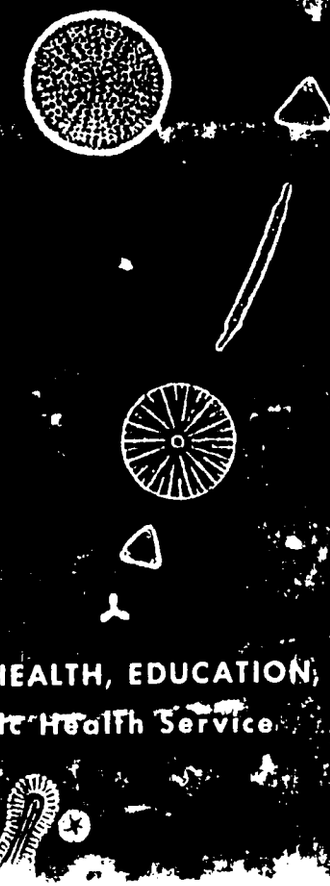
Pneumoconiosis IN DIATOMITE MINING AND PROCESSING



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Pneumoconiosis IN DIATOMITE MINING AND PROCESSING

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Division of Special Health Services
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Foreword

Diatomite, frequently designated diatomaceous earth, diatomaceous silica or kieselguhr, is composed of the siliceous skeletons of microscopic, unicellular, aquatic plants known as diatoms. Because of its remarkable properties this nonmetallic mineral has found many industrial uses, such as in filters, insulators, absorbents, and polishes.

The processing of diatomite in the United States assumed significant proportions during World War II. Concurrent with the growth of the industry, increasing interest was focused on the potential pneumoconiosis problem associated with exposure of workers to diatomite dust in its various forms. By the later 1940's, sufficient evidence became available relating the development of a disabling pneumoconiosis to certain exposures in this industry. However, fundamental questions pertaining to the etiology and pathology of the disease remained unanswered.

In 1952, the California State Department of Public Health requested the Public Health Service to assist in carrying out a comprehensive environmental and medical study of the diatomite mining and processing industry in California. Discussions with management and union officials led to an industrywide study which also covered plants in Nevada and Oregon.

As a result of this study, the problem has been more precisely defined, enabling industry to strengthen its control program. Recommendations emphasize engineering measures to reduce diatomite exposures, the display of suitable caution labels on shipping containers where indicated, the periodic medical examination of workers, and frequent epidemiologic assessment of the pulmonary status of the employees.

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Abstract

It was purposed to determine the health hazards associated with the mining and processing of diatomite, and the health status of the workers with reference particularly to the prevalence of pneumoconiosis.

The studies were conducted in each of five participating plants in California, Nevada, and Oregon. Three plants processed salt water diatomite and two fresh water diatomite. Four plants produced natural, high temperature straight-calcined and flux-calcined products, and the fifth only natural and low-temperature straight-calcined products.

The nature of the products and operations were such as to favor major dust dispersion.

The crude diatomite was essentially amorphous silica and contained less than 5 percent of quartz, and only traces of cristobalite and tridymite. The high-temperature, straight-calcined diatomite parent material had a cristobalite content of about 15 percent for main product, and 21 percent for baghouse product; for flux-calcined parent material, the cristobalite content was about 49 percent for main product, and 61 percent for baghouse product. Only traces of cristobalite were found in the low-temperature, straight-calcined product. Tridymite was found only in trace amounts in any of the diatomite products.

The source of the crude diatomite, whether of salt or fresh water origin, did not appear to influence the percent of cristobalite found in the finished products or their airborne dust.

The airborne mill dusts were generally of a uniform size regardless of product, and had a median size of about 1.1 microns. The size distribution of the dust favored maximum retention when inhaled. The airborne dust concentrations encountered were generally excessive for dusts with high crystalline silica content.

Roentgenographic examination of 869 diatomite workers showed changes interpreted as consistent with a diagnosis of pneumoconiosis in 9 percent, and doubtful changes in an additional 9 percent. Of 251 workers employed 5 or more years in various processes of the diatomite industry and who had no prior dust exposure, 25 percent had chest films consistent with a diagnosis of pneumoconiosis while the corresponding percent was almost 50 for 101 workers employed in those processes where the dusts contained a high percent of cristobalite. Exposures in the

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quarries, where the dust was essentially amorphous silica, were associated with a lower proportion of abnormal films; none of 25 employees who had worked there exclusively for over 5 years had a positive film, but 40 percent showed doubtful linear-nodular changes.

There was no evidence that tuberculosis, histoplasmosis, or coccidioidomycosis was related to the development of chest roentgenographic changes.

Pulmonary signs and respiratory symptoms correlated poorly with roentgenographic changes, except when there were massive confluent lesions.

Environmental studies made 1 year and 2 years after the initial study showed that marked improvement had been made in lowering dust concentrations.

Followup observations in 2 plants, in which 375 films were reviewed of workers with 2 years' additional exposure following the survey, revealed progression to a positive category in only 2 cases previously classified as negative or doubtful; 14 previously interpreted as positive showed slight to moderate progression.

Nature and Scope of Study

The diatomite deposits of California attracted attention as a potential industrial material toward the end of the last century. At that time the chemical and physical properties of diatomite as an insulation material were already recognized. It was not until sometime later, however, that the mining and processing of diatomite could be called an industry with a predictable future.

During the early developmental period, the diatomite was processed manually. It was taken from the beds in blocks and dried, and subsequently shipped in this form. The first mill for processing natural diatomite was constructed in 1906. The industry expanded rapidly as research found new uses for the material.

In the 1920's the industry developed a calcined product which had superior qualities for many uses, especially in filtration. The natural product, however, remained in dominant production until the 1930's. World War II had a profound influence on the industry. The demand for the calcined product rose sharply and soon accounted for a large part of the production.

Concurrent with the rapid growth of the industry, increasing interest was manifested in the potential pneumoconiosis problem associated with exposure of workers to diatomite dust in its various forms. However, reports on studies of quarrying and processing operations located in Europe and the United States presented a wide range of seemingly conflicting findings, and their interpretation was not unanimous concerning the effects of diatomite dust on humans.

Several factors may have accounted for these differences. The earlier studies paid little attention to the physical and chemical characteristics of the diatomite under investigation. No reference was made to associated impurities such as the quartz in the crude diatomite or to the amount of cristobalite which might have resulted from calcining. In many instances the workers studied had simultaneous exposures to known pneumoconiosis-producing dusts. Also, atmospheric dust concentrations were often massive. Adding still further to the confusion, various synonyms were used for diatomite in reporting the results of the studies. For example, diatomaceous earth, diatomite, kieselguhr, tripolite, infusorial earth, fossil flour, and fossil silicon all referred to the same general material. Tripoli and fuller's earth were also often confused with diatomite products.

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By the later 1940's sufficient evidence was available to affirm that a disabling pneumoconiosis could be associated with excessive exposures to certain forms of diatomite dust. It was also determined that the calcining of crude diatomite could convert a considerable percentage of the amorphous silica into a crystalline form, cristobalite, which is much more reactive biologically than the amorphous silica. Despite this accumulated knowledge, many questions still remained unanswered as to the seriousness of the problem, as well as to the precise etiology, diagnosis, effects on lung function, and proper control measures.

In 1952, the California State Department of Public Health requested that the Public Health Service assist in carrying out a comprehensive environmental and medical study of the diatomite-processing industry in California. Discussions with management and union officials led to a plan for an industrywide study. Through similar discussions, arrangements were made to extend the study to include plants in Nevada and Oregon.

The purpose of the study was to ascertain the health hazards associated with the mining and processing of diatomite; to determine the health status of the workers in the industry with special attention to the presence or absence of pneumoconiosis; and to develop methods which would prevent the occurrence of occupational diseases in the diatomite processing industry. The following were among the basic questions posed and on which information was sought in the conduct of the study:

1. What is the extent, degree, and prevalence of pneumoconiosis in the diatomite-processing industry, as revealed by the chest roentgenogram?

2. What is the relation between the various degrees of roentgenographic change and clinical manifestations, physiologic changes, pathologic findings, and disability?

3. What is the relation between the foregoing manifestations and the degree and type of exposure?

4. Is the pneumoconiosis associated with exposure to diatomite typical of silicosis? If not, wherein does it differ?

5. What is the significance of exposure to the different sources and forms of diatomite and the etiology of disease: (*a*) Sea water (marine) and fresh water (limnetic) deposits; (*b*) crude, natural, straight-calcined and flux-calcined diatomite?

6. What is the relation between particle size and the development of disease?

7. Is the etiologic agent diatomite or is it some other material associated with the diatomite?

8. What is the relation, if any, between the pneumoconiosis found in this industry, and tuberculosis or other respiratory diseases?

9. What dust controls are needed to prevent the development of pneumoconiosis?

The study was a cooperative effort of many groups, including labor, management, State and Federal agencies, and consultants.

The initial phase entailing the collection of basic data was carried out in 1953–54. Detailed environmental studies were made to determine the extent and nature of dust exposures. Medical studies of the employees included work and medical histories, physical examinations, chest films, clinical laboratory examinations, intradermal tests with tuberculin, histoplasmin and coccidioidin, and pulmonary function tests.

Followup studies were planned to include biennial chest films on workers in the plants participating in the study and on those with over 2 years' employment who had left the industry. Arrangements were also made for plant managements to submit periodic reports on dust concentrations by product and operation, and provide current information on technologic changes in plant operations.

The studies were conducted in each of five participating plants engaged in mining and processing diatomite in California, Nevada, and Oregon. Of these, 3 processed salt water and 2 fresh water diatomite. Four plants produced natural, high-temperature straight-calcined and flux-calcined products, and the fifth only natural and low-temperature straight-calcined products. All 5 plants operated on a 3-shift basis.

In accordance with the plans established for conducting the study, in all instances where there were clinical findings that were felt by the examining physicians to warrant prompt diagnostic studies, the employee was referred to his private physician for appropriate medical attention. With the written consent of the worker, summaries of the relevant findings were furnished to his physician when in the latter's opinion such information would prove helpful in the management of the case. In addition, in all instances where chest films and histories were consistent with a definite diagnosis of pneumoconiosis, reports were similarly submitted to the private physicians.

Those responsible for environmental studies maintained close liaison with the staff members of each plant responsible for industrial hygiene and transmitted to them the findings applicable to their plant.

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An extensive summary of environmental findings and clinical data was prepared in 1955 and made available in mimeographed form to participating State health agencies, the industries involved, interested labor organizations, and to others who had participated in the study. The major findings of the study were reported at the annual meeting of the American Conference of Governmental Industrial Hygienists in April 1955 (*56*), and at the 1956 meeting of the Industrial Hygiene Foundation of America (*57*).

This report covers a review of the literature on diatomite pneumoconiosis, a description of the industry, results of the initial environmental-medical studies and of followup studies, and environmental and medical recommendations for the control of pneumoconiosis in the industry.

Diatoms: Description and Distribution

Diatoms are microscopic, unicellular plants (algae) ranging in maximum dimensions from under 5 to over 100 microns. They may exist individually or in colonies.

Although the taxonomy of diatoms is not clear, in one classification (*37*), the Bacillariophyceae (diatomaceae) are specified as a class under the phylum Chrysophyta, subkingdom Thallophyta. It in turn is divided into two orders, Centrales and Pennales. Over 10,000 species of diatoms have been recognized. Environmental conditions of water composition, temperature, and light greatly influence the species found in any one habitat.

Diatoms are specially distinguished by the structure and chemical composition of their cell walls. The shell of the individual cell is composed of two symmetrical halves or valves held together by a girdle formed from hooplike connecting bands extending from each valve. The halves fit together much like the top and bottom of a salve box. The valves may assume a great number of shapes, but generally have an ornamentation that is radial from, or concentric about, a central point (Centrales) or is bilaterally symmetrical or asymmetrical (Pennales). The shell is composed of almost pure opaline silica secreted by the cell protoplasm. Both the chemical composition and the physical structure of the diatom fossil make it of great commercial value.

The Bacillariophyceae are worldwide in distribution. They grow prolifically under favorable environments. Upon dying, the diatoms sink to the bottom of the water and form an ooze which may reach several hundred feet in depth. The organic material of the cells decomposes and leaves the silicified cell walls which gradually become compacted into beds covered with sediment. These beds may eventually elevate above the surrounding water level, and through prolonged and repeated leaching, become more or less purified and white in appearance.

Impurities in the diatomite deposits consist of fossil remains of sponges and other silica-secreting aquatic life as well as small amounts of minerals, clays, and chert.

Although diatomite beds are currently forming in many areas, those now being worked are of the Jurassic to the late Tertiary age. The deposits in California are of the Miocene period and were laid down some 18 to 30 million years ago (*38–41, 47*).

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Diatomite deposits are usually classified commercially as to their fresh or salt water origin. Although environmental conditions greatly influence the species of diatom growing in any one habitat, no apparent chemical difference has been found in the opaline nature of their cell walls.

The remarkable properties of diatomite make it industrially useful. Its inertness and various shapes make it an excellent filter for liquids. Its chemical composition, along with the tremendous amount of incorporated dead air space, recommends its use both as a high temperature insulation material and as a liquid absorber. Its inertness, hardness, and small size make it suitable for use in polishes, flatteners, extenders, and fillers. It has more recently become of use as a source of silica for chemical manufacturing.

Review of Literature

The first report linking exposures to diatomite dust with an ensuing pneumoconiosis appears to be that of Legge and Rosencrantz in 1932 (*1*). The report led to active study of the problem by the major industries, and eventually to a program of periodic examination of the workers and to laboratory research. It also stimulated the interest of other research groups in the problem.

There was a long time interval between the report of Legge and Rosencrantz and the general recognition of the disease. Abrams (*2*), in reviewing the status of diatomaceous earth pneumoconiosis, stated it was not until about 1946 that it was acknowledged that exposure to certain forms of diatomite dust could lead to a disabling and sometimes fatal disease.

Epidemiologic Studies

Legge and Rosencrantz (*1*) in a 1932 report described results of the examination of 118 laborers employed in a plant in California processing diatomite. The authors reported roentgenographic evidence of pneumoconiosis in 81, or 68.5 percent, of the group examined. In 60 workers the changes were described as very early or early, in 15 as moderately advanced, and in 6 as advanced. All but one of those with advanced changes had been employed for 5 years or more. Physical signs were strikingly few and mostly of slight degree, except for a reported high prevalence of clubbed fingers. The nature and intensity of environmental dust exposures were not discussed.

No further observations were reported until 1936 when Middleton (*3*) described evidence of only slight fibrosis in 2 out of 6 workers exposed for 10 or more years to kieselguhr dust in England. Again, no information was given on the nature or extent of dust exposures.

Another 11 years elapsed before any further epidemiologic studies were reported. In 1947, Martin, Vallaud, and Champeix (*4*) published findings from an investigation of workers exposed for many years to fossil silicon. Chest roentgenograms of 3 out of 32 workers examined showed mild linear lung shadows.

In 1948, however, Vigliani and Mottura (*5*) described a different situation in two factories in Italy manufacturing filter candles from crude diatomite obtained from Tuscany. In the process,

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amorphous diatomite was mixed with coal and magnesite and calcined at 1,250° C. On X-ray diffraction, the calcined material showed an intense cristobalite pattern. Twenty workers exposed to this "ignited diatomite" were radiographed; 13 showed some stage of silicosis and 7 were described as in an advanced stage. One had tuberculosis. The condition was described as rapidly developing, with a majority of the affected workers showing radiographic signs after 4 years of exposure in the candle-turning department. There was no typical nodular stage, the fibrosis being diffuse and "lacelike." Conglomerate lesions were described and a tendency to spontaneous pneumothorax was indicated by its occurrence in 3 of the 7 advanced cases. Workers handling crude diatomite showed only mild changes. The authors concluded that the difference was probably due to the presence of cristobalite in the calcined form. Dust exposures were estimated at 400 to 500 particles per cubic centimeter (11–14 million particles per cubic foot of air). The dust samples were collected with a thermal precipitator and counted at a magnification of 200 ×. The particle size of the dust ranged from 0.5 to 2.0 microns.

Luton, Champeix, and Faure (*6*) in 1949 reported on clinical and radiographic examination of 31 workers engaged from 9 to 23 years in the quarrying or handling of natural diatomite in France. Thirteen were described as showing evidence of pneumoconiosis, but effects were regarded as relatively mild. High concentrations of dust existed in the working environment. Most of the dust particles ranged between 1 and 2 microns in size.

Observations of workers in United States plants were reported in 1952 by Smart and Anderson (*7*), who presented their findings in a serial study of several hundred employees in five plants in the Western United States. The authors concluded:

1. The inhalation of diatomaceous earth may produce a distinct type of pneumoconiosis.

2. The inhalation of crude diatomaceous earth and natural powders over a long period of time may produce a benign type of linear pulmonary fibrosis, leading to few if any symptoms and no demonstrable disability.

3. The calcined and flux-calcined powders may occasionally produce a rapidly progressive pulmonary fibrosis or granuloma with massive coalescence, bullous emphysema, extensive pleuritis, cor pulmonale, and not infrequently spontaneous pneumothorax.

4. Massive coalescent pulmonary lesions occasionally have developed in persons whose intradermal skin tests were completely and repeatedly negative to full dosage of standardized tuberculin, and in these cases we have been unable to identify

tuberculous infection either during life or at post mortem with the most sensitive bacteriologic and histologic techniques that were available.

5. When tuberculosis is superimposed on diatomaceous earth pneumoconiosis, the infection often pursues a benign course until cavitation supervenes, then the course seems to be slowly downhill in spite of modern treatment including collapse procedures and chemotherapy.

6. Fresh water diatomite appears to be much less toxic for workers engaged in processing this material, even when it is subjected to flux calcination, than are marine diatomaceous earth products.

Ebina, Takase, Inasawa, and Horie (*8*) in 1952 reported findings on 106 employees of diatomaceous earth plants in Japan, in which 11 percent were described as having pneumoconiosis. The shortest period of exposure associated with diagnosable disease was 3 years, and advanced stages were found only after 15 years. Dust exposures were heavy, ranging from 3,200 to 4,600 particles per cubic centimeter (90 to 130 million particles per cubic foot of air). The particle size of the dust was under 3 microns. No information was given on the percent of quartz that may have been in the crude diatomite or on the nature of the milling processes.

Gervais (*9*) in 1955 studied 146 workers in factories in France processing natural and calcined diatomite. No silicosis was found in persons with less than 2 years of exposure. As the years of employment increased, silicosis became pronounced. Dust concentrations were not given. The author did not distinguish between amorphous and crystalline forms of silica.

Luton, Champeix, Ravet, and Vallaud (*10*) in 1956 reported on a survey of 3 factories in France engaged in processing diatomite and employing 124 workers. The first factory employed 30 workers and had been in operation some 50 years. Six employees with many years of work in the plant had silicosis. The second and third plant calcined the diatomite. Composition and concentration of the dust were not given. Out of 92 employees, 10 cases of silicosis, including 2 deaths, were reported. The authors concluded that the amorphous silica is only moderately, if at all, harmful when inhaled, but that the calcined diatomite becomes as dangerous as quartz.

Barsi (*11*) in 1956 described a single case of pneumoconiosis in Italy from exposure to amorphous diatomite. The worker was engaged for about 12 years in the excavation, dehydration, and milling of diatomaceous earth. No calcining was done. The chest

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film revealed pulmonary emphysema and bilateral hilar adenopathy. The whole pulmonary bed showed discrete "eggshell" images with diffuse nodulation and confluence of micronodules into areas similar to stage 3 silicosis. Information was not given on dust concentrations or the amount of quartz that may have been in the crude diatomite.

A year later Barsi (*12*), 1957, again contributed to the literature by reporting on a study of 34 workers in Italy extracting, drying, and, to a limited extent, calcining, diatomite. Radiographic findings were normal on 28 workers employed 2 to 30 years; 2 workers employed 10 to 20 years showed diffuse reticulation; and 4 workers employed 10 to 30 years showed sparse and irregular micronodulation.

A comprehensive study of the silica brick industry in Pennsylvania reported by Fulton (*13*) in 1941 has a bearing on pneumoconiosis resulting from exposures to dusts with high cristobalite content. The calcining of the brick converted significant percentages of quartz to cristobalite and tridymite. Of the workers examined, 51.9 percent had silicosis. An average of 17.9 years was required for the development of stage 2 silicosis in workers exposed to approximately 16 million particles per cubic foot of the green uncalcined brick dust. Stage 3 silicosis developed after the same length of time in workers exposed to similar levels of burnt (calcined) brick dusts but having high percentages of cristobalite and tridymite.

Pulmonary Pathology in Man

In 1941, Nordmann (*14*) reported the results of 6 autopsies on individuals exposed from 2 to 16 years to kieselguhr having a high quartz content. Two cases, with approximately 2 years' exposure, had stage 1 silicosis; 2 cases with 4 to 7 years' exposure had stage 2 silicosis; and 2 cases with 15 to 16 years' exposure had stage 3 silicosis, complicated with tuberculosis. The last two cases also had exposure to asbestos.

Systematic study of the pathologic changes in the lungs of individuals who had been exposed to diatomite was carried out for a number of years at the Saranac Laboratory of the Trudeau Foundation by Vorwald, Durkan, Pratt, and Delahant, who described in 1949 (*15*) the changes observed in 10 such cases. It was concluded that diatomaceous earth could produce pulmonary disease in man, but that the lesions were different in character from those produced by quartz, in that there were no clear-cut discrete hyalinized nodules, and the foci of reaction were essentially cellular with relatively slight deposition of collagen. Some of their cases exhibited massive areas of fibrosis and necrosis.

In 1954, Carnes in a personal communication reported observations on the pathologic findings in 27 workers who had been employed in the diatomite industry in the Western United States; 18 of those studied had died from causes apparently unrelated to their dust exposures. The cases fell into 2 groups, similar to those defined by Vorwald et al. (*15*) in a report of the first 10 cases of the same series, and corresponding to the classical separation of pneumoconiosis into simple and complicated forms.

In the first group of individuals that had had no pulmonary symptoms and whose radiographic abnormalities were simple linear exaggerations, the pathologic changes consisted of "accumulations of dust cells in the alveoli, in the interstitial tissue of the lung, including the alveolar walls, and in the hilar lymph nodes, with either no fibrosis or in the longstanding cases a very delicate reticular fibrosis."

