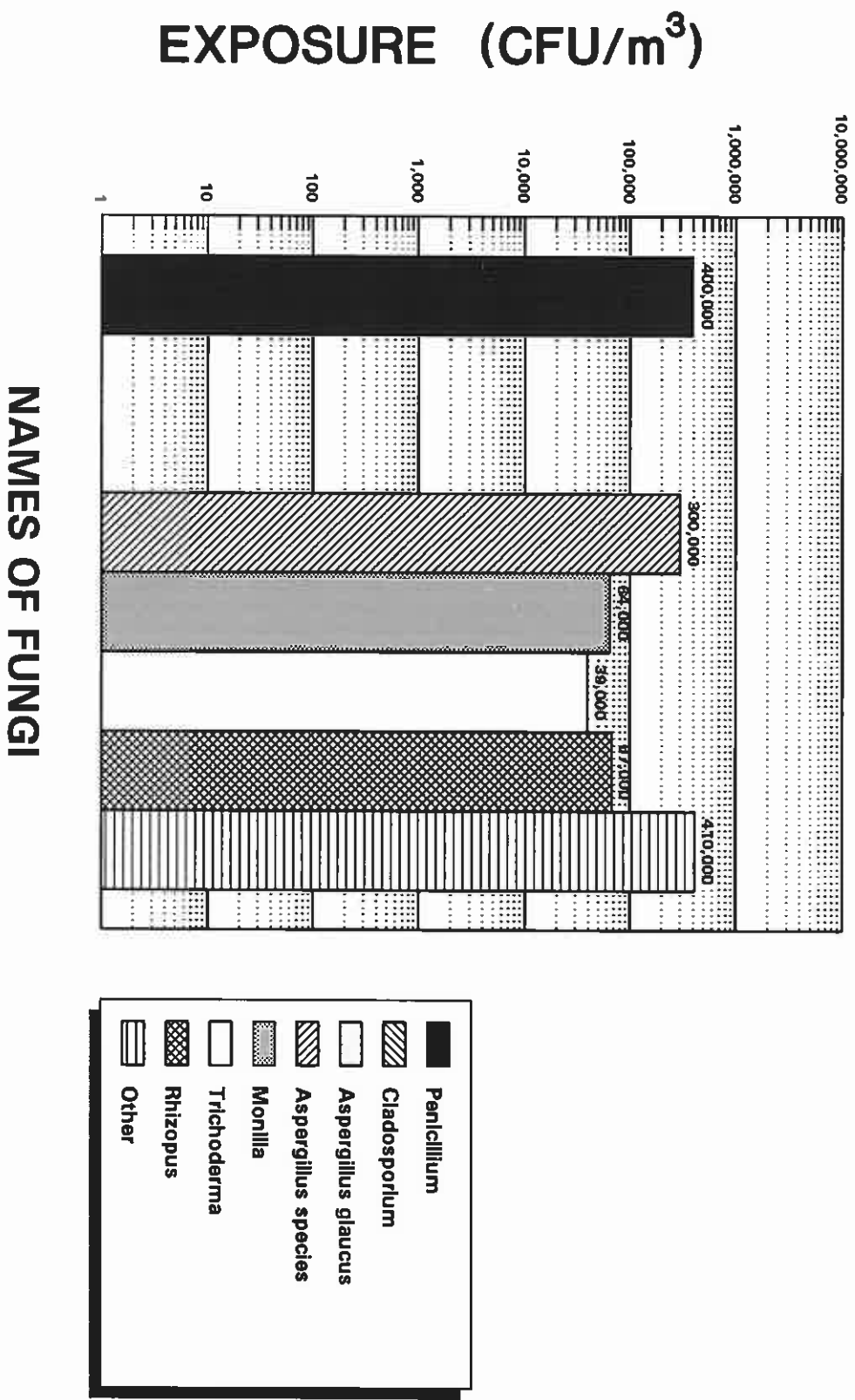


FIGURE B-14.