In the second group of cases, there was, "in addition to the foregoing changes more or less massive confluence of the lesion in the upper thirds of the lungs, with necrosis and marked fibrosis." Death was regarded as probably attributable to pneumoconiosis in at least 4 of the 6 cases of the latter type. The role, if any, of infection in producing the coalescent lesions could not be clearly defined from study of this group.

More recently, on April 12, 1958, personal communication with Carnes (*16*) has provided new information. Among 49 cases examined through 1957, 21 have had massive coalescent lesions. In contrast to the 7 cases of coalescence reported in 1954, in whom no evidence of tuberculous infection has been adduced by clinical or pathologic examination, tuberculosis was proved by cultural or microscopic means in 9 of the 14 cases with coalescence examined since 1954. Those cases in whom tuberculosis was proved were distinguishable from the other cases of massive coalescence by the presence of typical caseation or cavity formation, or both. The clinical course of these cases indicates that tuberculous infection can lead to massive coalescence in the presence of diatomaceous earth pneumoconiosis. The evidence is still lacking that coalescence always indicates complicating infection.

Pulmonary Function Studies

The importance of objective tests to measure lung function changes is being increasingly recognized in the study of pulmonary dust diseases. In 1955, Motley (*17*) published measurements of

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the 3-second timed vital capacity and maximal breathing capacity measurements on 5 selected workers, one of whom had worked about 2 years with exposure to diatomaceous earth. Although this worker had no specific complaints, a decrease was noted in his maximum breathing capacity and exercise oxygen uptake.

In 1956, Motley, Smart, and Valero (*18*) published the results of ventilatory and blood gas exchange measurements on 50 selected workers in the diatomite industry. These cases represent in part cases included in the present study, selected as indicated in the medical section of this report. It was concluded that although correlation was poor between the lung function measurements and the chest roentgenologic appearance of the workers studied, diatomite pneumoconiosis may produce severe impairment of pulmonary function. With advanced disease, there was noted a marked decrease in timed vital capacity and maximal breathing capacity, lowering of oxygen saturation of arterial blood, a decrease in oxygen uptake upon exercise, and a severe degree of emphysema.

Studies in Lower Animals

Podwyssozki (*19*) in 1910 produced a granulomatous reaction by injecting diatomite subcutaneously into animals.

A cellular type of proliferative response was described by Solowiev and Pinus (*20*) in 1928 in the lungs of animals exposed to diatomite.

Beintker (*21*) in 1935 reported the results of exposing rabbits by inhalation to kieselguhr. The composition of the kieselguhr and its exposure concentration were not given. The response was one of proliferation of the lymph tissue with replacement by connective tissue.

In 1936, Policard (*22*) reported on experiments in white rats exposed to purified calcined kieselguhr. The exposure concentration was not given but apparently was very heavy. No data were given on the chemical and physical characteristics of the purified calcined kieselguhr. The effect on the lungs was primarily that of exposure to inert foreign substances. No fibrotic reaction was noted and the pulmonary tissue finally resumed its normal appearance.

Gardner (*23, 36*) in 1938 reported on experiments in which rabbits were injected intravenously and guinea pigs intraperitoneally with various mineral dusts. Responses to cristobalite and tridymite were more severe than from quartz, and the fibrosis that followed was more of a diffuse form, rather than nodular.

Pure diatomite provoked a progressive fibrosis indistinguishable from the reaction of quartz.

Diatomite led to a proliferative response when injected intraperitoneally in guinea pigs in experiments reported by Miller and Sayers (*24*) in 1941. The crystalline or amorphous nature of the diatomite was not stated.

In 1946, Duvoir, Derobert, and Journet (*25*) introduced kieselguhr intratracheally into the lungs of rabbits. The lungs at autopsy showed peribronchial nodules surrounded by collagenous fibers. The composition of the kieselguhr was not stated.

Vigliani and Pecchiai (*26*) in 1949 reported nodular reactions in the peritoneal cavities of guinea pigs injected with calcined diatomite. In contrast, the peritoneal cavities of guinea pigs injected with crude diatomite showed little change.

Vorwald, Durkan, Pratt, and Delahant (*15*), in the same paper in which were described pathologic studies in man, reported on inhalation and injection experiments in several species of lower animals. The authors observed that both natural and flux-calcined diatomaceous earth caused an inflammatory response of a diffuse cellular type, which could progress to fibrosis and hyalinization. Natural diatomite was found to be less active in producing pulmonary reactions than the flux-calcined material. The investigators also reported that flux-calcined diatomaceous earth adversely affected the course of tuberculosis in the lungs of guinea pigs.

In 1952, Gärtner (*27*) described experiments in which he exposed rabbits to amorphous silica, ranging in particle size from 100 to 500 angstroms for a period up to 3 years, to observe the effects of small-size particles of amorphous silica on the lungs. A predisposition to secondary infections was noted. However, there was no indication of increased fibrosis or evidence of silicotic nodules.

As further evidence of the high reactivity of lung tissue to cristobalite, King, Mohanty, Harrison, and Nagelschmidt (*28*) in 1953 reported on experiments in which were studied the reactions of rats to intratracheal injections of highly purified fused silica, quartz, cristobalite, and tridymite. Cristobalite exceeded quartz in the rapidity with which it produced a tissue reaction.

Recently, Beard and Tebbens (*29*) completed experiments in which guinea pigs were exposed for 50 weeks to atmospheres containing high concentrations of natural diatomaceous earth dust. The animals showed dense infiltration of the alveolar septa by macrophages and many multinucleated cells filled with dust particles, but there was no connective tissue proliferation.

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Chemical and Physical Studies on Diatomite

Considerable research has been devoted to studying factors influencing the conversion of amorphous silica and quartz to cristobalite and tridymite (*30–33*). These studies show that the rate of conversion from quartz to cristobalite and tridymite is directly related to time and temperature. Fluxes greatly accelerated the conversion, and decreased the time and temperature otherwise required. Alkali oxides were found to be excellent flux materials.

In discussing methods for the determination of free silica in industrial dust, Durkan (*34*) in 1946 stated that amorphous and crystalline forms of silica were sometimes present together in the same material, and that calcined diatomaceous earth contained cristobalite. Caution was expressed that dust samples to be studied by X-ray diffractions or petrographic methods should not be subjected to prolonged ignition or high temperature because of the danger of converting the quartz to another form of free silica.

Bailey (*35*) in 1947 reported the effects of temperature, time, and fluxes on the conversion to cristobalite of diatomite in its amorphous form. The investigator showed that heating the diatomite alone at 1,150–1,200° C. for 30 minutes converted 2 percent of the amorphous silica to cristobalite. The addition of 10 percent sodium carbonate as a flux under the same temperature and time conditions converted 22 percent of the amorphous silica to cristobalite. It was also shown that conversion was progressively more rapid with decreasing particle size.

The Diatomite-Processing Industry

More than 300,000 tons of diatomite were produced in the United States in 1953 (*42*), with a value at the mine, according to the U. S. Bureau of Mines *Mineral Facts and Problems*, 1956, of more than $10 million. The 5 plants, located in California, Nevada, and Oregon, participating in the study, accounted for over 95 percent of the diatomite produced in this country at that time. The remaining production came from smaller plants, many of which operated only intermittently.

Description of Operations

Except for specialty products, the processes in each of the plants studied are essentially the same. The description of operations is limited to production processes common to each of the plants participating in the study. Figure 1 shows a typical flow diagram of a diatomite processing plant.

Quarrying

Diatomite is mined by the open quarry method with the use of conventional, heavy duty, dirt removal and transport equipment. The operation consists of removing overburden, loosening the underlying crude diatomite bed, and loading the crude diatomite into trucks and hauling it to the mill. In one plant, the crude diatomite is transported to a system of "glory holes" and in turn hauled by an underground tunnel-train system to the mill as needed. In the other plants, it is transported directly from the quarry to the mill. The crude diatomite is then crushed, screened, and put into storage bins from which blends for producing the desired product are made and fed to the mill.

Material Treatment

In purification and treatment, the crude diatomite is dried in a pneumatic transport system or in a rotary drier. Either during drying or subsequently, the individual diatom skeletons are separated from each other with a minimum of fragmentation. Drying temperatures range from 300° to 800° F.

The material then passes through a series of separators to remove coarse and extraneous material such as chert and clay.

From the separators, the material is pneumatically or mechani-

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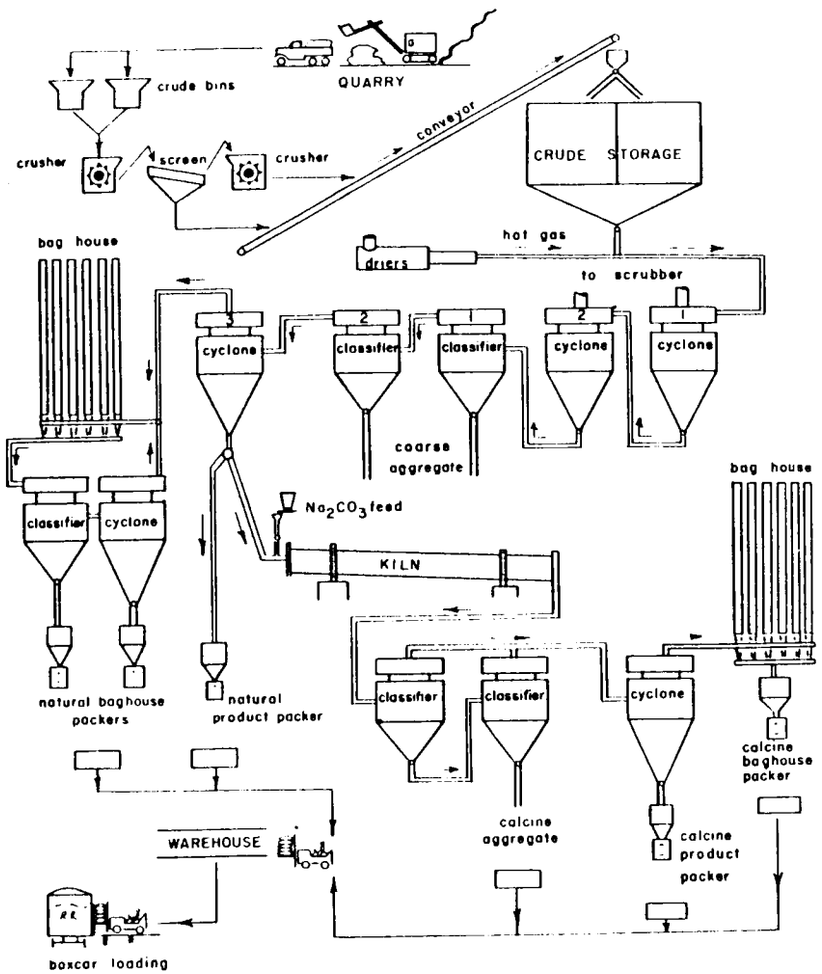


Figure 1. ***Typical flow diagram. The various processes to which the diatomite is subjected are schematically shown as it is moved from quarry to railroad boxcar.***

cally transported to the classification system from which a material is obtained suitable for processing into natural or calcined diatomite products.

In producing natural powder, the refined and dried diatomite is further mechanically air classified into products of desired particle size by centrifugal and baghouse separators. In making calcined products, the refined diatomite is further subjected to either a straight heat or a heat and fluxing process for approximately 45 minutes.

Straight calcining is done in a rotary kiln at either a low (approximately 1,600° F.) or high (1,800 –2,000 F.) temperature.

Flux-calcining consists of mixing the purified crude material with a flux, usually sodium carbonate, and passing it through a rotary kiln at a temperature of approximately 2,000° F.

The straight-calcined (pink) and flux-calcined (white) materials, upon leaving the kiln, are classified into *main* and *baghouse* products (*42–45*).

Packing

The finished product is packed into paper bags by mechanical packers especially designed for handling extremely fine particulate materials. The filled bags are placed on pallets. Excessive air is removed from the bags by compressing them on the loaded pallets, with hydraulic presses, or by allowing them to settle under their own weight on the pallets.

Shipping

Both unit- and hand-loading methods are used in loading boxcars and trucks. In unit loading, the bags are placed on pallets so designed that a forklift truck can pick up the bags from the pallet and set them in place in the boxcars. In hand loading, the bags are removed manually from the pallet and stacked in the boxcar or motortruck.

Maintenance

Maintenance and operation of equipment are special problems in processing diatomite. For uniformity of product, it is essential that a balanced flow be maintained throughout drying, milling, classification, calcining, and final product preparation since the material is pneumatically transported using both positive and negative pressure systems.

A "plug-up" in any phase of the system if not immediately cleared would soon make the entire system inoperative. Worn and improperly operating equipment alters the physical properties of the materials passing through the affected systems and makes quality control extremely difficult.

Sources of Airborne Dust

Specific operations in the diatomite-processing industry studied were predominantly unisolated except for distance and partial enclosures. Factors which influence the airborne dust concentra-

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tion at any one operation include: (1) nature of product, (2) specific operations, (3) work habits, (4) dust load of ambient air, and (5) condition of operating equipment.

Management was generally aware of the several operational sources of dust dispersion and had under development at the time of the initial study comprehensive plans for further dust control.

Nature of Product

As measured by sedimentation methods, the particle sizes of the finished diatomite powder products are predominantly under 10 microns (*43, 44*). The dryness of the powders, along with their elevated temperatures, influences their tendency to disperse at some operations and become airborne. On the other hand, the extremely high static charge on the product influences a strong tendency for the powder to flocculate. Consequently, at any one operation multiple forces interplay in influencing the nature and extent of associated dustiness. In general, however, the nature of the products and operations is such as to favor major dust dispersion.

Specific Operations

Most of the operations in processing diatomite must be considered potential sources of dust dispersion. This discussion, however, will be limited to those operations comprising major sources of dispersion along with some of the control measures that had been instituted and were in use at the time of the initial survey.

Quarrying.—The operations of loosening and removing overburden, loading into trucks, and hauling and dumping, were all associated with considerable dust dispersion. The amount of dust varied greatly depending upon the moisture content of the overburden, wind direction and velocity, and relative humidity. Similar factors influenced the amount of dust created in loosening, removing, and transporting the crude diatomite to the mills.

Much of the dirt loosening and removal equipment, as well as the hauling trucks, had enclosed cabs. These were not very effective in keeping out dust since in many instances the windows of the cabs had to remain open for visibility and comfort reasons. Respirators were provided but not generally used.

Material treatment.—The crushing, screening, and transferring of crude diatomite to storage bins created dust. Respirators, primarily, were relied on for protection of the workers.

Exhaust gases from the driers and calcining kilns transported considerable diatomite fines and dispersed them from stacks into the air. In some instances, the stack effluents under adverse

meteorologic conditions contaminated occupied areas inside the plants.

The pneumatic transporting system was at times a source of dust dispersion because of leaks in joints and flanges. The importance of maintenance in this system for quality control was recognized, however, and good attention was given to this aspect of operations.

In many instances the baghouses were not enclosed and bags were shaken manually. The wearing of respirators was mandatory during this activity, but dust from the operation contaminated other areas and increased the dust load of the ambient air.

Packing.—Bag filling with subsequent handling of the bags dispersed dust into the air. The mechanical bag packers were generally provided with local exhaust ventilation through annular slots surrounding the packing spouts. Supplemental exhaust ventilation was also provided at each packer by means of wall fans behind the packers or lateral hoods adjacent to or enclosing the packers. The bags were constructed to minimize dust dissemination during filling and subsequent handling. Dust from these sources generally arose from the use of compressed air to unblock the packer, contaminated exteriors of bags, and tossing of filled bags onto wooden pallets. Supplied air or filter respirators were worn by the workers during these operations.

Shipping.—The hand loading of bags into boxcars and onto trucks was extremely dusty. Broken bags spilled their contents over neighboring ones and onto the floor. Subsequent handling of the contaminated bags and walking over the spilled diatomite created clouds of dust. Filter-type respirators were worn by the workers during these operations.

A major improvement of unit loading had just been developed and was introduced in several plants during the initial study. This eliminated much of the hand-loading activity.

Work Habits

Carelessness in operating the equipment and in work habits was observed at times to create excessive and unnecessary dust concentrations at otherwise adequately controlled operations. There was little appreciation for the necessity of establishing proper operational procedures and of strict adherence to the procedures to minimize the dispersion of dust.

Dust Load of Ambient Air

When materials of extremely small particle size are handled, the dust load of the ambient air represents a composite effect of

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all specific operations in the general area disseminating dust and especially reflects the extent of good housekeeping and maintenance practices.

As with careless operating procedures and work habits, it was observed that poor housekeeping created a serious airborne dust hazard. Products spilled on the warehouse floor from broken bags became airborne when traversed by motorized equipment. Dust dislodged from rafters and other structural supports remained suspended in the air for prolonged periods. Air currents from moving equipment and winds from the outside picked up dust settled on bagged product, equipment, and floors, and dispersed it into the air.

The dust load of the ambient air was important in evaluating the effectiveness of local exhaust ventilation. Although the ventilation system may have been effective in controlling the dust at its sources, it usually could not reduce the dust concentrations at the operator's breathing zone below that of the ambient air. Management realized the value of good housekeeping and had begun to emphasize this aspect of dust control.

Condition of Operating Equipment

The importance of proper equipment maintenance was repeatedly demonstrated in the prevention of dust dispersion from the positive pressure system which conveyed the diatomite through processing stages. Loosened flanges, ductwork eroded by the abrasive action of the dust, loosened and worn-out filter bags, and blowbacks from plugged systems resulted in massive dust exposures in a short period of time unless corrected or repaired immediately. A small leak seemingly insignificant might in a relatively short period increase the dust load of the general area severalfold. Lack of attention to such situations also made good housekeeping difficult. Management was aware of the necessity of proper equipment operation for quality control and had instituted good maintenance programs.

Environmental Studies

The environmental studies included the determination of dust concentrations at various operations according to type of product, characterization of the physical and chemical properties of the dusts encountered, evaluation of existing dust control methods, and recommendations for an overall dust control program for the industry.

A total of 1,562 samples was collected in the initial environmental study of the 5 participating plants for defining the dust exposure, and the physical and chemical characteristics of the dust. Of these, 1,160 were impinger samples for determining atmospheric dust concentrations. The remaining 402 were special samples of parent material, settled dust, and airborne dusts for determining physical and chemical properties.

Atmospheric dust samples were collected at all operations where exposures to crude, intermediate, and finished diatomite products were encountered. In addition, general air samples were collected to determine the source and concentrations of dust arising from process equipment, interarea contamination, and outside conditions.

The number of atmospheric samples taken at any specific activity was governed by operational variation, range of dust counts obtained, and by the number of employees engaged in a specific area or task. Samples were taken on different days and during all three work shifts.

The sample collecting period was variable. Most samples were collected for a period of 10 to 20 minutes. In areas where the dust concentration appeared to be extremely high or low, the sampling period varied accordingly.

This report covers approximately 75 percent of the samples collected during the initial study. The remaining 25 percent representing samples taken in specialty areas or in connection with operations not common to all plants are not included in this report.

Approximately 400 additional samples were collected during the first year followup study and 850 during the second year followup study. The number of samples per plant was about the same for each of the 3 years covered by the report.

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Atmospheric Sampling Methods

Standard and Midget Impinger

The standard and midget impingers were selected for collecting atmospheric dust samples for light field counting. The same methods and techniques used in previous pneumoconioses studies were employed to secure comparable correlation of clinical and environmental findings and to express recommended maximum allowable concentrations on a uniform basis.

It was necessary first, however, to establish the comparative collecting efficiencies of the standard and midget impingers, and to determine the importance of particle fracturing as well as the breaking up of flocculated particles by impingement.

The efficiency of the midget impinger compared to the standard impinger for collecting diatomite dust for light field counting was determined by taking, in each of 10 different areas of uniform dust distribution, a pair of simultaneous atmospheric samples using the 2 instruments. The dust concentration values determined by one instrument were in close agreement with the corresponding values determined by the other, the differences being within ±7.6 percent.

To determine the extent of particle fracturing and the breaking up of flocculated dust by impingement, simultaneous midget impinger and membrane filter samples were taken of dust from diatomite powder products dispersed into a testing chamber.

The particle size distribution of each dust sample collected by the two methods was similar. For example, by oil immersion microscopy, the median particle size of dust dispersed from natural powder was 1.0 micron (μ) when collected with the membrane filter and 1.1μ when collected with the impinger, compared to 1.3μ for the parent material. By electron microscopy, the membrane filter sample gave a median particle size of 1.0μ. A partial explanation of the greater median particle size of the parent material over its airborne component is that the heavier particles settled rapidly from the air and were not collected by the air-sampling instrument. The decreased efficiency of the impinger in collecting submicron particles may have accounted for the greater median particle size for the impingement over the membrane filter sample, though the difference noted was not considered great.

In a second series of chamber tests, comparative dark and light field dust counts were made on the 3μ-and-under fraction of natural, high temperature straight-calcined, flux-calcined powders, and the airborne components from the same parent materials as collected with a midget impinger. The natural powder 3μ-and-under fraction had a dark to light field ratio of 1.6:1 compared to 2.2:1 for the airborne component of the parent material. The high-temperature, straight-calcined 3μ-and-under fraction had a dark to light field ratio of 1.8:1 compared to 1.9:1 for the airborne component of the parent material. In the flux-calcined material, the 3μ-and-under fraction had a ratio of 1.5:1 compared to 2.0:1 for the airborne component of the parent material. These values for dark to light field ratios indicate that there may be some particle fracturing by impingement. Although the impinger has decreased efficiency in collecting submicron particles and would favor low values, these would be somewhat counterbalanced by the number of submicron particles always present in the air and collected by the impinger but unrelated to the test.

As a further check against the breaking up of particles by the bubbling action of the impinger, counts and particle size distributions were made on diatomite products suspended in a midget impinger flask prior to and after filtered air was passed through the flask at the designated sampling rate for 20 minutes. Dust counts in the flask prior to and after agitation with air were within ±9.0 percent. Particle size distributions were not appreciably changed. For example, with a natural powder product the median particle size prior to agitation was 1.46μ compared to 1.30μ after air agitation.

From these tests it was concluded that although some particle fracturing and breaking up of flocculates was likely, these were not important factors in the size ranges of particles entrapped by the impinger for light field counting. Thus, the midget and standard impingers were considered satisfactory instruments for collecting airborne diatomite dust for light field dust counting.

The impingers were periodically calibrated for airflow throughout the study. Distilled water with a predetermined blank was used as a collecting fluid.

Electrostatic Precipitator and High-Volume Sampler

The electrostatic precipitator and the high-volume air sampler were used to collect airborne dust samples for subsequent X-ray diffraction analysis for quartz and cristobalite content. Sampling time ranged from 3 to 17 hours, depending on the atmospheric dust load.

Membrane Filter

Atmospheric dust samples for particle size determination were collected on aerosol-type membrane filters. Since particle sizing

was done in the laboratory subsequent to the fieldwork, length of sampling varied so that the dust loads on the filter samples at any one station would be light, medium, and heavy. The filter with the appropriate dust load was then used for particle size determination.

Simultaneous airborne dust samples were taken with the membrane filter and thermal precipitator in 2 test series to compare the median particle size of the dust collected by the 2 methods. With the use of the oil-immersion technique of measurement, the median particle sizes of the dust collected on the membrane filter were 1.6 and 1.5μ compared to 1.5 and 1.75μ, respectively, when collected by the thermal precipitator. Although the comparative tests were limited, the results indicated that both instruments had similar performances in collecting diatomite dusts.

Since the membrane filter method of collecting airborne dust has many advantages and conveniences over the impingement method, a series of tests was made to determine if the membrane filter was satisfactory for collecting diatomite dust samples for light field counting. Stimultaneous airborne dust samples were taken with the midget impinger and membrane filter in nine test series, using all types of processed diatomite powder as the source of dust. The impinger samples were counted by the standard light field method. The membrane filters were made transparent by cedar oil and the dust was counted directly on the membrane filter using the light field counting microscope. The dust concentrations using impingement collection were 2.4 to 5.6 times the concentrations determined by membrane filter collection on simultaneously collected samples.

Further investigation revealed that all of the dust on the filter was not being observed with light field magnification because of the small difference in the refractive indices of the filter and the dust. The refractive index for amorphous diatomite (opal) is 1.43, cristobalite 1.48, and the molecular filter approximately 1.51. The molecular filter does not become transparent if the oil used is outside the range of about 1.49 to 1.51.

In a series of six tests, diatomite dust from impinger samples was placed on clean microscope slides and the water evaporated by air drying. The dust in a defined area on each slide was counted with the light field microscope. A drop of cedar oil, refractive index 1.51, was placed on the slide and the same area counted. It was observed that many of the dust particles became invisible as the oil spread over the slide. In the 6 tests, the number of particles in the prescribed area counted averaged 2.1 times greater when counted by the light field microscope (100 ×) without the oil. In a second series of 6 tests, using oil immersion (970 ×), the number of particles counted in the prescribed area averaged the same before and after the use of the oil.

The results of these series of tests show that the membrane filter was not a satisfactory method for collecting diatomite dust for light field counting with the use of the techniques described.

Chemical and Physical Methods

Analytical Methods

The percentages of cristobalite and quartz in the samples were obtained by X-ray diffraction using photographic internal standard techniques. The primary standards used in the preparation of calibration curves were natural specimens of optical grade Brazilian quartz and cristobalite of high purity from Durango, Mexico, obtained through the U. S. National Museum. The diffraction photographs were obtained with a General Electric XRD, type 1 diffraction apparatus. The line densities were read on a Leeds & Northrup recording microphotometer.

Figure 2 shows typical X-ray diffraction patterns for crude, natural, high-temperature straight-calcined and flux-calcined diatomite products.

Particle Size Determination

The membrane filter on which the airborne dust was collected for determining particle size distribution was placed dust side down on a clean microscope slide. An immersion oil with refractive index of 1.515 was placed on the filter. The oil immersion objective (97 ×) and a 10 × ocular were used in a standard microscope with Kohler illumination. An ocular disk (May's modification of a Patterson graticule) was used as a reference to size a minimum of 200 dust particles for each sample. The results were plotted on logarithmic probability paper, and the median size and standard geometric deviation determined.

Dust-Counting Procedure

The light field dust counting technique using Dunn cells and a magnification of 100 × (16-mm. objective, 10 × ocular) was used in accordance with the procedures outlined by the Subcommittee on Standard Methods in the Transactions of the Fifth Annual Meeting of the American Conference of Governmental Industrial Hygienists. Samples were counted within 24 hours of collection. Settling time, averaging 40 minutes, was allowed in the Dunn cells. The Dunn cells were calibrated for depth and the appropriate correction factor was applied.

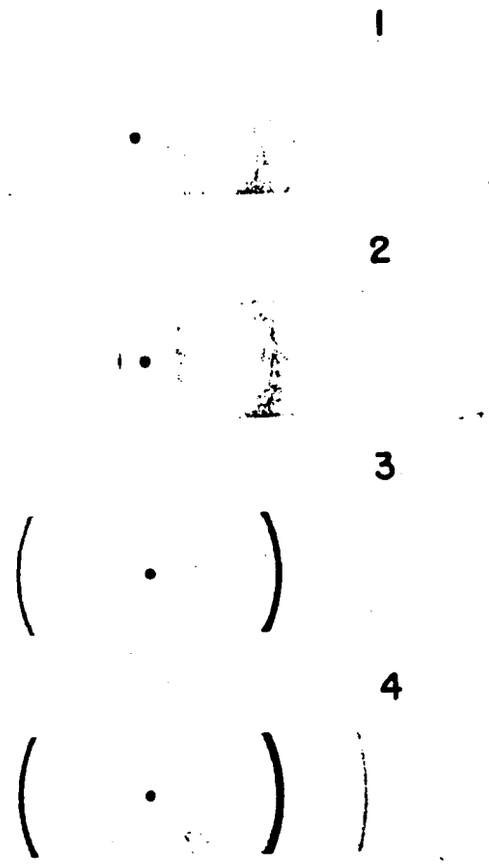


Figure 2. *X-ray diffraction patterns of diatomite products. 1. Crude diatomite. Except for traces of impurities the absence of lines shows material to be noncrystalline. 2. Low temperature calcined diatomite. Faint additional line superimposed on the diffuse band shows presence of a trace of cristobalite. 3. High temperature straight-calcined diatomite. Distinct lines are those characteristic of cristobalite. 4. Flux-calcined diatomite. Increased intensity of lines and disappearance of diffuse band show greater conversion of amorphous silica to cristobalite.*

Results of Environmental Studies

Composition of Crude Diatomite

The percent composition by dry weight of crude diatomite samples from salt and fresh water sources is shown in table 1. The value for any one component may vary according to the source and purity of the crude diatomite. As an example, the calcium component may range from a trace to 3 percent and over. The moisture content may exceed 5 percent. The values in the table are within the general range reported by others (*38, 39, 47, 48*). No apparent difference is noted in the chemical composition of the crude diatomite from the two sources.

Table 1. *Percent composition by dry weight of crude diatomite according to source*

Component	Percent by dry weight		Component	Percent by dry weight	
	Salt water diatomite	Fresh water diatomite		Salt water diatomite	Fresh water diatomite
Ignition loss	6.4	8.1	MgO	0.5	0.2
SiO_2	[1] 87.8	[1] 85.5	K_2O	.2	.1
Al_2O_3	2.6	3.6	Na_2O	.6	.1
Fe_2O_3	.9	1.6	Undetermined	.8	.5
TiO_2	.2	.2			
CaO	[2] .0	.1	Total	100.0	100.0

[1] Essentially amorphous silica
[2] Trace.

Quartz in Parent Material, Settled Dust, and Airborne Dust

Table 2 shows the percent by weight of quartz in overburden, crude diatomite, and mixed mill dust. The crude and various diatomite products, and their settled and airborne components, had a mean quartz content of 2 percent and under. Overburden had a mean quartz content under 5 percent. Although the percentage values for quartz will vary with the source of the crude and within the same deposit, these values based on a total of 68 samples are believed to be representative. The values found indicate that exposure to quartz is not a problem in the diatomite processing industry studied.

Table 2. *Percent by weight of quartz in parent material, settled dust, and airborne dust according to product, 5 plants combined*

Product	Parent material			Settled dust			Airborne dust		
	Number of samples	Quartz percent by weight		Number of samples	Quartz percent by weight		Number of samples	Quartz percent by weight	
		Range	Mean		Range	Mean		Range	Mean
Overburden	4	0-12	5	3	2-7	4	1		1
Crude diatomite	11	0-7	2	6	<1-3	2	4	0-4	1
Milled product	13	0-5	<2	23	<1-4	2	3	1-2	2

Cristobalite in Parent Material, Settled Dust, and Airborne Dust

No cristobalite was noted in the overburden, crude diatomite, natural diatomite or low-temperature straight-calcined diatomite

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products. Although a small percentage of cristobalite was found in one sample of airborne natural powder dust, this was likely due to contamination, from high-temperature straight-calcined and flux-calcined materials. The crude diatomite and the natural and low-temperature straight-calcined products were essentially amorphous silica. In this report, low-temperature straight-calcined diatomite was included and treated as a part of the natural powder category. Diatomite with only trace amounts of cristobalite is classed as cristobalite-free material.

Tridymite was not detectable in any of the parent materials, settled dust or airborne dust by X-ray diffraction techniques and does not appear to constitute a problem in the diatomite processing industry studied.

The percent of cristobalite in parent material, settled dust, and airborne dust according to type of diatomite product is shown in table 3.

TABLE 3. *Percent by weight of cristobalite in parent material, settled dust, and airborne dust according to product, 5 plants combined*

Product	Parent material			Settled dust			Airborne dust		
	Number of samples	Cristobalite, percent by weight		Number of samples	Cristobalite, percent by weight		Number of samples	Cristobalite, percent by weight	
		Range	Mean		Range	Mean		Range	Mean
Natural:									
Main product	6	0-<1	<1	1		<1	1		<5
Baghouse product	1		0	3		<1	0		
Straight-calcined [1]									
Main product	4	10-20	15	3	8-37	27	3	12-26	17
Baghouse product	2	11-31	21	1		[2] 52	1		22
Flux-calcined:									
Main product	5	44-59	49	8	16-66	38	7	15-46	32
Baghouse product	4	58-64	61	4	24-64	45	4	23-40	32
				4	57-95	[2] 75			
All types (mixed)				18	10-53	25	4	7-26	16

[1] High temperature.
[2] Baghouse classification area.

The high-temperature, straight-calcined diatomite had an average cristobalite content of 15 percent for main product, and 21 percent for baghouse product. Flux-calcined diatomite had an average cristobalite content of 49 percent for main product, and 61 percent for baghouse product. The cristobalite content of the high-temperature straight-calcined product was variable and was probably influenced by the amount of natural flux in the purified crude. X-ray diffraction patterns showing percent of cristobalite

in various diatomite products are presented in the previously shown figure 2.

Of special interest is the range of differences and the lack of a close relation in the percent of cristobalite in parent material, settled dust, and airborne dust of the high-temperature straight-calcined, flux-calcined, and mixed products. For example, the mean cristobalite content of high-temperature straight-calcined main and baghouse product settled dust is approximately twice that of the parent material. On the other hand, with flux-calcined products, the mean cristobalite percent of the settled dust, except for the baghouse classification area, is less than the corresponding parent material. The cristobalite content of airborne dust is approximately the same as that of the corresponding parent material for high-temperature straight-calcined products, while in the flux-calcined products the cristobalite content of the airborne dust is only one-half to two-thirds that of the parent material.

Several factors influenced these variations. Different types of end products with varying physical properties such as particle size distribution were processed in the same product category. Bailey (*35*) showed that conversion of amorphous diatomite to cristobalite was progressively more rapid and complete with decreasing particle size. The variation shown in the cristobalite content of the parent material would likely represent the ranges existing among different products.

The settled dust samples were collected on structural members as near head height as possible. These samples, because of natural air classification, would be expected to have a higher cristobalite content than the parent material. However, a direct relation did not exist between the cristobalite content, parent material, and settled dust since the settled dust samples were not necessarily from a single product category and often contained dust from other operational areas. In many instances, natural, straight, and flux-calcined products were processed in the same areas and equipment.

The percent of cristobalite in the airborne dust was much lower than would be expected. As mentioned earlier, few specific operations were completely isolated from adjacent activities and cross-contamination was frequent. Also, equipment such as packers had an appreciable amount of local exhaust ventilation, both through annular slots surrounding packing spouts and laterally at each side or behind the packers. These ventilation systems, in addition to collecting the dust at its source, brought in replacement air. The dust load of the replacement air would then be an important factor in the operator's exposure. The

amount of cristobalite in the dust of the ambient air was much less than that of the settled dust.

The values in table 3 clearly indicate that the flux-calcined product and its airborne component have a much higher cristobalite content than the corresponding high temperature straight-calcined material. They also show that even the high-temperature, straight-calcined product and its airborne component have an appreciable cristobalite content. The source of the crude diatomite, whether of salt or fresh water origin, did not appear to influence the percent of cristobalite found in the finished products or their airborne dust.

Cristobalite in Different Size Fractions of Parent Materials

The percent of cristobalite in the different size fractions of parent materials is shown in table 4. The parent materials were separated by air elutriation into 3 size fractions calculated on the basis of quartz of specific gravity 2.65. The actual size limits separated, as would be expected, varied inversely with the true densities of the parent materials.

TABLE 4. *Percent by weight of cristobalite in different size fractions of product*

Product	Percent by weight of cristobalite		
	Less than 3 microns	3-10 microns	10 or more microns
Straight calcined [1]			
Main product:			
Sample No. 1	16.0	15.0	8.0
Sample No. 2	12.0	18.0	17.0
Baghouse product			
Sample No. 1	30.0	33.0	30.0
Sample No. 2	9.0	13.0	16.0
Flux-calcined			
Main product			
Sample No. 1	57.0	51.0	31.0
Sample No. 2	61.0	57.0	38.0
Sample No. 3	61.0	55.0	45.0
Baghouse product			
Sample No. 1	62.0	57.0	47.0
Sample No. 2	66.0	65.0	58.0

[1] High temperature.

The data bear out generally the observation that the percent cristobalite of the parent materials increased as the particle-size range decreased.

Particle Size Distribution

Crude diatomite beds contain fossils representing a great number of diatom species. Consequently, the individual skeletons of



Figure 3. ***High quality, salt water, crude diatomite, 600X. This sample was taken from the crude material as removed from the ground. Note the extreme variation in the sizes, the extensive fragmentation, and the visual difference in density of the particles. The finely detailed structure would indicate that the bulk material would have a very great surface area, which has been found to be from 12 to 40 square meters per gram. The instrumental magnification by the electron microscope was 130 diameters and the width of the field approximately 0.2 mm.***

the bed will vary in size, ranging in maximum dimension from a few to over a hundred microns.

Figure 3 illustrates typical whole fossils of different species found in a crude diatomite bed of salt water origin. Figure 4, on the other hand, shows an actual sample from a diatomite bed of fresh water origin.

Figures 5 and 6 represent natural diatomite main and baghouse products, respectively, and figures 7 and 8, flux-calcined main

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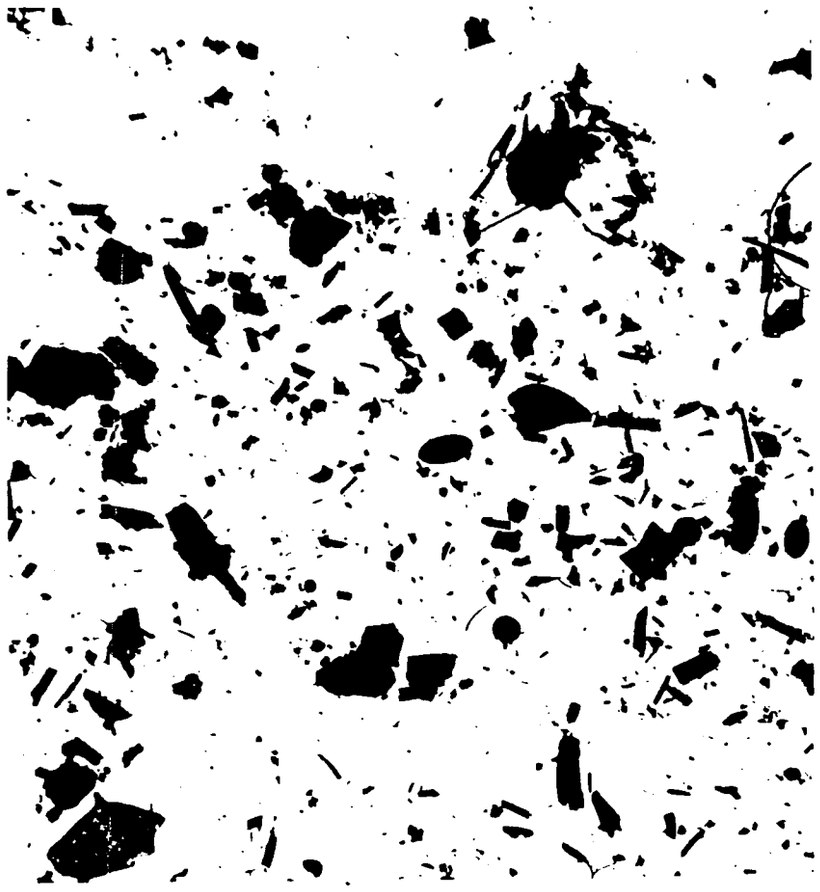


Figure 4. ***High quality, fresh water, crude diatomite, 600X.***

and baghouse products. Photomicrographs bringing out details of structure of natural and flux-calcined products are shown in figures 9 and 10.

The preparation of uniform products is one of the objectives of processing, hence it is designed to remove extremely fine and large particles from the product. This is reflected in the particle size distribution pattern observed in the airborne dusts. The distribution of particle size of the airborne dust samples in the five plants by product category is shown in figure 11. Average values are shown for the combined samples by product, regardless of sampling location. The median particle size values of these samples are given in table 5. It must be noted that since all the dust samples were collected during the nonheating season, and



Figure 5. ***Milled salt water natural diatomite (main product), 600X. This material is essentially the same as that in figure 3. Note the absence of whole diatoms.***

the plants were generally isolated from inhabited areas, there was minimal superimposed airborne particulate contamination from community sources.

TABLE 5. *Particle size of airborne dust according to product, 5 plants combined*

Product	Number of samples	Median particle size in microns		
		Range	Median	Mean
Crude	14	0.6–2.0	1.5	1.4
Natural	16	5.1–7	1.2	1.1
Straight calcined [1]	6	8.1–5	1.0	1.2
Flux calcined	31	5.2–2	1.1	1.2
Miscellaneous	34	7.1–7	1.2	1.1

[1] High temperature.

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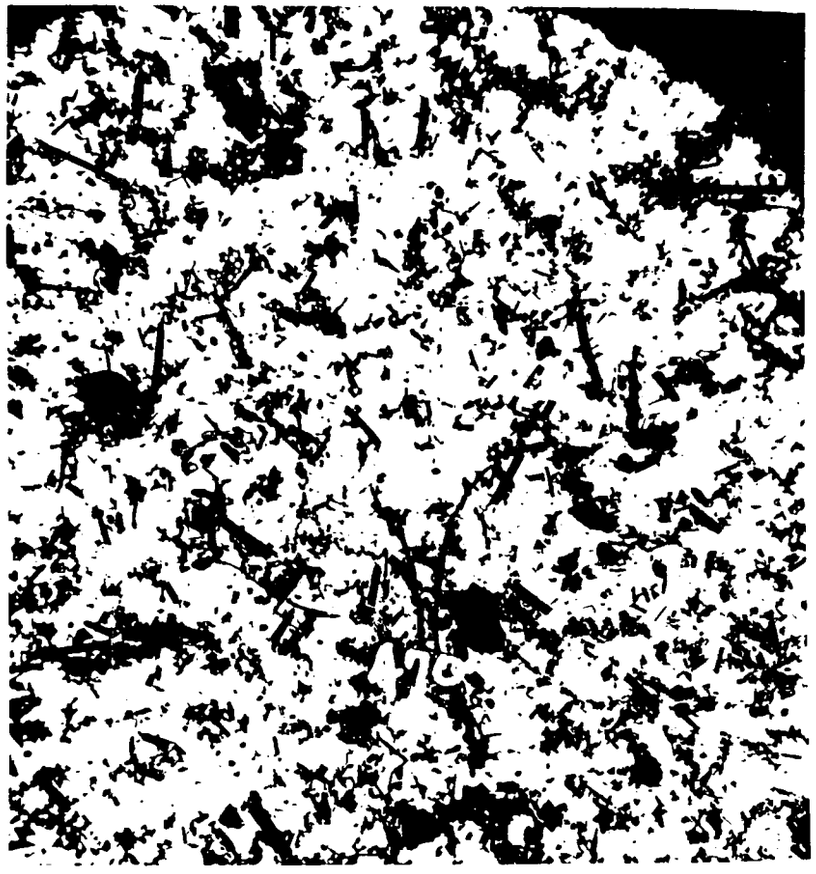


Figure 6. *Milled salt water natural diatomite (baghouse product), 600X. Note the greatly increased number of fines in comparison with figure 5.*

The median particle size values, excepting the crude, were similar for the airborne dust of each of the diatomite categories, varying between 1.0 and 1.2μ with median values of individual samples ranging from 0.5 to 2.2μ. The crude diatomite dust had a median particle size of 1.5μ. Ninety percent of the natural powder airborne dust particles were under 3.2μ in size compared to 4.8μ for the crude diatomite dust, and 4.4μ for the flux-calcined dust.

Only small differences were noted in the particle size distribution of dusts by operations. Certain operations, such as crushing the crude diatomite and hand loading bags into boxcars were associated with heavy dust concentrations and larger median



Figure 7. *Flux-calcined milled salt water diatomite (main product), 600X.*

particle sizes of the airborne dusts. A wide range of values was associated with the packing and palletizing operations where many of the individual samples had median particle size values in the range of 0.5 to 1.0μ. The average of the median particle size values for the packing operations by product, however, ranged from 1.0 to 1.1μ, and was similar to the average values by product regardless of operations. Since most of the plant operations were in unconfined areas and ambient air dust loads played an important role in the dust characteristics at any one specific location, no attempt has been made to give particle size distribution of airborne dusts by plant operation. No apparent difference was noted in particle size of airborne dusts in the 5 individual plants.