AVG. EXPOS., PELLET MILL/WAREHOUSE WKRS. MONITOR SUGAR COMPANY, JUNE, 1991

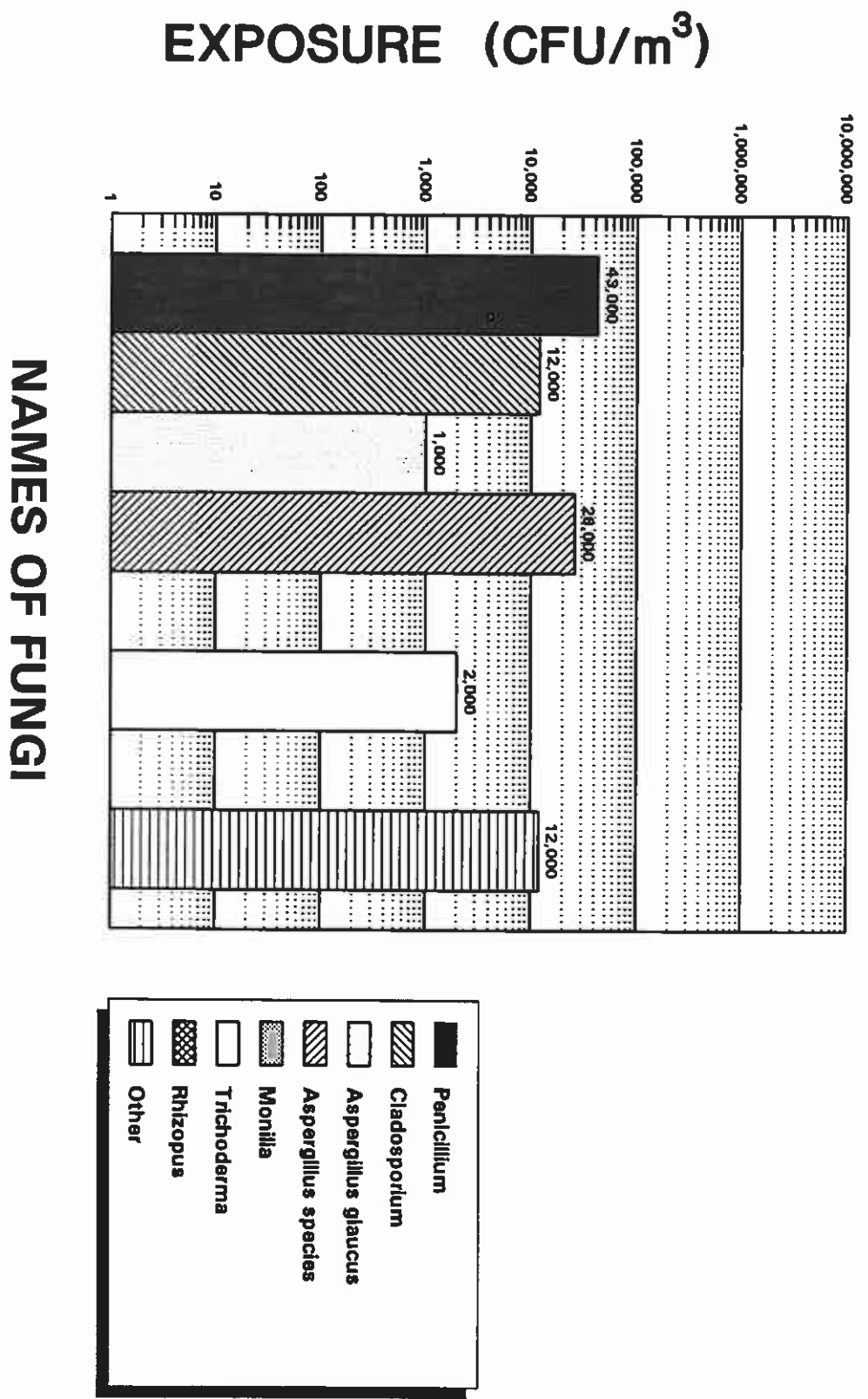


FIGURE B-15