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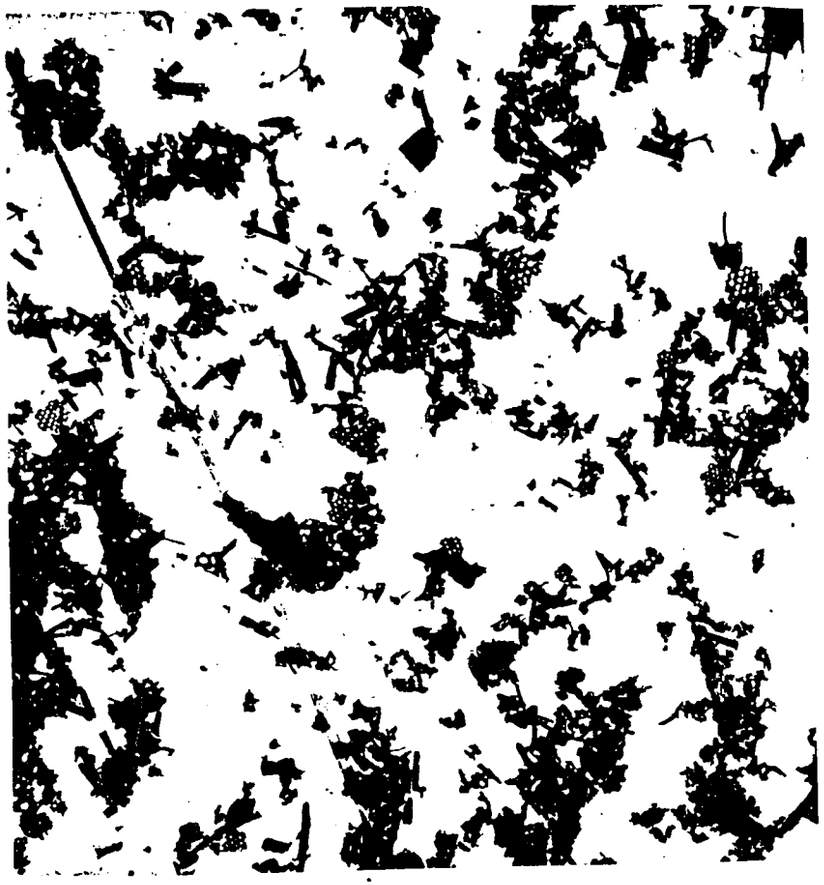


Figure 8. ***Flux-calcined milled salt water diatomite (baghouse product), 600X.***

To assure that these values were not a reflection of the limitations of the techniques used, particle size distributions were determined both by oil immersion and electron microscopy on the same inplant airborne membrane filter samples in the lower range particle sizes. No appreciable difference was noted in the distribution pattern by the two methods. On 3 separate membrane filter samples, the median particle size was 0.8μ each determined by oil immersion microscopy as compared to 0.77, 0.70, and 0.73μ, respectively, by electron microscopy.

As a further check, particle size distributions were determined on the 3μ-and-under fraction of the same product produced by 3 different plants. The distribution patterns were the same, with the median particle sizes of the 3 samples ranging from 1.0 to 1.1μ.

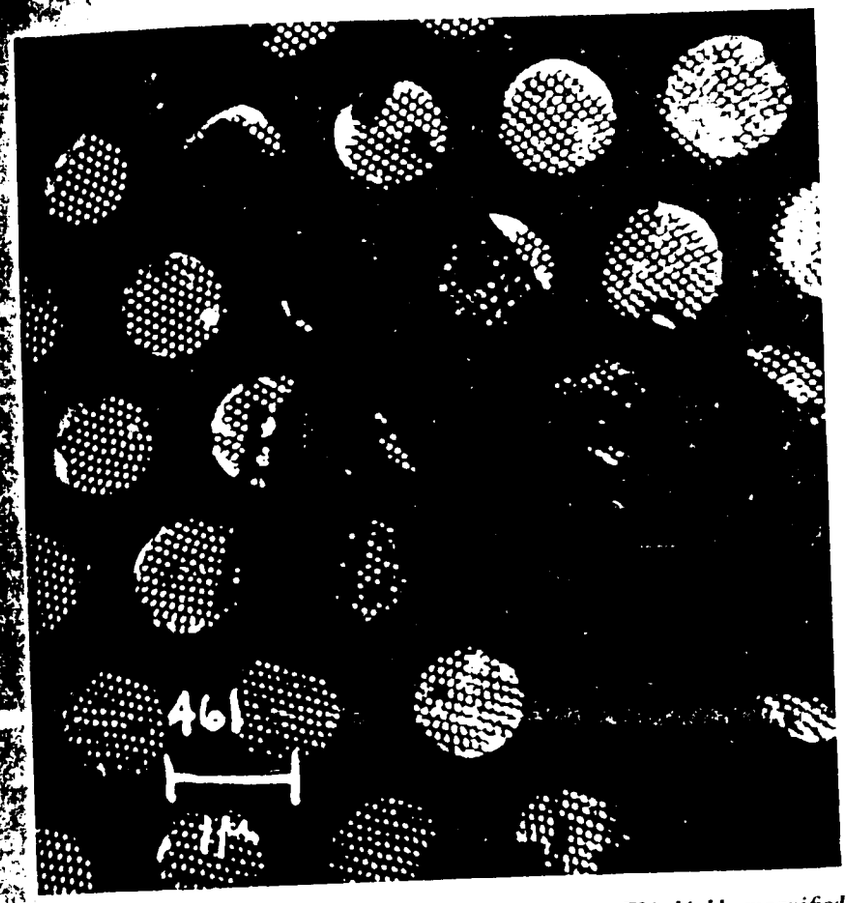


Figure 9. ***Milled natural salt water diatomite, 30,000X. This highly magnified view through the interstices of a typical untreated diatom fragment shows the precise regularity of form that is characteristic of the structure as well as the fine structure within the interstices which accounts for the extremely high surface area of this material. Although the skeletal substance is primarily amorphous silica with a true density of approximately 2.3 the submicron perforations give the final product an extremely low effective or bulk density.***

A logical explanation for the similarity of the distribution pattern is that the particle size distribution of airborne dust at any one location is greatly influenced by the distribution pattern of the dust in the ambient air. This interpretation appears supported by the particle size distribution pattern of the miscellaneous airborne dust, which likewise had a mean and median value of 1.1 and 1.2μ, respectively.

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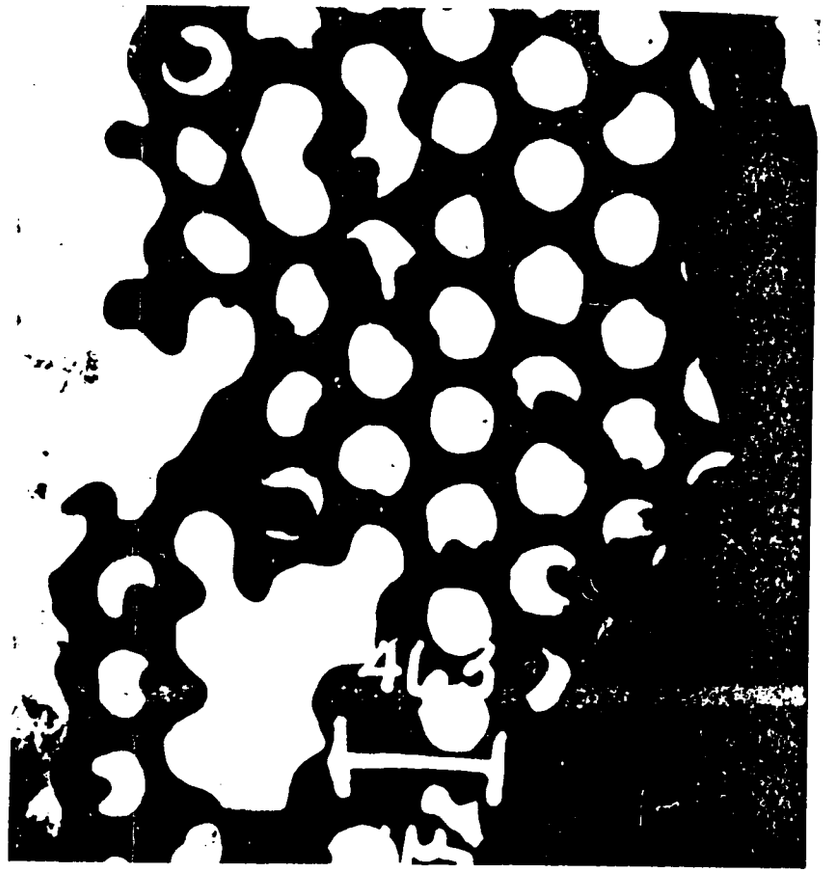


Figure 10. ***Milled flux-calcined salt water diatomite, 30,000X. The obvious distortion of the normally regular diatom structure is due to fusing. The loss of the fine structure within the interstices results in a 10- to 20-fold decrease in the surface area of the finished product.***

There did not appear to be a predominance of low-range, submicron, airborne particles. This was borne out by the similarity of the distribution patterns of the lower range median particle size values regardless of whether the determinations were made by oil immersion or electron microscopy. It is significant that the particle size range of the airborne dust was such as to favor maximum retention when inhaled (*49*). Since the size distribution of the airborne dust was fairly uniform, it was impossible to correlate exposure to different particle size values of the dust with the development of pneumoconiosis.

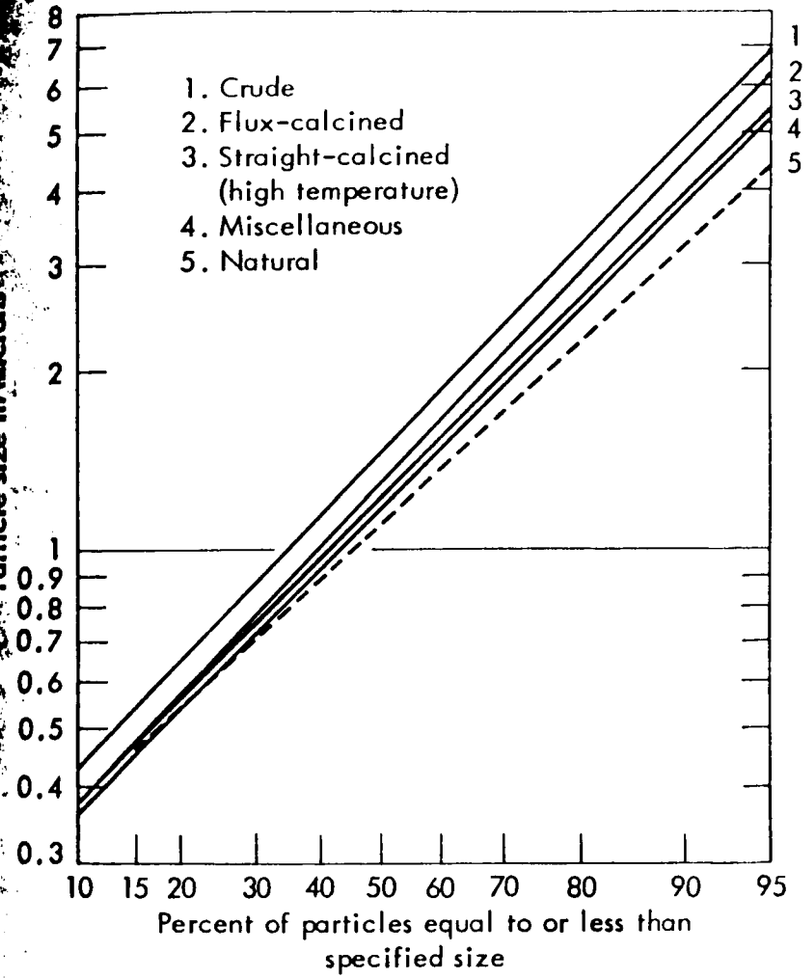


Figure 11. ***Particle-size distribution of air-borne dust by product category. Logarithmic-probability grid.***

Atmospheric Dust Concentrations

Table 6 shows the atmospheric dust concentrations found during the initial study (1953–54) by product and operation common to all 5 plants. The range and average of maximum values are given to define the relation of intermittent exposures to peak dust concentrations. The average of minimum values indicates dust concentration under optimum conditions of equipment operation,

housekeeping and maintenance, performance of work, and outside atmospheric conditions. The average of median values gives an estimate of the more common levels of dust concentration according to operation and product.

TABLE 6. *Atmospheric dust concentrations by product and operation, 1953–54, 5 plants combined*

Product and operation	Number of samples	Millions of particles per cubic foot of air			
		Range of maximum values	Average of maximum values	Average of minimum values	Average of median values
Overburden:					
Quarry-earth moving [1]	77	13–336	[2] 106 (61)	2	10
Quarry-general air	7	14–43	[3] 28	2	8
Crude:					
Quarry-earth moving	47	27–98	53 (42)	6	11
Quarry-general air	26	4–110	33 (10)	2	7
Materials treatment [4]	71	21–99	59	2	11
Natural product:					
Materials treatment	27	5–185	51 (8)	5	11
Main product packers	22	7–84	55	7	21
Baghouse product packers	12	11–32	21	5	9
Pallet formation	13	22–63	41	8	14
Hand loading (boxcars, trucks)	12	47–1,560		31	66
Unit loading	1	22			
General air samples	12	9–10	10	2	5
Straight-calcined product:					
Materials treatment	14	7–20	13	3	8
Main product packers	17	4–48	31	5	10
Baghouse product packers	2	[5] 5		[5] 2	4
Pallet formation	7	10–25	17	5	7
Hand loading [6]	4	16–56	32	30	31
General air samples	5	5–8	6	3	4
Flux calcined product:					
Materials treatment	19	4–10	7	1	4
Main product packers	36	13–52	37	3	9
Baghouse product packers	9	8–12	10	3	6
Pallet formation	27	6–11	9	1	3
Hand loading	11	10–41	27	8	18
Unit loading	9	5–18	12	3	8
Miscellaneous	26	5–8	7	1	3
Diatomite mixture:					
Materials treatment	22	4–12	9	2	4
Maintenance [7]	26	15–164	101 (156)	1	5
Outside air [8]	44	4–9	6	1	1
Stocking shaking	20	[3] 236–247	242	13	58
Reload	14	[3] 31–98	66	12	33
General air, miscellaneous	77	2–55	22 (15)	1	6

[1] Includes roping, dozing, shoveling, grading, and hauling.
[2] Median value in parentheses.
[3] 2 plants only.
[4] Includes crushing, drying, classifying and calcining.
[5] 1 plant only.
[6] One sample in each of 2 plants, and 2 samples in a third plant.
[7] Includes waste trucks, shops, garages, and sweeping.
[8] Both upwind and downwind from plant.

The average of the median dust concentrations for all operations ranged from 1 to 66 million particles per cubic foot of air (m.p.p.c.f.). Thirty-four percent of the values were 5 m.p.p.c.f. and under, 33 percent 6 to 11 m.p.p.c.f., and 33 percent 11 m.p.p.c.f. and over. The average maximum concentrations ranged from 6 to 242 m.p.p.c.f. with 29 percent of the values 10 m.p.p.c.f. and under, 42 percent 11 to 51 m.p.p.c.f., and 29 percent 51 m.p.p.c.f. and over.

These dust concentrations were excessive for dust containing an appreciable percent of crystalline silica (*50*) and pointed to the need for additional control measures.

There was insufficient information to correlate in this report past levels of dust exposure with clinical findings. The absence of adequate data on the levels of dust concentration by specific operation during the past 15 years made an accurate assessment of the past weighted dust exposures impossible. Also, since the industry had undertaken at the time of the initial study in 1953–54 an extensive dust control program, the dust concentration levels found at that time were transitory.

Dust Control Program

In the early history of the diatomite industry, little attention was given to dust control except as it was an integral part of production. Studies at selected operations conducted by the Bureau of Adult Health, California State Department of Public Health, since 1944, indicated that atmospheric dust levels in the past were significantly greater than they were during the time of the study in 1953–54. In addition, those levels were undoubtedly accompanied by intermittent periods of extremely heavy dust loads.

The subsequent technologic advances in the industry resulted not only in better operating procedures but also in the gradual lowering of atmospheric dust concentrations. Examples of this are evidenced in the improved construction and operation of pneumatic transporting systems, the changeover from burlap to paper bags, the development of enclosed baghouses with automatic bag shakers, and the replacement of hand bag loading by mechanical unit loading procedures. Since about 1948, however, the industry has given increased attention to dust control as a special problem.

Through information and observations gained from the initial study in 1953–54, the following dust control program was recommended for the diatomite processing industry. Much of it was

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put into operation during the initial study and the 2-year followup period reported on. The program, a composite of various techniques and procedures known to be generally effective in the control of dust, was based on: (1) control of dust at the source of dispersion, (2) routine dust evaluation, (3) improved housekeeping and maintenance, and (4) personal respiratory protection.

Control of Dust at Source of Dispersion

Detailed dust studies should be made of new and unchecked operations. Where high dust concentrations prevail, the operating procedure should be evaluated to determine if changes in method will effect lower dust concentrations. Where indicated, additional engineering dust controls should be instituted. The operation should then be followed up by a second detailed dust study. When dust concentrations have been found to be below a safe level, the operation should be included in the routine dust evaluation program.

Routine Dust Evaluation

To assure the proper functioning of operational and dust control equipment, a program of routine dust evaluation should be inaugurated. Areas of high dust levels should be checked to determine the condition of the operating and dust control equipment and any departure from approved methods of doing the work. The dust load of the ambient air should likewise be routinely evaluated as a check on housekeeping, maintenance, and work habits.

Improved Housekeeping and Maintenance

To reduce the dust load of the general air, constant attention should be given to improved housekeeping. This includes: (1) cleaning up spills immediately; (2) repairing leaks and improperly operating equipment; (3) routine cleaning of all inplant areas including floors, structural supports, and equipment; (4) periodic cleaning of areas outside plant; and (5) an educational program for instructing employees in methods of operation and work habits to minimize dispersion of dust.

Personal Respiratory Protection

U. S. Bureau of Mines-approved respirators should be used as a supplementary measure in areas of high dust concentration until satisfactory engineering methods of dust control are developed and instituted. Respirators should be worn by maintenance and other personnel when working in areas of high intermittent dust exposures. A routine schedule should be formulated for issuing, cleaning, inspecting, and maintaining respirators.

Comparison of Initial and Followup Studies

Table 7 shows a comparison of dust concentrations found in the five plants by product during the initial study (1953–54), followup study (1954–55) and routine plant studies (1956). The data indicate a marked improvement in plant environmental conditions. Except for the high-temperature, straight-calcined product, the dust concentrations have been greatly reduced. Over three-fourths of the overall dust levels reported in 1956 were under 5 million particles per cubic foot of air. The high peak values found earlier were also reduced. For example, only 47 percent of the flux-calcined, airborne dust counts were under 5 million particles per cubic foot of air in 1953–54 compared to 84 percent in 1956. Twelve percent of the values were over 21 million particles per cubic foot in 1953–54 compared to none for 1956.

TABLE 7. *Summary of dust concentrations according to product during initial study, 1953–54, followup study, 1954–55, and routine plant studies, 1956, 5 plants combined*

Product	Year	Number of samples	Millions of particles per cubic foot of air: 5 or under (Percent of samples)	6–10 (Percent of samples)	11–20 (Percent of samples)	21 or over (Percent of samples)
Overburden and crude	1953–54 [1]	265	21	23	26	30
	1954–55 [2]	87	41	20	21	18
	1956 [3]	74	69	27	4	0
Natural	1953–54	163	19	21	19	51
	1954–55	63	30	21	14	35
	1956	64	66	20	5	9
Straight calcined (high temperature)	1953–54	58	43	32	15	10
	1954–55	60	38	32	17	13
	1956	102	44	23	23	10
Flux calcined	1953–54	174	47	27	14	12
	1954–55	99	63	14	12	11
	1956	257	84	14	2	0
Miscellaneous	1953–54	205	65	18	9	8
	1954–55	79	74	15	6	5
	1956	356	91	7	1	1
All products combined	1953–54	965	38	23	17	22
	1954–55	388	51	19	14	16
	1956	853	79	13	5	3

[1] Initial study by Public Health Service and State departments of health.
[2] Followup study after 1 year by Public Health Service and State departments of health.
[3] Routine dust evaluation program by plant staff.

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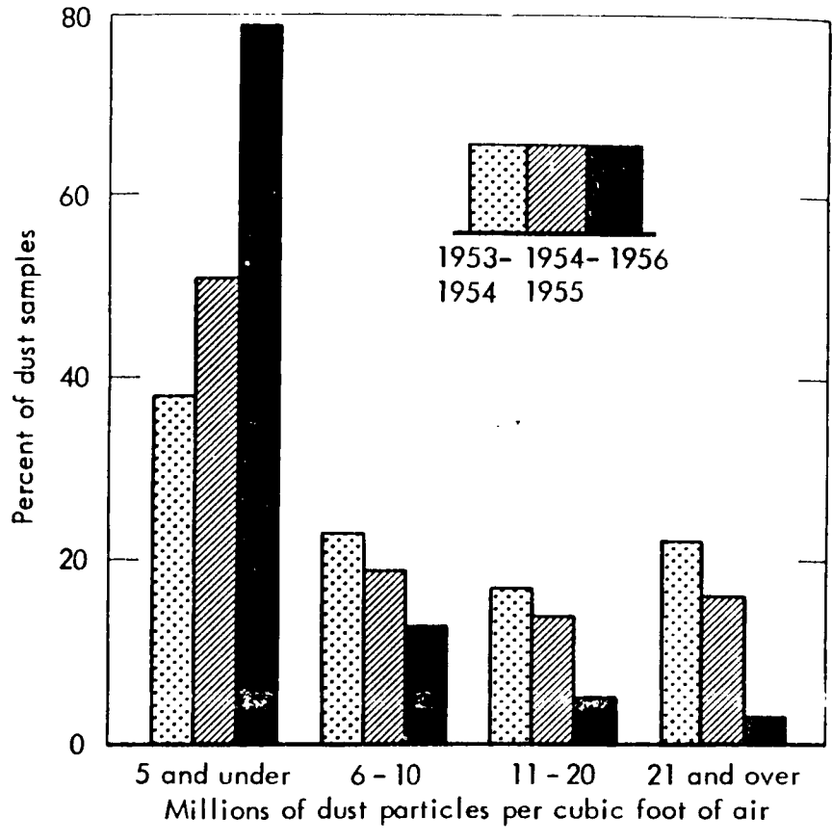


Figure 12. ***Percent of samples showing indicated dust concentrations in million particles per cubic foot of air determined in the 5 plants during initial study of 1953–1954, in the follow-up study of 1954–1955 and in routine plant studies during 1956.***

The bar chart, figure 12, showing distribution of dust counts over this same period for all products combined dramatically presents this contrast. Out of 865 airborne dust samples collected in 1953–54, only 38 percent were under 5 million particles per cubic foot and 22 percent were over 21 million particles per cubic foot. In 1956, of 853 samples collected by the plants, 79 percent were under 5 million particles per cubic foot and only 3 percent were over 21 million particles per cubic foot.

No reduction was noted in airborne dust concentrations for the high-temperature, straight-calcined product during the period covered. Although this product accounted for only a minor portion of the production, it contains an appreciable percent of cristobalite.

The improvements in environmental conditions were undoubtedly attributable to the concentrated efforts of the companies in improving their dust control programs during the interim period. The engineering planning, however, was done prior to this period.

Illustrative of the concentrated efforts made by the companies to improve their dust control programs are the following:

All of the 5 plants performed routine dust evaluations. One plant provided all quarry mobile equipment cabs (figs. 13 and 14) with filtered air (*49, 50*). Another plant provided operators of quarry equipment with air supplied hoods (fig. 15). Very extensive engineering programs were instituted to control dust at its source. As examples, improved ventilation was provided at diatomite product packers (figs. 16, 17, and 18). Bag air cleaners were used (fig. 19) to remove diatomite product from the exterior of bags and facilitate good housekeeping. The palletizing press was provided with exhaust ventilation (fig. 20) in one plant. Figure 21 shows a special blowoff booth designed to remove dust from work clothes, while figure 22 illustrates an exhaust ventilated booth used for blowing off equipment. Modern mechanically operated, enclosed baghouse dust-collecting equipment is shown in figures 23 and 24. A tremendous improvement was noted in housekeeping.

Figure 25 shows a view of typical mill operations and illustrates the difficult problem of housekeeping in such an area. The former practice of cleaning work areas and equipment by blowing off with compressed air has been replaced by other methods such as a vacuum hose (fig. 26) and portable vacuum cleaning units (fig. 27). Still another improvement in operation which greatly reduced dust dissemination was the development of a method of unit loading of bagged products (fig. 28).

It seems evident that the increased attention to dust control measures during this period resulted in a marked decrease in the dust concentrations over those found during the initial study. As indicated in table 7, however, some areas are still in need of additional dust control measures. In an industry of this type, continued observance of the dust control program and vigilance are required, otherwise excessive dust exposures are certain to arise.

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Figure 13. *Quarry truck-loading operation. Both truck and tractor cabs are completely enclosed and provided with filtered air. An air cleaning unit can be seen atop the trailer cab.*



Figure 14. *Ventilating unit in truck cab showing replaceable air filter. The filter is changed at regular int[illegible]re adequate dust control inside the cab.*



Figure 15. *Operator of carryalls in quarry wears an air supplied hood provided with clean air.*



Figure 16. *Packing station. Operator removing filled bag which is being dropped onto conveyor. In the background and shortly above to the right of the packing spout is located a small outlet approximately 4 inches in diameter attached to the ventilating [redacted] packer is provided with such an outlet which will pick up [redacted] the spout as each bag is filled.*

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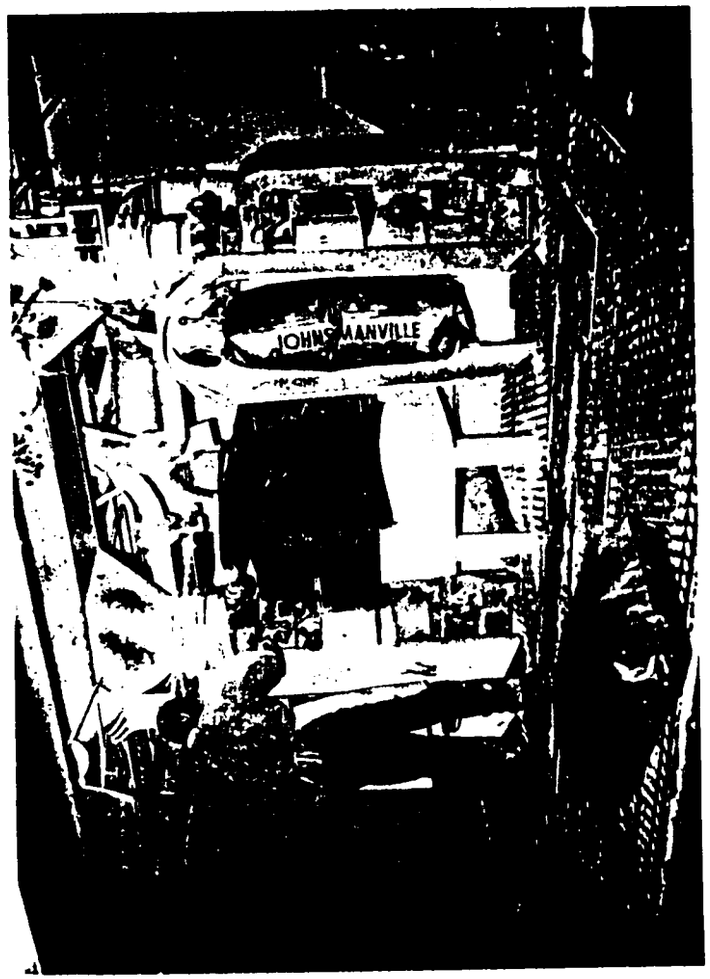


Figure 17. *Product packing operation illustrating the use of local exhaust ventilation. The annular exhaust take-off at the packing spout is not visible here. A moving belt under the floor grating catches and transports spilled product to the waste collection area, facilitating housekeeping. The worker wears a filter type respirator for added protection.*

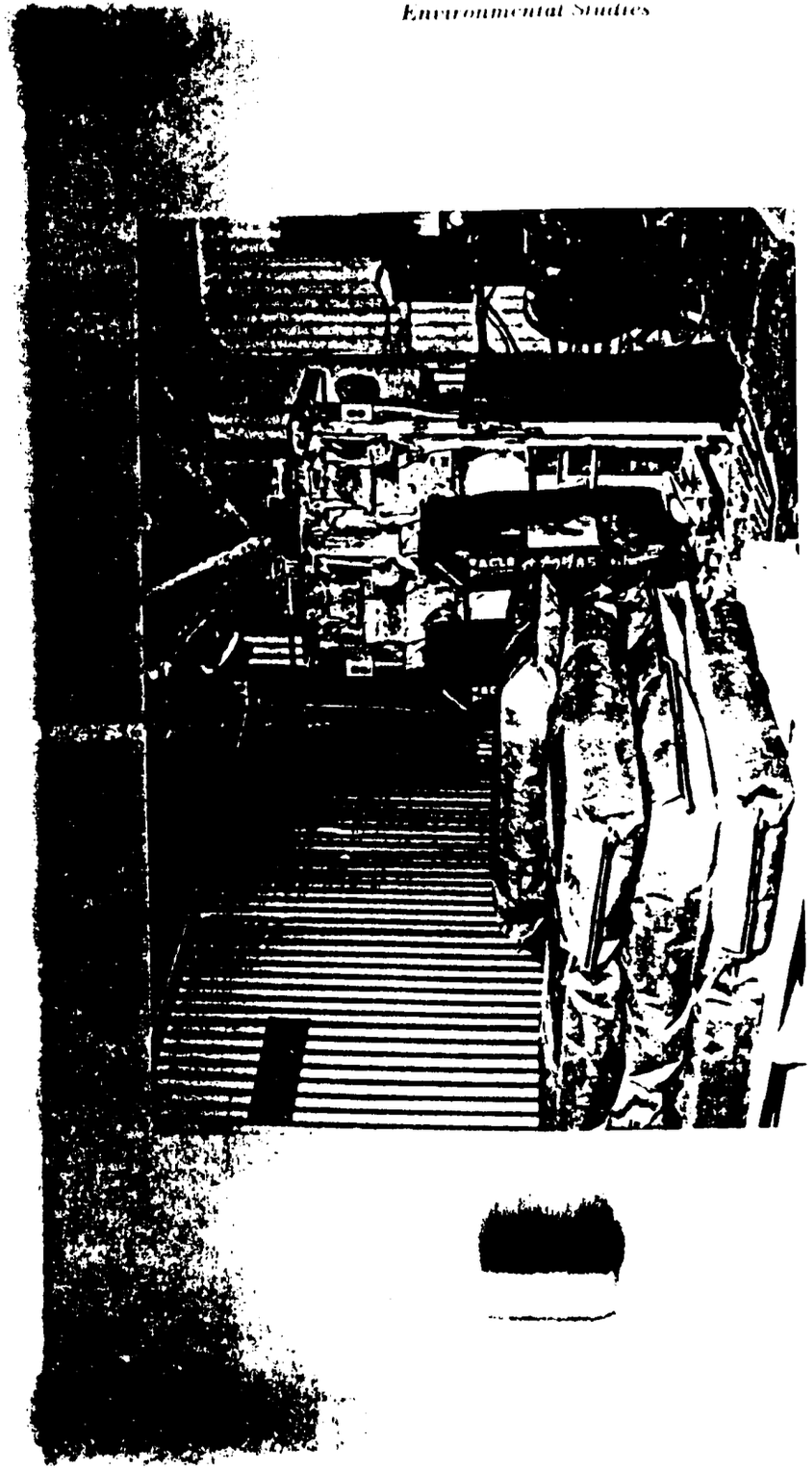


Figure 18. *Product packing station. Local exhaust ventilation is provided at each packing spout. Ductwork can be seen behind packers. Floor grating collects diatomite spilled during packing and facilitates housekeeping. Excessive air is removed from filled bags by settling under own weight on wooden pallets.*

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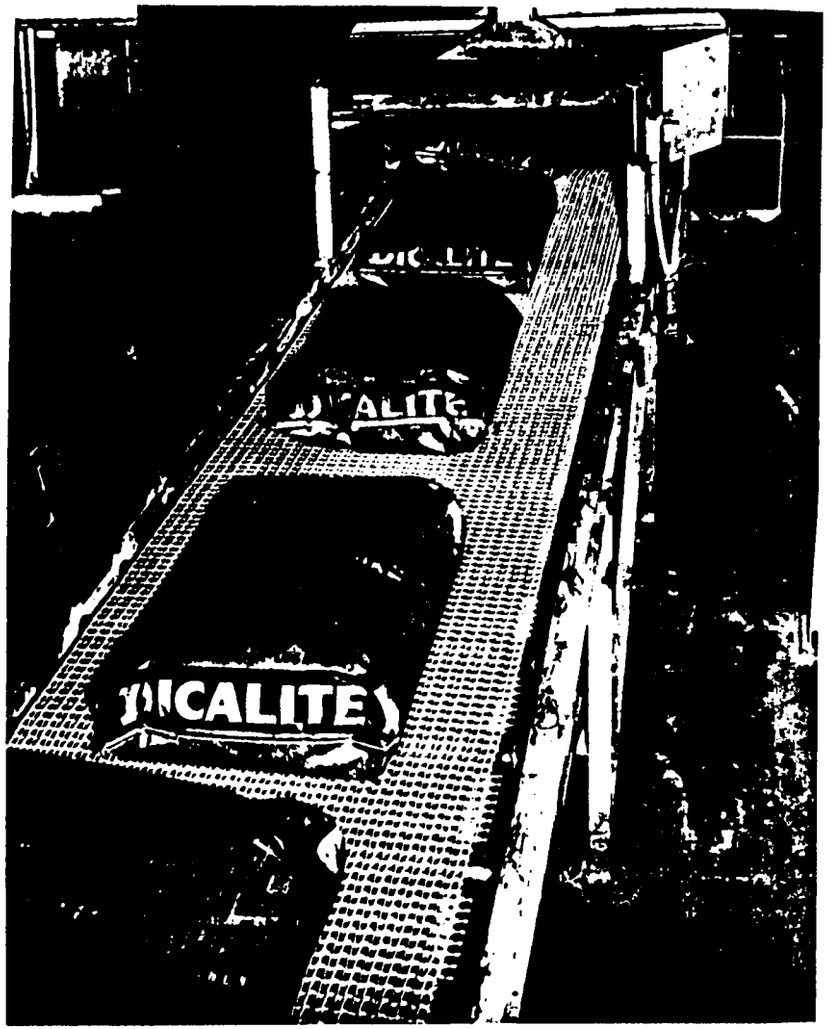


Figure 19. *Conveyor from packers to palletizing pit. Bag air cleaner is located at end of conveyer.*



Figure 20. *Palletizing press. Note louver under pallet rack, whereby suction air provides cleanliness at the station.*

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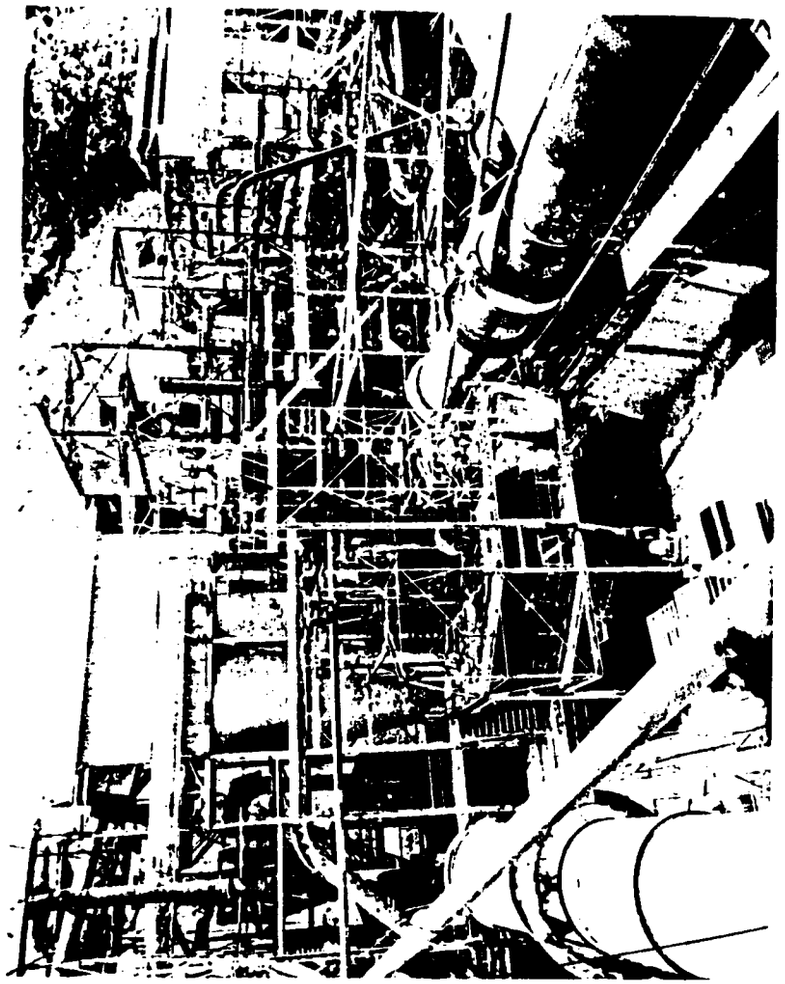




Figure 25. Processing area showing rotary kilns and classifying equipment.

Figure 26. Mill cleanup showing central vacuum system standpipes. Used for cleaning spills, structural members and mill floors.



Figure 21. *Personnel blow-off booth. In normal operation the door is closed and the dust blown off the worker is picked up by the downdraft exhaust system under the floor grating.*

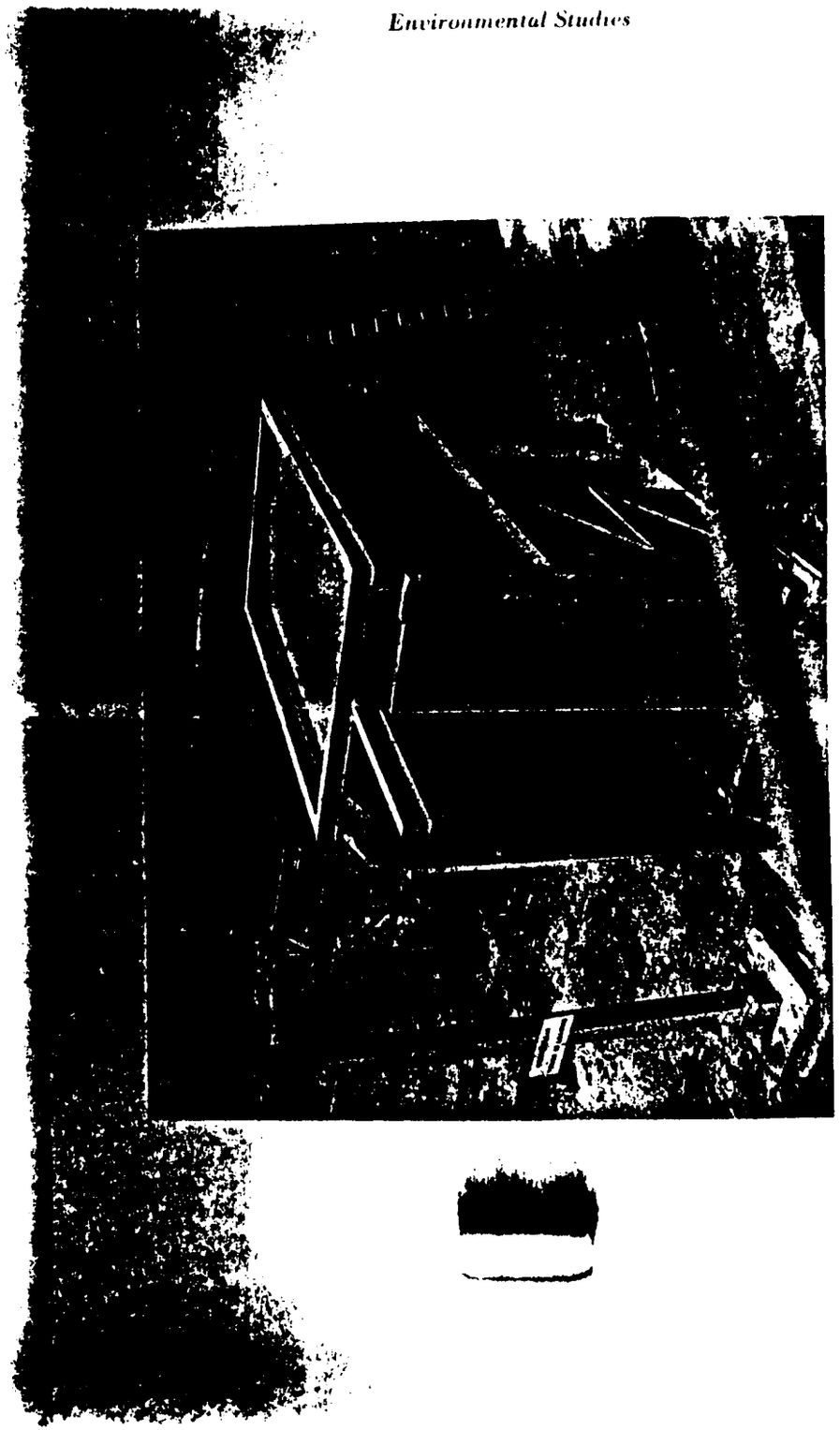


Figure 22. *Blow-off booth. Used for cleaning diatomite dust from equipment with compressed air. The doors are closed in normal operation.*

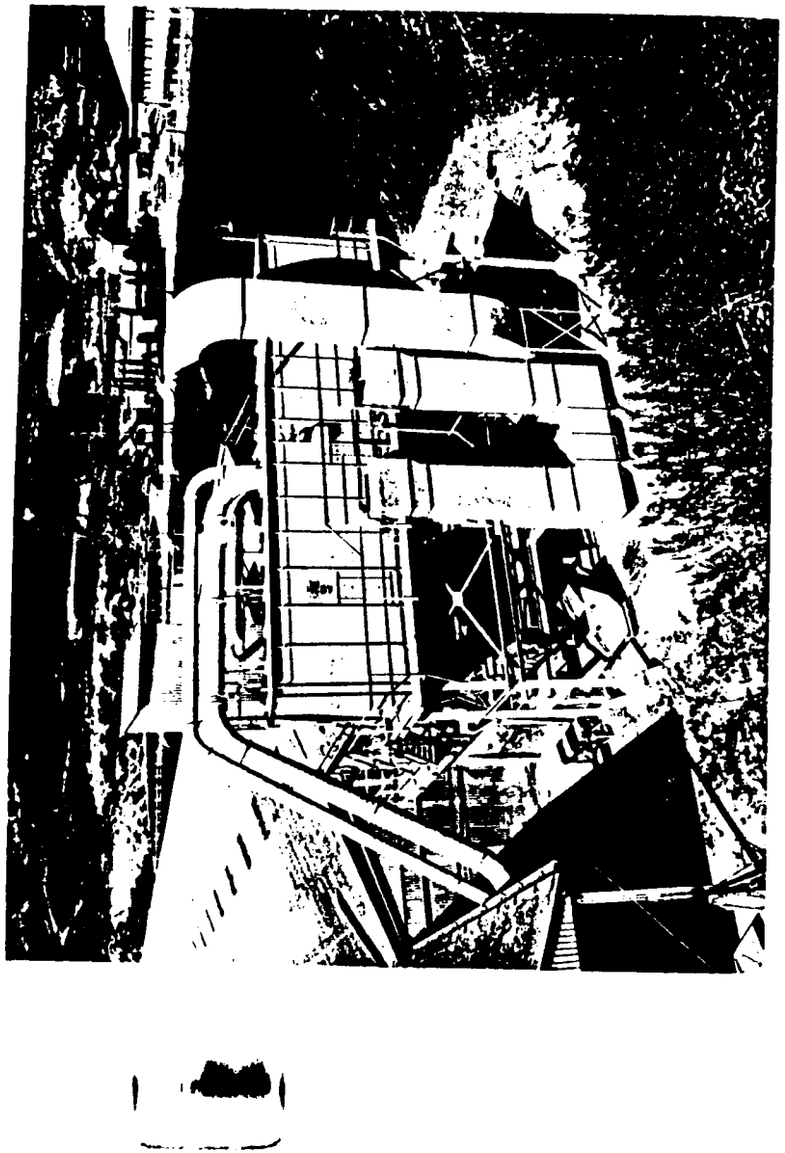


Figure 23. *Dust collection system showing completely enclosed baghouse.*

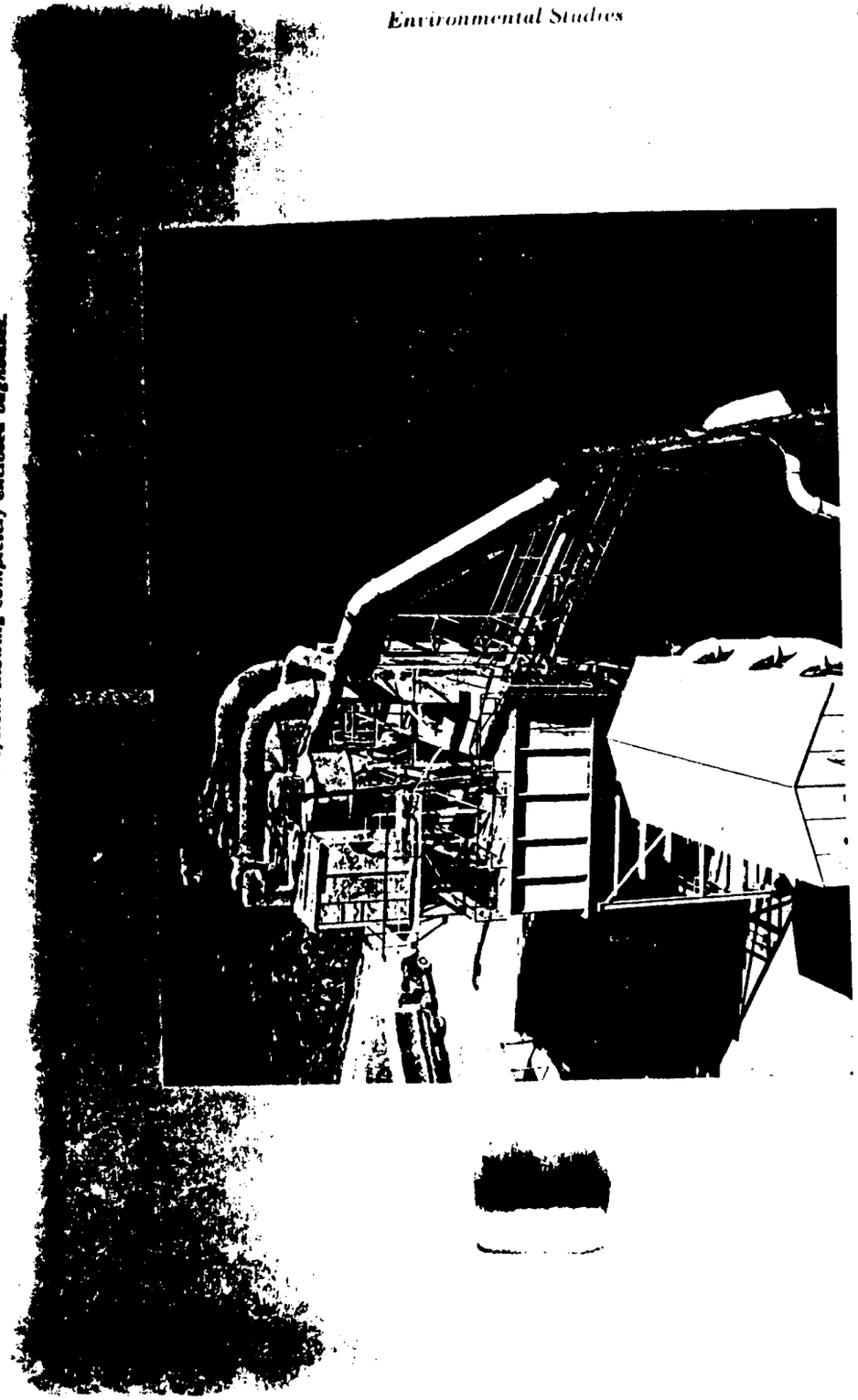


Figure 24. *Dust collection system showing cyclone collectors and completely enclosed baghouses.*

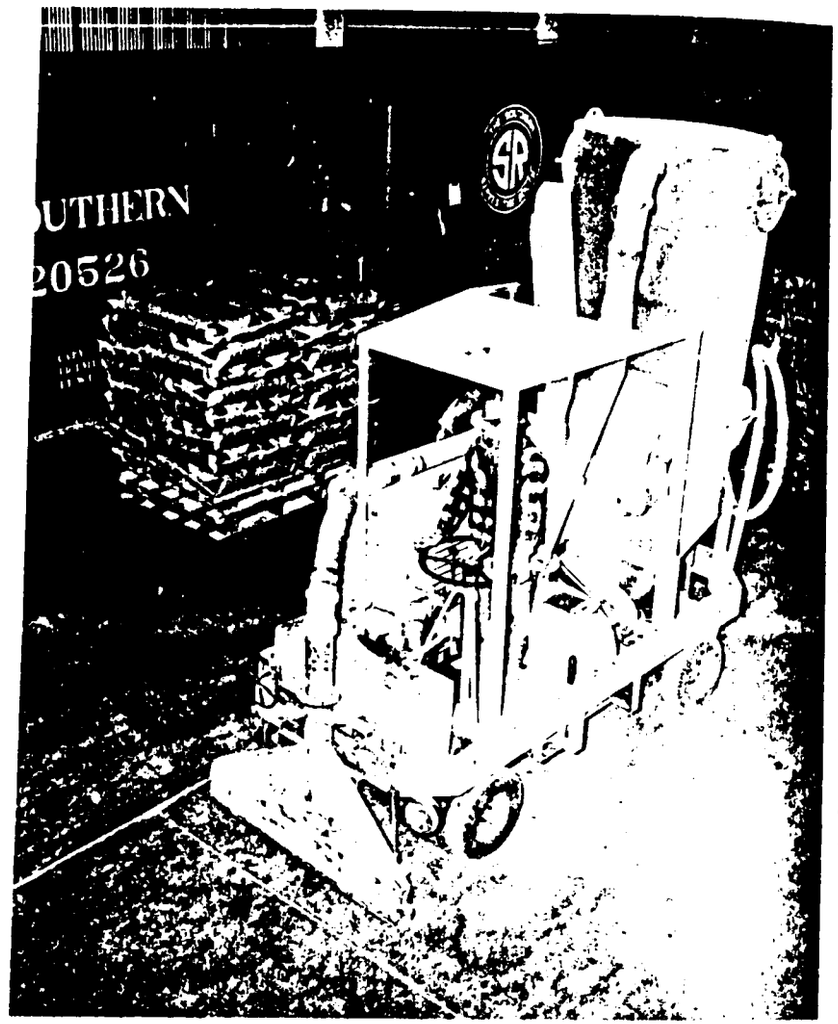


Figure 27. *Mobile vacuum cleaning unit for warehouse floor cleanup. Note the unit-loading of the freight car in the background.*

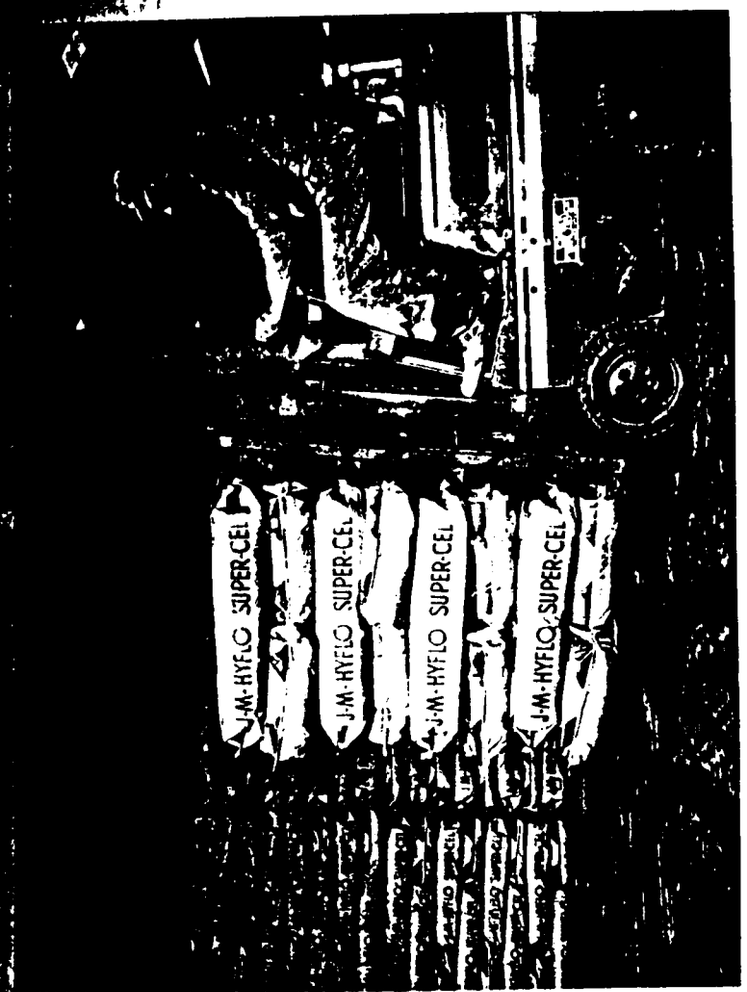


Figure 28. *Unit loading of boxcar. The prestacked bags have been lifted off the warehouse pallets and are being placed directly in the boxcar.*

Medical Studies

The major objective of the medical studies was to determine the prevalence of pneumoconiosis in the diatomite industry and to provide data for better definition of etiologic factors. It was hoped also to gain useful information relating various degrees of roentgenographic change in the lungs to clinical manifestations, physiologic changes, and laboratory findings.

Although detailed examinations were carried out, only those results which have a direct bearing on pneumoconiosis are reported at this time. For the most part, the findings described were derived from a single examination of employees. Such a study of a cross section of conditions in the working population has obvious limitations, since it does not permit estimation of the incidence of roentgenographic changes, symptoms, or altered function, nor does it permit observation of progression of the disease and the environmental factors influencing change.

Preliminary to the study, the five participating plants supplied the examining staff with case records of former employees with a diagnosis of pneumoconiosis, together with past chest films and relevant laboratory data. Lack of information on the number of individuals employed the many years during which these cases had developed, and on the number of less severe cases, made it impossible to determine accurately the incidence of pneumoconiosis in the past. Available records on absenteeism and cases compensated for disability likewise provided inadequate material for meaningful analysis.

Personnel and Facilities

Physical examinations of workers in the five plants were carried out by a field team from the Occupational Health Program of the U. S. Public Health Service, consisting of a physician, a physiologist, and a medical technician. In the study of the California plants, a physician, medical technician, nurse, and X-ray technician were assigned by the California State Department of Public Health. Medical and occupational histories, physical examinations, and skin tests were responsibilities of the physicians; the physiologist [redacted]ormed pulmonary ventilatory tests and obtained screening electrocardiograms, while the medical technicians performed laboratory studies of blood and urine.

Procedures

[redacted]d Physical Examinations

[redacted]ational histories were taken to obtain information on [redacted] and past employment in the diatomite industry and to [redacted] whether employees had been exposed previously to other [redacted] industrial hazards. Medical histories were designed to [redacted] information on current symptoms, and on past illnesses [redacted]ight have left sequelae a[redacted]e physical, radio- [redacted] or laboratory findings. Physical examinations included [redacted] of height, weight, pulse rate, blood pressure, and [redacted]ture; examination of the chest; palpation of the abdomen; [redacted]ion of the skin and mucous membranes; and examination [redacted]xtremities for edema or clubbing of fingers.

[redacted]ntgenograms

[redacted]copic chest roentgenograms were taken on 14- by 17- [redacted]ms at a target distance of 60 or 72 inches, at 200 milli- [redacted] using stationary equipment.

[redacted] Examinations

[redacted]ollowing determinations were made when possible on all [redacted]: white blood cell count, differential blood cell count based [redacted] cells, photoelectric estimation of oxyhemoglobin using a [redacted]on colorimeter, sedimentation rate by the Wintrobe [redacted], hematocrit levels, and serologic test for syphilis.

[redacted]tine urinalyses were carried out consisting of the determi- [redacted] of specific gravity, pH, albumin, and sugar together with [redacted]croscopic examination of centrifuged sediment.

[redacted]mal Tests

[redacted]mployees were given intradermal tests with tuberculin, his- [redacted]in, and coccidioidin. The tuberculin was a purified protein [redacted]ative supplied by the former Division of Chronic Diseases and [redacted]culosis of the U. S. Public Health Service; the dose was [redacted] mg. Histoplasmin was also supplied by the same Division, [redacted]lot H–42, and was used in a dilution of 1:100. Coccidioidin [redacted] obtained from the School of Public Health of the University [redacted]California, through the co[redacted]of Dr. C. E. Smith, and was [redacted] in dilution of 1:100. Re[redacted]e read 48 hours after in- [redacted]on and were classified on the basis of the extent of induration, [redacted]0 mm. being designated 1-plus (+); 10 to 20 mm., 2-plus [redacted] over 20 mm., 3-plus (+++); and severe reactions with [redacted], 4-plus (++++).

Pulmonary Function Tests

Maximal breathing capacities, vital capacities, and 3-second timed vital capacities were determined from tracings prepared with the use of a 13½ liter spirometer by the methods described by Motley (*17*). A predicted value for maximal breathing capacity was calculated for each male subject by Motley's formula (*17*, p. 264):

$$MBC = (97 - A/2)\ (BSA)$$

Where

MBC = Maximum breathing capacity in liters per minute,
A = Age of subject in years, and
BSA = Body surface area in square meters

Prior to the function tests, a screening 3-lead electrocardiogram was made by means of a direct-writing electrocardiograph.

General Characteristics of Workers Examined

Approximately 940 workers were employed by the 5 plants at the time of the examinations. Of this group, chest roentgenograms were made of 869 employees, or about 94 percent; the percents in individual plants ranged from 80 to 100. An additional group of 12 employees had physical examinations but missed chest films. For 84 of the 869 having roentgenograms, no histories and physical examinations were obtained. Thus, there were 785 employees, or 84 percent of the employment rolls, with complete examinations. Data presented in this part of the report are based either on this number or on the 738 workers who had no prior history of other dust exposures.

Sex, Race, Age, and Duration of Employment

The population studied was 94 percent male. As to race, 98.6 percent were white, of whom approximately 22 percent were of Spanish-American origin.

The age distribution which is presented in table 8 suggests that the workers examined were relatively young, with largest percents found between ages 20 and 34 years. When compared to other industries studied by the Public Health Service, the age pattern parallels that of workers examined in Utah nonferrous metal mines (*51*), but differs, as shown in table 9, from that of workers in foundry (*52*), chromate (*53*), and open hearth steel (*54*) industries.

8. *Age distribution of 785 diatomite workers examined in 1953–54*

Age (years)	Number of workers	Percent of workers	Age (years)	Number of workers	Percent of workers
	39	5.0	45–49	66	8.4
	128	16.3	50–54	34	4.3
	170	21.6	55 or over	37	4.7
	124	15.8			
	105	13.4	Total	785	100.0
	82	10.5			

Age distribution of 785 diatomite workers examined in 1953–54, and of workers in other industries studied by the Public Health Service

Industry	Number of workers examined	Percent of workers		
		Under 30 years	30–49 years	50 years or over
	785	42.9	48.1	9.0
	727	34.7	53.3	12.0
metal mines	1,937	21.8	45.9	32.3
	897	14.5	51.3	34.2
steel	350	15.4	52.0	32.6

comparison shows that the diatomite industry had the t percentage of workers under 30 years of age and smallest ntage of workers over 50 years of age. The proportions of between 30 and 49 years were fairly close for all 5 referred to.

distribution by years employed (table 10) shows that 85 nt of the employees examined had worked less than 10 years diatomite industry. The proportion of workers with less 0 years of employment in the other industries studied was smaller. In the study of nonferrous metal mines, it was 54 nt; foundry industry, 55 percent; chromate industry, 59 nt; and in the open hearth steel industry, 35 percent.

10. *Distribution by years employed in diatomite industry of 785 workers examined in 1953–54*

ars employed	Number of workers	Percent of workers	Years employed	Number of workers	Percent of workers
	273			19	2.4
	243			22	2.8
	153			785	100.0
	51	6.5	Total		
	24	3.0			

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Occupation

For purpose of analysis, occupations were classified into three categories: quarry, mill, and office and maintenance. The classification of the 785 workers into these 3 categories, as of the time of the 1953–54 study, is shown in table 11.

TABLE 11. *Occupational distribution of 785 diatomite workers as of 1953–54*

Occupation	Number of workers
Quarry	**104**
Truck driver	33
Tunnel and train worker	15
Bulldozer operator	11
Crane-shovel operator	9
Foreman and supervisor	7
Dragline operator	6
Grader operator	6
Laborer	4
Miner and driller	2
Miscellaneous	11
Mill	**311**
Packer	82
Loader	36
Brick plant worker	30
Foreman and superintendent	27
Lift truck operator	21
Laborer	14
Millman	14
Shipping department	12
Packer and loader	11
Miscellaneous (bagghouseman, dryer-kiln operator, fireman, janitor, leaderman, sackroom worker and others)	64
Office and maintenance	**370**
Office:	
Administrative and executive officeworkers	71
Laboratory worker	64
Engineering department worker	34
Miscellaneous (garageman, driver, and others)	30
Maintenance:	
Maintainer	45
Welder	28
Carpenter	21
Electrician	20
Mechanic	13
Sheet metal man	13
Miscellaneous (blacksmith, bricklayer, erector, guard, machinist, oiler, painter, plumber, rigger and others)	30
Total	784

Quarry workers numbered 104 and represented all who were engaged in the quarrying of crude diatomite, including the removal of overburden, loosening the underlying crude diatomite bed, loading the crude diatomite into trucks and hauling it to the mills. Most of the quarry workers were employed in the operation of dirt removal and transport equipment. From environmental studies, it may be concluded that the exposures of these workers were almost exclusively to crude amorphous diatomite with little or no cristobalite content.

Mill operations included the purification and treatment of the crude diatomite, and the packing and shipping of finished products. The 311 mill employees examined were engaged in operating and tending crushing and screening equipment, driers and calcining kilns, pneumatic transporting systems, product purification classification systems, packing and loading equipment, maintenance and plant housekeeping. It was in the mill that dust exposures occurred to calcined and flux-calcined diatomite containing appreciable amounts of cristobalite.

The *office and maintenance* group, which totaled 370 employees, included those with executive, administrative, or clerical duties, also those engaged in a variety of nonmill maintenance, laboratory and housekeeping assignments. In all of these, dust exposures could be regarded as definitely less than those in the quarry or mill. Because of the small size of some of the plants and the proximity of various operations, few assignments could be regarded as dust exclusive of cross exposures to various dusts. No attempts were made to calculate weighted dust exposures, due to frequent changes in work assignments, as well as to lack of qualitative and quantitative information on past dust conditions.

Pulmonary Findings

Objective data referable to the lungs were obtained from chest roentgenograms, physical examinations, pulmonary ventilatory tests, intradermal tests, and bacteriologic studies in selected cases. Additional evidence was derived from occupational histories, previous illnesses, and present symptoms as given by the workers.

Classification of Roentgenographic Abnormalties

All chest films were initially inspected by the physician members of the field team for quality control and for detection of abnormalities requiring the immediate notification of an employee's private physician. The films were subsequently filed for later interpretation by a panel of three radiologists.[1]

Smart and Anderson (7), from their study of chest films in a large number of diatomite-exposed individuals, concluded that the earliest recognizable changes were simple linear exaggerations of the finer bronchovascular pattern, which they designated as P_1. Later there was evidence of definite linear thickening, extending out to the periphery of the lung fields, but without nodulation, designated as P_2. A third linear stage, described by them as P_3, was charged on first-stage nodulation, but with poorly defined nodules seldom as discrete or well defined as in quartz silicosis." The authors described as associated with the coarser linear changes, a

[1] Dr. Waldo R. Oechali, roentgenologist, Bureau of Tuberculosis Control, California State Department of Public Health; Dr. George Jacobson, chief of radiology, Los Angeles County General Hospital, and professor of radiology, University of Southern California School of Medicine, Los Angeles, Calif.; and Dr. Armand E. Brodeur, radiologist, Division of Special Services, U. S. Public Health Service, comprised the panel that interpreted and revaluated films in this study. Subsequently, Dr. Bernard Kordan succeeded Dr. Brodeur as the Public Health Service roentgenologist on the panel.

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"cross-hatching, reticulation, or fine mottling" which simulated a ground-glass appearance but which was actually of a "lacylike character." On rare occasions was noted a nodular fibrosis, but with fuzzy ill-defined borders. More advanced stages were characterized by the development of massive opacities which in serial observations were usually preceded by diffuse, fuzzy, localized mottling. Changes consistent with compensatory emphysema, emphysematous bullae, and gross distortion of the pulmonary structures accompanied later stages.

In the current study, the panel of radiologists, after reviewing serial films in proved cases of diatomite pneumoconiosis, observing pathologic material in a number of cases, and classifying the abnormalities observed in the 869 films taken in the study, agreed that the major changes fell essentially into 2 categories.

One category included films showing fine linear or minute nodular-appearing shadows, and the other, those showing similar shadows accompanied by more extensive confluent opacities. In the initial classification of films, an attempt was made to grade separately the extent of involvement by abnormal linear and nodular opacities. It soon became apparent, from comparisons of successive interpretations, that the differentiation of the two was often impossible and that the changes were usually coexistent. In the final classification, therefore, linear and nodular manifestations were combined into one category, namely, linear-nodular changes.

In final form, the classification of films was in accordance with the following scheme:

LN_1—Slightly increased linear or linear-nodular changes, beyond those considered average or normal for the given age and suggestive of very early perivascular thickening.

LN_2—Definitely abnormal linear-nodular changes, extending over a total area equivalent to one lung field or less, in one or both lungs.

LN_3—Definitely abnormal linear-nodular changes, extending over a total area equivalent to more than one lung field. Characteristically there was a more noticeable nodular component in these.

C_1—Shadows suspicious of confluent opacities, usually superimposed on definite linear-nodular changes.

C_2—Definite confluent opacities superimposed on linear-nodular changes, the former extending over a total area less than the equivalent of three anterior rib interspaces, located in one or both lungs.

C_3—Definite confluent opacities extending over a total area equivalent to three or more anterior rib interspaces, but not greater than the equivalent of one hemithorax. A minor degree of distortion of lung and surrounding structures may be present.

C_4—Massive confluent opacities, involving an area greater than the equivalent of one hemithorax, with gross distortion of the relationships of the hili, heart, trachea, and diaphragm.



Figure 29. *Chest film interpreted as consistent with advanced pneumoconiosis with coalescence. Classified LN_3C_2.* *See Case 1, p. 78.*

all the films observed in this series, nodules were small and never so dense or discrete as those characteristic of quartz silicosis. In serial films, progression appeared to be accompanied often by an apparent increase in the profusion or concentration of these linear or minute nodular changes, than by an increase in the apparent size of nodules. In all cases with confluent opacities there was an underlying pattern of linear-nodular change, but this was sometimes minimal.

Although as a group the films presented some distinctive characteristics, the basic resemblance to other forms of pneumoconiosis, both simple and complicated, was apparent. Certain films were indistinguishable from some films seen in cases of pneumoconiosis in granite workers and coal workers.

Four examples of films classified as having coalescent changes (C_1 – C_4) are shown in figures [redacted] examples of films showing only linear-nodular changes have not been illustrated because of difficulty in satisfactory reproduction.

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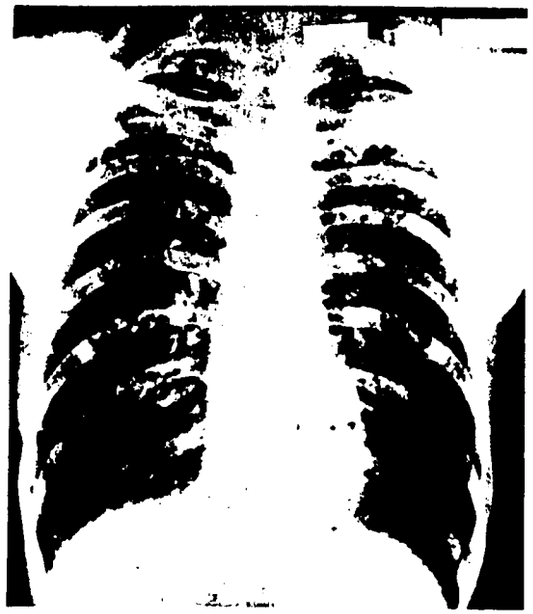


Figure 30. ***Chest film interpreted as consistent with advanced pneumoconiosis with coalescence bilaterally. Classified LN_3C_2. See Case 2, p. 79.***

Film Interpretations

Films were read independently by the 3 radiologists on 2 separate occasions, once using the tentative classification and again using the simplified classification presented above.[2] At an intermediate session, 184 films, approximately one-half of them problem cases, were given special review. Where there was disagreement in independent interpretations, conferences were held at the end of the session and a consensus was reached. In neither the initial interpretations nor in conferences was information on work history available prior to reaching a decision. In certain doubtful cases past films were used for comparison with the study films. Correlation of initial readings (prior to knowledge even of the existence of a file of previous films) with final readings, and with occupational histories, provided evidence for the objectivity of the interpr[redacted]ns.

Analysis of the several readings showed the usual intraobserver and interobserver variations, particularly apparent in the doubt-

[2] Ninety-nine films from plants studied in 1954 were re[redacted] at only one session using the final classification.

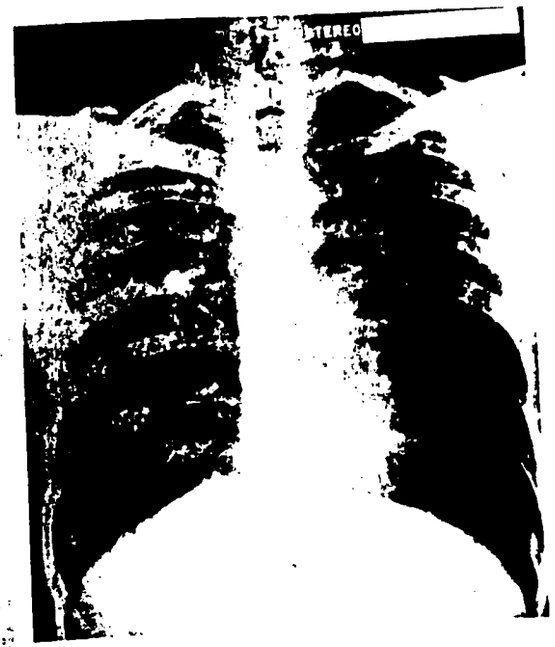


Figure 31. ***Chest film interpreted as consistent with advanced coalescent pneumoconiosis, with distortion of intrathoracic structures and basal emphysema. Classified LN_2C_4. See Case 3, p. 79.***

[redacted] categories (LN_1 and C_1). Nevertheless 518 (60 percent) of [redacted] 869 films in the series were interpreted as normal by all observers, at all sessions. Another 69 were unanimously regarded [redacted] definitely abnormal, although the degree of abnormality was [redacted]riously interpreted. Films from 231 employees did not fall [redacted]animously into any category of negative, doubtful, or positive, [redacted]nd it was these cases which led to most of the conferences of [redacted]e radiologists, leading to the final interpretations used.

In the following discussions the term "doubtful" or "doubtful [redacted]idence of pneumoconiosis" refers to films falling in category [redacted]LN_1. "Positive" or "definite" roentgenographic evidence consistent [redacted]ith pneumoconiosis implies categories LN_2 and LN_3 alone or in combination with C_1, C_2, [redacted]. "Simple pneumoconiosis" [redacted]implies linear-nodular chang[redacted] definite evidence of con[redacted]fluent lesions, namely, LN_2 or LN_3 alone, or with doubtful con[redacted]fluent shadows (C_1). "Confluent pneumoconiosis" or "confluent [redacted]ease" is limited to categories C_2, C_3, or C_4.

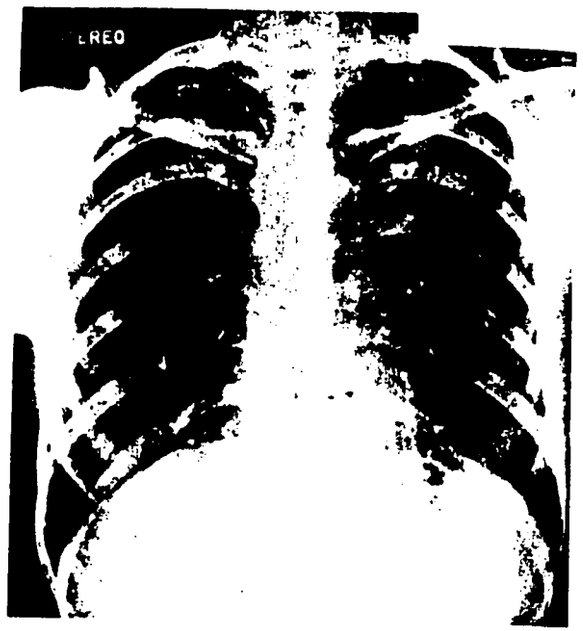


Figure 32. ***Chest film interpreted as consistent with advanced pneumoconiosis, with coalescent densities in both upper lung fields. Classified LN_2C_4. See Case 4, p. 80.***

Although the roentgenogram provides the best objective evidence available in diagnosing the dust diseases, short of tissue studies, it is recognized that diagnosis cannot depend upon film interpretation alone. Changes described in the films are considered as consistent with, but not diagnostic of, pneumoconiosis.

Films Interpreted as Abnormal

In the final classification, 713, or 82 percent, of the 869 films were interpreted as normal; 78, or 9 percent, as showing doubtful linear-nodular changes (LN_1); 29, or 3 percent, as definitely linear-nodular (LN_2 or LN_3); 17, or 2 percent, as definitely linear-nodular plus doubtful confluent (C_1); and 32, or 4 percent, as showing definite linear-nodular changes plus definite confluent shadows (C_2, C_3, or [illegible]). Thus of the entire group of films, 78, or 9 percent, were interpreted as doubtful, and another 78, or 9 percent, as having definite roentgenographic changes consistent with a diagnosis of pneumoconiosis.

As pointed out earlier, histories and physical examinations were lacking on 84 employees. Exclusion of these individuals

analysis did not significantly alter the percentages of positive films in the various groups, as shown in table 12.

Table 12. Comparison of results of interpretations of chest films of workers in the diatomite industry, taken during 1953–54, by study group

Chest film interpretation	Study group					
	All workers in study		Workers with complete examination		Workers with history of no dust exposure prior to entering diatomite industry (see text)	
	Number	Percent	Number	Percent	Number	Percent
[illegible]	713	82.0	642	81.8	612	83.0
[illegible]	78	9.0	69	8.8	58	7.9
[illegible] LN_1						
[illegible]	29	3.3	28	3.6	24	3.2
[illegible] LN_2–LN_3	17	2.0	16	2.0	16	2.1
[illegible] $LN+C_1$	32	3.7	30	3.8	28	3.8
[illegible] C_2, C_3, C_4						
[illegible]	869	100.0	785	100.0	738	100.0

[illegible] occupational histories were reviewed to identify workers who [illegible] exposures in dusty environments previous to their employ[illegible] in the diatomite industry. The last column in table 12 shows [illegible] effect of the exclusion of all individuals examined who re[illegible] prior employment involving exposure to silica dust for [illegible] year, or to other dusts for over 2 years.

The excluded workers totaled 47 (785 minus 738, see table 12) [illegible] film interpretations as follows: 30, normal; 11, LN_1; 4 as [illegible] or LN_3; and 2 as C_2, C_3, or C_4 (confluent lesions).[3] Although

[3] The 30 individuals with normal chest films who were excluded from analysis because of previous dust exposures included 11 individuals with hard rock mining experience, 4 who had worked as coal miners, 4 who had been exposed to perlite, 3 former foundry workers, and 8 with miscellaneous exposures.

The 11 exclusions in doubtful category (LN_1) were:
1. Coral dust exposure in a 21-year-old employee with only 3 months in diatomite industry.
2. 5 years in a brass foundry in an employee with only 3 months in diatomite industry.
3. 1 year of pilot plant work, with a variety of exposures.
4. 10 years of grain dust exposure.
5. 2 years of heavy cotton dust exposure in an employee with only 6 months in diatomite industry.
6. 4 years' hard rock mining.
7. 10 years as rock mason's helper and 2 years as molder's helper.
8. 6 years' hard rock mining.
9. 15 years' hard rock mining and surveying [illegible] mine.
10. 15 years as ore crusher and mule driv[illegible]
11. 8 years' grain dust exposure.

The 4 exclusions in categories LN_2 and LN_3 were:
1. 21 years as soft coal miner.
2. 4 years as hard rock miner.
3. 15 years as hard rock miner.
4. 6 years as asbestos worker

The 2 exclusions in categories C_2, C_3, and C_4 were:
1. Hard rock miner 1 year.
2. Hard rock miner 1½ years.

the abnormal films in individuals with prior exposures were not characteristic of quartz or other pneumoconiosis, they have been excluded from analyses where their inclusion might lead to erroneous conclusions.

Chest Films as Related to Duration and Type of Exposure

The relation between film interpretations and duration of employment is shown in table 13. Simple additions show that of 251 employees in the industry for 5 years or more, who had no prior exposure to other dust, 64 or 26 percent had chest films consistent with a definite diagnosis of pneumoconiosis (that is, greater than LN_1); of 109 employed 10 years or more, 45 or 42 percent had such films; of 63 employed 15 years or more, 29 or 46 percent had such films.

TABLE 13. *Interpretations of chest films of 738 workers examined in 1953–54 by duration of employment in the diatomite industry, workers with history of other dust exposures excluded*

Duration of employment (years)	Workers examined	Chest film interpretation				
		Normal 0	Doubtful LN_1	Definite		
				Simple		Confluent
				LN_2-LN_3	$LN+C_1$	C_2, C_3, C_4
	Number of workers					
Less than 1	261	253	7	1	0	0
1–4	226	214	9	1	1	1
5–9	142	102	21	10	4	5
10–14	46	21	9	7	5	4
15 or over	63	22	12	5	6	18
Total	738	612	58	24	16	28
	Percent of workers					
Less than 1	100.0	96.9	2.7	0.4	0	0
1–4	100.0	94.8	4.0	0.4	0.4	0.4
5–9	100.0	71.8	14.8	7.1	2.8	3.5
10–14	100.0	45.6	19.6	15.2	10.9	8.7
15 or over	100.0	34.9	19.1	7.9	9.5	28.6
Total	100.0	82.9	7.8	3.3	2.2	3.8

As stated earlier, the work assignments of each worker were classified as quarry, mill, or office and maintenance. Each individual's total employment in the diatomite industry was described in terms of the approximate number of years spent in

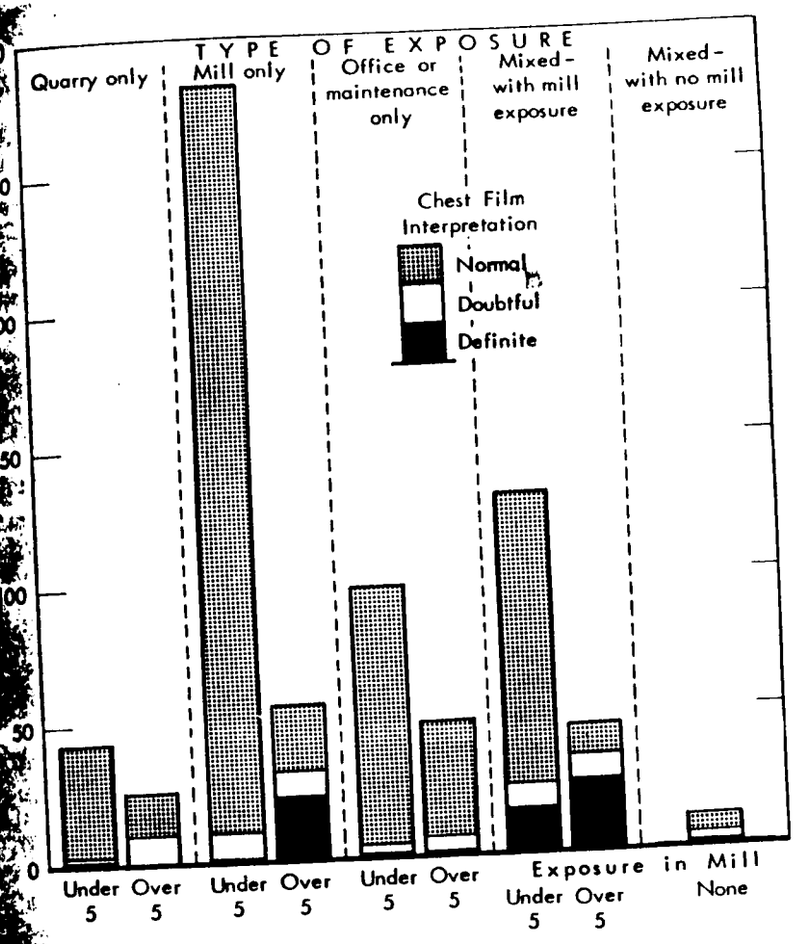


Figure 33. *Chest film interpretations classified according to type, and duration of exposure. See table 14.*

each type of activity. In table 14 and figure 33 is presented the distribution of chest film interpretations for the 738 workers examined, those workers with prior exposures to other dusts having been excluded. It is evident that nearly all definitely abnormal films are associated [redacted] employment in the mill where the workers may be exposed to calcined diatomite containing cristobalite. Forty-eight out of 101 employees whose work had included 5 or more years in the mill had roentgenographic changes definitely consistent with pneumoconiosis (LN_2 or more); 21 of these had definite confluent lesions.

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TABLE 14. *Interpretations of chest films of 738 diatomite workers examined in 1953–54 by type and duration of exposure, workers with history of other dust exposures excluded*

Type of exposure	Duration of exposure (years)	Workers examined	Chest film interpretation				
			Normal 0	Doubtful LN_1	Definite		
					Simple		Confluent
					LN_2–LN_3	$LN+C_1$	C_2,C_3,C_4
		Number of workers					
Office or maintenance only	Under 5	98	94	3	0	1	0
	5 or more	48	42	5	1	0	0
Quarry only	Under 5	43	41	1	1	0	0
	5 or more	25	15	10	0	0	0
Mill only	Under 5	283	273	9	1	0	0
	5 or more	56	24	9	10	5	8
Mixed—with mill	Under 5 in mill	130	106	9	4	4	7
	5 or more in mill	45	11	9	6	6	13
Mixed—no mill	None in mill	10	6	3	1	0	0
Total		738	612	58	24	16	28
		Percent of workers					
Office or maintenance only	Under 5	100.0	96.0	3.0	0	1.0	0
	5 or more	100.0	87.5	10.4	2.1	0	0
Quarry only	Under 5	100.0	95.4	2.3	2.3	0	0
	5 or more	100.0	60.0	40.0	0	0	0
Mill only	Under 5	100.0	96.4	3.2	.4	0	0
	5 or more	100.0	42.9	16.0	17.9	8.9	14.3
Mixed—with mill	Under 5 in mill	100.0	81.5	6.9	3.1	3.1	5.4
	5 or more in mill	100.0	24.5	20.0	13.3	13.3	28.9
Mixed—no mill	None in mill	100.0	60.0	30.0	10.0	0	0
Total		100.0	82.9	7.8	3.3	2.2	3.8

[1] A 70-year-old man, employed only 1¼ years with no known previous exposure. Because of short and nondusty exposure, almost certainly not diatomite pneumoconiosis.
[2] This employee worked 9 years in laboratory.
[3] Unexplained changes in an employee exposed for only 6 months and not regarded as due to diatomite pneumoconiosis.
[4] This employee had a history and physical signs consistent with rheumatic heart disease.

Despite the division of exposures at the 5-year point, it should not be assumed that 5 years is in any sense a critical period of exposure. Several workers were observed with definite roentgenographic evidence of pneumoconiosis who had from 1 to 3 years' exposure in the mills with subsequent work in the quarry, maintenance or office. Workers with unusual susceptibility or subjected to very heavy exposures apparently may show roentgenographic changes in less than 5 years. On the other hand, a number of employees were found who had worked in the mills

for many more than 5 years and whose films were unanimously interpreted as normal.

Workers whose employment was confined to the quarry exhibited practically no abnormal films, although prolonged work in the quarries was associated with a high proportion of doubtful linear-nodular changes (LN_1). This evidence is in agreement with the earlier observations by Vigliani and Mottura (*5*), and Smart and Anderson (*7*), that risk of pneumoconiosis is relatively low in workers whose exposure is confined to crude diatomite as compared to those exposed to calcined material. It is unwarranted, however, to regard the natural material as innocuous since it is not known to what extent quarry exposures may contribute to the pulmonary reactions resulting from dusts of greater biologic activity. Moreover, the average and the peak concentrations to which the quarry workers were exposed in the past were not necessarily of the same order of magnitude as those in the mill environment.

Roentgenographic Changes and Age

In table 15 the chest film interpretations of the diatomite workers are classified according to age of worker. Although the age distribution reflects in large measure the duration of exposure associated with various degrees of roentgenographic change, it is of interest to note the large number of positive films in the age groups 35 to 44 years and 45 to 54 years.

Chest Films of Workers Exposed to Fresh Water Diatomite

Two of the plants studied, with 89 workers on whom chest films and examinations were made, processed diatomite of fresh water origin; the other 3 plants with 696 workers handled only salt water diatomite. Because it has been suggested that the two types of diatomite may differ in their biologic effect, data were analyzed to determine if any such difference could be established. Among workers employed in fresh water diatomite plants, there were 6 with doubtful linear-nodular (LN_1) changes, 7 with definite changes (4 with LN_2 or LN_3, 2 with LN_2 or LN_3 plus C_1 and 1 with definite confluent lesions). In all these cases, workers with previous dust exposures had been excluded. These figures indicate that changes consistent with pneumoconiosis may occur in workers exposed to fresh [redacted]tomite. Only 46 workers in the fresh water diatomite plants had been employed for over 5 years, and only 15 for over 10 years. Despite the fact that only one case with definite confluent lesions appeared among this group, no conclusions are warranted as to a difference in reactivity of diatomite based on its source of origin.

TABLE 15. *Interpretations of chest films of 738 diatomite workers examined in 1953–54 by age, workers with history of other dust exposures excluded*

Age (years)	Workers examined	Chest film interpretation				
		Normal 0	Doubtful LN_1	Definite		
				Simple		Confluent
				LN_2–LN_3	$LN+C_1$	C_2, C_3, C_4
	Number of workers					
Under 25	166	161	2	2	0	1
25–34	283	259	17	4	2	1
35–44	173	133	13	11	8	8
45–54	86	46	20	6	3	11
55 or over	30	13	6	1	3	7
Total	738	612	58	24	16	28
	Percent of workers					
Under 25	100.0	97.0	1.2	1.2	0	0.6
25–34	100.0	91.5	6.0	1.4	.7	.4
35–44	100.0	76.9	7.5	6.4	4.6	4.6
45–54	100.0	53.5	23.2	7.0	3.5	12.8
55 or over	100.0	43.4	20.0	3.3	10.1	23.3
Total	100.0	82.9	7.8	3.3	2.2	3.8

Case Histories

Four films, reproduced as figures 29–32, were previously referred to in the discussion of the classification of roentgenographic abnormalities. To make the films more meaningful and increase the clinical value of the study, a résumé is given of the case histories associated with the films.

CASE 1.—A 48-year-old white married male, born in Texas, and employed in the diatomite industry for 12 years. First worked as a packer, 1½ years; then as transporter of crude diatomite for 4 years, operated quarry equipment for 6 years. Work history classified as 10 years in quarry and 2 years in mill. Smokes about 20 cigarettes per day. History of pneumonia in 1950. Only complaints at time of survey were intermittent palpitation and of moderate exertional dyspnea, although he felt "his wind is about as good as other sedentary individuals of his age." Physical findings essentially normal except for diminished breath sounds over right upper lobe posteriorly, with fine inspiratory rales. Sedimentation rate, 11; hematocrit, 48 percent; serologic test for syphilis, negative; hemoglobin, 14.8 grams percent; white blood

cell count, 9,000, with normal differential count. Urinalysis normal. Skin tests with tuberculin (0.0001 mg. PPD and 0.005 mg. PPD), histoplasmin and coccidioidin, negative. Maximal breathing capacity, 164 liters per minute, or 111 percent, of predicted 148; 3-second timed vital capacity, 4.33 liters, or 92 percent, of total vital capacity of 4.7 liters. Chest film, figure 29, interpreted as consistent with advanced pneumoconiosis with coalescence. Classified LN_3C_2. Followup films at 2 years interpreted as showing no progression.

CASE 2.—A 46-year-old married white male, born in Colorado and employed in the diatomite industry for 26 years, with work history classified as being approximately 13 years quarry and 13 years mill. Relatively nondusty work for 9 years. History of pneumonia in 1941. Febrile disease in 1949 for 4 months at which time he was told his "lungs were bad but negative for tuberculosis." Hemoptysis twice 1950. Symptoms at time of survey included palpitation, mild exertional dyspnea for 6 to 8 years, occasional chest pain. No abnormal physical findings except for a few coarse inspiratory rales in apices and below clavicles anteriorly. Sedimentation rate, 26; hematocrit, 44 percent; hemoglobin, 14.4 grams percent; serologic test for syphilis, negative; white blood cell count, 8,800 with 64 percent polymorphonuclear neutrophils, 21 percent lymphocytes, 7 percent monocytes, 5 percent eosinophils, and 3 percent basophils. Urinalysis normal. Maximal breathing capacity, 99 liters per minute, or 76 percent, of predicted 130; 3-second timed vital capacity, 2.98, or 81 percent, of total vital capacity. Tuberculin test with 0.0001 mg. PPD, negative, with 0.005 mg. PPD positive; coccidioidin and histoplasmin tests, negative. Bacteriologic studies negative for tubercle bacilli. Chest film, figure 30, interpreted as consistent with advanced pneumoconiosis with coalescence bilaterally. Classified LN_3C_2. Followup film 2 years later interpreted as showing no progression.

CASE 3.—A 32-year-old married white male, born in Wisconsin, was first employed in the diatomite industry 12 years before the survey, with no previous dusty employment. He had mixed exposures, with 1 year handling calcined products, 6½ years in the laboratory, and 5 years in the mill. He was a nonsmoker. Past history included bronchitis and questionable pleurisy in 1935 following a rib fracture. Renal stones 1948. No shortness of breath and no other respiratory symptoms except slight pain in left lower chest on deep inspiration. Physical examination was described as normal except for "double inspiratory breath sounds" over left lower lobe posteriorly. Laboratory studies included

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sedimentation rate of 5, hematocrit 47 percent, hemoglobin 14.4 grams percent, serologic test for syphilis negative. White blood cell count 5,700 with normal differential. Urinalysis normal. Skin tests with tuberculin (0.0001 mg. and 0.005 mg. PPD), coccidioidin and histoplasmin, negative. Maximal breathing capacity 159 liters, or 95 percent, of predicted 169 liters; 3-second timed vital capacity 5.35, or 97 percent, of total 5.49 liters. Chest film, figure 31, interpreted as consistent with advanced coalescent pneumoconiosis, with distortion of intrathoracic structures and basal emphysema. Classified LN_2C_4. Followup film 2 years later interpreted as consistent with progression of coalescence.

CASE 4.—A 24-year-old single, Spanish-American female, born in Arizona, was first employed in the diatomite industry 7½ years before the survey. She worked in the mill area with exposure to calcined diatomite products for 7 years (4 years without a respirator) and was then transferred to office work. Work history classifed as 7½ years total, with 7 years mill and one-half year office. Does not smoke. Only complaint is mild dyspnea for 1 year if works too hard or walks too fast. No positive physical findings. Laboratory data included sedimentation rate of 20, hematocrit of 43 percent, serologic test for syphilis negative, hemoglobin 12.4 grams percent, white blood cell count 9,200 with normal differential. Urinalysis normal. Skin tests with tuberculin (0.0001 mg. and 0.005 mg. PPD), histoplasmin and coccidioidin, negative. Maximal breathing capacity 86 liters; 3-second timed vital capacity 2.98 liters, or 94 percent, of total vital capacity of 3.16 liters. Chest film, figure 32, interpreted as consistent with advanced pneumoconiosis, with coalescent densities in both upper lung fields. Classified LN_2C_4. Followup: Employment terminated 3 years after survey. Film taken at this time was interpreted as showing slight progression. The coalescent lesions showed increased density and evidence of beginning calcification.

Results of Intradermal Tests

To secure evidence bearing upon the possible relation of infection and the development of pulmonary changes in individuals exposed to diatomaceous earth, workers were tested for intradermal sensitivity to tuberculin (0.0001 mg. PPD), histoplasmin, and coccidioidin.

In table 16 are summarized the results of the tests which were performed and read in 741 of the 785 workers who had chest films and physical examinations. Tests were either not performed or not read in the remaining 44 subjects in this group.

TABLE 16. *Positive reactions to intradermal tests with tuberculin, histoplasmin, and coccidioidin in relation to interpretations of chest films of 741 diatomite workers examined in 1953–54*

Chest film interpretation	Workers tested	Tuberculin		Histoplasmin		Coccidioidin	
		+	++ or more	+	++ or more	+	++ or more
		Number of workers tested with positive reactions					
Normal 0	603	78	115	70	103	36	35
Doubtful LN_1	66	9	18	5	14	6	5
Definite:							
Simple LN_1–LN_3	26	5	7	5	2	2	1
Simple $LN+C_1$	16	3	4	4	2	1	2
Confluent C_2, C_3, C_4	30	6	7	3	4	1	2
Total	741	101	151	87	125	46	45
		Percent of workers tested with positive reactions					
Normal 0	603	12.9	19.1	11.6	17.1	6.0	5.8
Doubtful LN_1	66	13.6	27.3	7.6	21.2	9.1	7.6
Definite:							
Simple LN_1–LN_3	26	19.2	26.9	19.2	7.7	7.7	3.8
Simple $LN+C_1$	16	18.8	25.0	25.0	12.5	6.3	12.5
Confluent C_2, C_3, C_4	30	20.0	23.3	10.0	13.3	3.3	6.7
Total	741	13.6	20.4	11.7	16.9	6.2	6.1

Most of the positive reactions to histoplasmin and coccidioidin could be explained by previous residence in areas where sensitivity to these antigens is known to be prevalent.

Although there was a higher proportion of positive tuberculin reactions (++ or more) in workers with abnormal chest films (23.3 to 27.3 percent) when compared with those with normal films (19.1 percent), this is of doubtful significance (P = 0.05 to 0.10). Even this difference disappears when the series is corrected for age. Two-thirds of the normal films were of employees under 35 years of age, of whom 16.1 percent showed definite positive tuberculin reactions, while one-third was from the group aged 35 and over, with 26.4 percent showing positive reactions. Abnormal films, on the other hand, occurred preponderantly in those 35 years old and over. When age corrections are applied, the number of positive tuberculin reactions (++ or more) expected in the 138 workers with abnorm[illegible] 33.8 compared with the 36 that actually occurred.

It is of great interest to note that only 23.3 percent of the workers with definite confluent lesions (C_2, C_3, C_4) had positive

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(++ or more) reactions to tuberculin, with an additional 20 percent having questionable (+) reactions. The group did not differ significantly in the proportion of positive reactions from those with doubtful LN_1 or definite LN_2 —LN_3, or C_1 changes, nor when age adjustments were made, from those with films interpreted as normal.

Results of the skin tests do not suggest any relation between tuberculosis, histoplasmosis, or coccidioidomycosis and the roentgenographic changes found in these workers.

Other Studies for Tuberculosis

Additional attempts to secure evidence of tuberculosis were carried out in 28 out of 30 employees in whom confluent shadows were found.[4] Twelve of the 17 who were negative to intermediate strength tuberculin (0.0001 mg. PPD) were given tests with second strength tuberculin (0.005 mg. PPD). Nine again gave negative responses, while positive reactions were obtained in 3.

In 12 of the 16 workers with confluent lesions and 1-plus or greater reactions to tuberculin, attempts were made to culture tubercle bacilli from sputum and gastric contents. Twenty-four-hour sputum samples were obtained from 10 employees and fasting gastric contents were secured from all 12. Upon culture, the specimens were reported negative for tubercle bacilli. Sputum and gastric samples from an additional group of three employees with doubtful confluent lesions were cultured and reported negative.

Obviously single gastric and sputum samples are inadequate to rule out tuberculosis in any individual case, but the high proportion of negative tuberculin reactions and the completely negative results of cultural tests are strong evidence that these lesions do not represent active tuberculous infections. Because the pathogenesis of tuberculosis is so often atypical in the pneumoconiotic, it is hazardous to draw more sweeping conclusions. Caldwell (*55*) in 1958 reported a number of proved cases of tuberculosis in individuals with confluent diatomite pneumoconiosis, and Smart and Anderson (*7*) similarly described such cases in their series.

One cannot draw conclusions as to the incidence nor the course of tuberculosis in subjects with diatomite pneumoconiosis on the basis of a cross-section survey. The medical programs of the

[4] Retesting these subjects and obtaining sputum and gastric contents for culture were carried out by a physician from the Bureau of Tuberculosis and a physician from the Bureau of Adult Health of the California State Department of Public Health. Bacteriologic procedures were performed by the Division of Laboratories of the same health department.

industry include frequent chest films and bacteriologic studies when indicated. Thus, workers with active tuberculous infections would presumably be detected and would not appear in the study group.

Physical Signs and Chest Film Interpretations

Physical examination of the chest, as carried out in the survey, was not of consistent value in the detection of the pulmonary abnormalities revealed by the roentgenogram. Even in individuals with definite confluent lesions, 57 percent were reported as exhibiting no abnormal physical findings. In those with definite linear-nodular changes but without confluent shadows, 72 percent were reported as normal by physical examination. The signs most frequently reported were altered breath sounds (diminished, bronchial or bronchovesicular breath sounds dependent upon types of lesion) and occasional inspiratory rales and expiratory wheezes. Only one individual was found with severely clubbed fingers, and from his history this was apparently congenital. Five individuals, and this included the subject with most severely impaired pulmonary function, had slight clubbing of the fingers.

Respiratory Symptoms and Ventilatory Function

Physical examination records of employees with definitely abnormal chest films and without history of previous exposure to silica or other dusts were reviewed with respect to symptoms referable to the respiratory tract and the results of pulmonary ventilatory tests. Twenty-three cases with LN_2 and LN_3 lesions, 14 with doubtful confluent lesions (C_1), and 28 with definite confluent lesions (C_2, C_3, and C_4) were regarded as appropriate cases for analysis.

Of the 23 employees with definite linear-nodular changes but with no suggestion of confluent changes, 13 had no respiratory complaints. Four had only minor complaints, such as morning cough and fleeting chest pains; 4 others had mild exertional dyspnea, with or without palpitation, occasional cough, and mild chest pain; and 2 had moderate exertional dyspnea. One of the last had roentgenographic evidence of bullous emphysema. Three of the 23 had maximal breathing capacities slightly below 80 percent of their predicted values (maximal breathing capacities were 79 percent, 77 percent, and 74 percent), and 1 had a 3-second timed vital capacity of 75 percent of total vital capacity. None of these borderline function test results was from those who had symptoms; the employee with bullous emphysema was not included in the physiologic tests.

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Similar analysis of 14 subjects with questionable confluent lesions (C_1) revealed that 11 were free of respiratory symptoms, although all had definite linear-nodular changes. One had a nonproductive cough and two had mild exertional dyspnea. All had maximal breathing capacities above 80 percent of expected values, and only 1 had a 3-second timed vital capacity below 80 percent.

Of 28 employees with definite confluent lesions, 11 had no respiratory symptoms. Five complained of mild exertional dyspnea, 4 of moderate dyspnea, and 1 of severe dyspnea. Six had complaints of cough. There were scattered complaints of chest pain, hoarseness, and wheezing. The individual with severe dyspnea had had this symptom for 4 years; he also complained of severe productive cough, which had been greatly improved by treatment, including bronchodilator drugs begun 1½ years before the study.

Maximal breathing capacity or timed vital capacity was below 80 percent of predicted values in 13 of the 28 individuals with confluent lesions. The maximal breathing capacity was low in 5 workers; the timed vital capacity low in 4 workers; and in another 4 workers both tests were low. In the worker with severe dyspnea, maximal breathing capacity was only 23 percent of predicted, and 3-second timed vital capacity was 57 percent of total vital capacity.

In general, symptoms and pulmonary ventilatory tests correlated poorly with roentgenographic findings except in the most severely involved cases with confluent lesions. Only in the group with definite confluent lesions did an appreciable number of individuals show impaired ventilatory function by the methods and criteria applied, when compared with controls of the same age chosen at random from those with negative films. Analysis of the results of pulmonary function tests in those with normal films showed no impairment correlated with increasing exposure beyond changes to be expected with increasing age.

To secure more information on possible changes in function associated with the inhalation of diatomite, a group of approximately 150 workers in the study was selected, on the basis of age, exposure, history, and chest films, for more intensive study under independent auspices at the University of Southern California. Motley (*18*) has reported findings on the first 30 such subjects examined and has compared the results with those in 20 other patients with diatomite pneumoconiosis who were studied because of suspected impairment. While some of the study subjects showed evidence of reduced ventilatory function, the reduction in the subjects selected from the present study group was far less than in other cases seen for evaluation of suspected disability, in some of whom there was severe emphysema and far-advanced impairment of function. This confirms the caution necessary in appraising the full clinical significance of pneumoconiosis from a sample of people actively at work. Equal caution is necessary in drawing conclusions from those who seek medical care since such workers do not adequately represent those who remain free of symptoms and lead an active life despite roentgenographic evidence of extensive pneumoconiosis.

Followup Observations

To obtain information on any ensuing radiographic changes in diatomite workers for correlation with dust exposures, followup observations at 2-year intervals were planned as part of the overall study. These followup observations consist of a review of chest films of workers with over 2 years of employment whether they are still employed or have left the diatomite industry, and also periodic analyses of dust concentrations routinely submitted by the plants. Workers who have left the industry are traced by the State health department which then arranges for the taking of chest films either during community surveys or through local health agencies.

The first of a series of the 2-year followup studies covered 1955–56 and the results are presented here. A total of 375 chest films have been reviewed. These films were from 2 of the plants which employed 585, or about 75 percent of all the workers examined in the original 1953–54 study. The 375 films, moreover, represent practically all of the workers who were still employed. The followup films were reviewed by the same radiologists who participated in making the original interpretations. Each film was interpreted according to the classification developed for this study. The film was then compared with the original study film and an opinion was reached as to whether or not any change had occurred in the intervening 2-year period. Of the 375 films reviewed, 19 were regarded as showing progression, as summarized in table 17. Only 1 of 284 cases formerly examined in the study and reported as normal was now classified as definitely positive, and only 1 of 40 cases formerly called doubtful was now interpreted as positive. The changes observed in definitely positive cases are of less significance in appraising current dust hazards, since roentgenographic evidence of progression may occur in well-developed pneumoconiosis in the absence of continued dust exposures. Enough evidence is not available from the few individuals, who have terminated employment and have been traced, to state how often this may be expected in diatomite pneumoconiosis.

These observations are encouraging but should not be considered final since they are based on only a 2-year followup period.

TABLE 17. *Summary of chest films of diatomite workers interpreted as showing progression between initial study in 1953–54 and followup in 1955–56, based on 375 workers who continued at their employment*

1953–54 study		Number of workers with chest films showing progression in 1955–56				
				Definite		
Chest film interpretation	Number of workers	Total	Doubtful LN_1	Simple		Confluent
				LN_1-LN_2	$LN+C_1$	C_2,C_3,C_4
Normal 0	284	4	3	1	0	0
Doubtful LN_1	40	1	0	1	0	0
Definite:						
Simple LN_1-LN_2	22	4	0	0	1	3
Simple $LN+C_1$	7	2	0	0	1	1
Confluent C_2,C_3,C_4	22	8	0	0	0	8
Total	375	19	3	2	2	12

Summary and Conclusions

Environmental Findings

A review of past operating procedures, technologic development in the industry, and available dust concentration data indicated that dust exposures in the diatomite industry in the past were probably severalfold greater than they were during the study of the industry in 1953–54.

The initial study of five processing plants in 1953–54 provided baseline data on the concentrations, and chemical and physical characteristics of the dusts encountered for subsequent observations in the industry. The data obtained indicated:

1. The crude diatomite in the plants studied was essentially amorphous silica. It contained less than 5 percent quartz and only traces of cristobalite and tridymite.

2. The high-temperature, straight-calcined diatomite parent material had a cristobalite content of about 15 percent for main product and 21 percent for baghouse product; for flux-calcined parent material, the cristobalite content was about 49 percent for main product and 61 percent for baghouse product. Only traces of cristobalite were found in the low-temperature, straight-calcined product. Tridymite was found in trace amounts only in any of the diatomite products.

3. The source of the crude diatomite, whether of salt or fresh water origin, did not appear to influence the percent of cristobalite found in the finished products or their airborne dust.

4. The airborne mill dusts were generally of a uniform size regardless of product and had a median size of about 1.1 microns. The size distribution of the dust favored maximum retention when inhaled.

5. The airborne dust concentrations encountered were generally excessive for dusts with high crystalline silica content.

Environmental followup studies made of the 5 plants approximately 1 year and 2 years after the initial study showed that marked improvement had been made in lowering the dust concentrations. However, some areas were still in need of additional dust control measures.

The nature of the products, and operations in processing diatomite are such as to favor major dust dispersion. A continued and strict adherence to a comprehensive dust control program is essential in maintaining dust concentrations at safe levels.

W. Clark Cooper and Lewis J. Cralley, Pneumoconiosis in Diatomite Mining and Processing (1958)
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Medical Findings

1. Roentgenographic examination of 869 diatomite workers showed changes interpreted as consistent with a diagnosis of pneumoconiosis in 9 percent, while doubtful changes were found in an additional 9 percent.

2. When workers with previous dust exposures or missing occupational histories were excluded, roentgenographic findings consistent with a presumptive diagnosis of diatomite pneumoconiosis were found in the same percentage (9 percent), and doubtful findings in 8 percent.

3. Abnormal films were positively correlated with duration of employment in the diatomite industry. Of 251 workers employed 5 years or more and who had no prior dust exposure, 64, or 25 percent, had chest films consistent with a diagnosis of pneumoconiosis.

4. The prevalence of abnormal chest films was especially high in employees in the mills. Of those employed in the mills for 5 or more years, approximately one-half (48 out of 101) had films consistent with a diagnosis of pneumoconiosis. The mill dusts contained a high percent of cristobalite.

5. Exposures in the quarries were associated with a lower proportion of abnormal films; none of 25 employees who had worked there exclusively for over 5 years had a positive film, but 40 percent showed doubtful linear-nodular changes. The dust in the quarries was essentially amorphous silica.

6. There was no evidence to indicate that tuberculosis, histoplasmosis, or coccidioidomycosis was related to the development of roentgenographic changes in the employees studied. Limitations of the survey did not permit the drawing of conclusions as to the incidence and the course of tuberculosis in workers exposed to diatomite dust.

7. Pulmonary signs and respiratory symptoms correlated poorly with roentgenographic changes, except when there were massive confluent lesions.

8. Workers with advanced confluent lesions showed reduced pulmonary ventilatory function in some instances. Those with only linear-nodular changes displayed no consistent pattern of disturbed function.

9. The extent and severity of pneumoconiosis, as evidenced by roentgenographic changes, appeared to correlate with cristobalite content of the dust and the length of exposure. In general, exposure to dust with high cristobalite content elicited severe responses in relatively short periods of exposure. In contrast, the response to the amorphous diatomite was much milder and required relatively long periods of exposure.

10. Followup observations in 2 plants, in which 375 films were reviewed of employees with 2 years' additional exposure following the survey, revealed evidence of progression to a positive category in only 2 cases previously called negative or doubtful. Fourteen previously interpreted as positive were described as showing slight to moderate progression.

Recommendations

Although data are still not available upon which to base final recommendations for maximal allowable concentrations, present evidence warrants that atmospheric exposures to cristobalite-containing dust be kept under 5 million particles per cubic foot of air as determined by standard light field counting procedures.

Atmospheric exposures to amorphous silica dust should be kept under 20 million particles per cubic foot of air, based on good engineering dust control practices, until additional data are available to define biologic activity. High-level exposure to amorphous or crystalline silica, even though brief and intermittent, should be avoided.

Dust Control

The following recommendations are given as a guide for dust control in the processing of diatomite. They are the essentials of any good dust control program regardless of the industry.

1. Control dust, insofar as possible, at its source of generation.
2. Enforce a rigid program of good housekeeping.
3. Give special attention to maintenance programs. Repair all dust leaks immediately, and in the case of major leaks, close down equipment involved until repairs have been made.
4. Instruct workers in proper operational procedures for minimizing dust dispersion and assure adherence to these procedures.
5. Enclose baghouses and equip them with automatic bag-shaking devices.
6. Assure that stack effluents do not contaminate work areas.
7. Institute a program of routine evaluation of dust exposures.
8. Provide a respirator program supplementary to the environmental control program for protection against intermittent high dust exposures. A routine procedure should be established for issuing, cleaning, and maintaining respirators. Only U. S. Bureau of Mines approved respirators should be used.

Labeling

Suitable caution labels should be displayed on all shipping containers for cristobalite-bearing diatomite products where high atmospheric dust concentrations may arise in their handling and subsequent use.

Medical Program

The present program of preplacement and periodic medical examinations should be continued. This program should include chest roentgenograms, studies of pulmonary function, and tests to insure early detection of active tuberculosis. At frequent intervals there should be an epidemiologic revaluation of the pulmonary status of the working population.

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