ENVIRONMENTAL CHARACTERIZATION AND MORTALITY EXPERIENCE OF ATTAPULGITE CLAY WORKERS

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16. Abstract (Limit: 200 words)

A retrospective cohort study of attapulgite (12174117) clay mill and mine workers at Engelhard Minerals and Chemicals Corporation (SIC-1454) was carried out, and environmental samples were collected and analyzed. All men who worked for at least 1 month during 1940 through 1975 at the facility made up the cohort. The vital status of less than 6 percent of the workers had not been determined. Death certificates were obtained for most of the workers known to have died; the underlying cause of death was coded based on these certificates. General air samples, personal breathing zone air samples, and settled dust samples were analyzed for free silica (7631869) and trace metals. Particulates were subjected to electron microscope characterization. Iron (7439896) was the only trace metal found in any appreciable quantity. Free silica exposures were within the NIOSH recommended limit of 0.05mg/m3 as a time weighted average (TWA), and respirable dust concentrations were below the OSHA standard of 5mg/m3 as a TWA. The main constituent of samples was attapulgite clay. Individual attapulgite fibers ranged from 0.1 to 2.5 microns in length and 0.02 to 0.1 micron in diameter.

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ABSTRACT

In 1976 the National Institute for Occupational Safety and Health (NIOSH) performed an industrial hygiene study and initiated a retrospective cohort mortality study of attapulgite clay mill and mine workers at the Engelhard Minerals and Chemicals Corporation to determine if exposures to attapulgite clay can elicit adverse health effects. Environmental samples were collected to evaluate exposures to respirable and total dust, free silica, and trace metals (Cd, Co, Cr, Fe, Mn, Ni, and Zn), and to characterize airborne particulate material by transmission electron microscopy (TEM).

Sample analyses for trace metals indicated only the presence of iron (1.0-2.4%) in any appreciable quantity. Time-weighted average (TWA) exposures for free silica calculated for various occupational groups (by job title) were within NIOSH recommended limits (0.050 mg/m^3). All TWA concentrations for respirable dust were below the Occupational Safety and Health Administration standard (5 mg/m^3) although some TWA concentrations for total dust exceeded the Mine Safety and Health Administration standard (10 mg/m^3). Airborne samples selected for TEM were analyzed utilizing selected area electron diffraction and energy dispersive X-ray analysis. Attapulgite clay was identified as being the major constituent in the samples and was often observed as individual fibers (particles $\geq$ 3:1 aspect ratio) which tended to agglomerate into single jagged aggregates that ranged in diameter from 0.5 to 5.0 micrometers (µm). Individual fibers demonstrated lengths of 0.1 to 2.5 µm and diameters of 0.02 to 0.1 µm.

Currently underway is the completion of the retrospective cohort mortality study which includes all males who worked for at least one month any time between January 1, 1940 and December 31, 1975. To date, the vital status of 2302 workers has been determined with 147 (∿6%) left to be traced. The results of the mortality study will compare the observed deaths by cause for these workers versus expected deaths based on U.S. mortality rates.

INTRODUCTION

The evidence of adverse pathologic effects from exposure to asbestos(1,2) has stimulated research to determine the causative factors. The concensus among researchers is that the carcinogenic effects of asbestos and other fibrous mineral types are related to physical (i.e. morphology, size, etc.) rather than chemical properties. In 1976 because of the fibrous nature of attapulgite clay and the concern that airborne exposures may result in similar pathologic effects, the National Institute for Occupational Safety and Health (NIOSH) initiated a retrospective epidemiologic mortality study of attapulgite clay mine and mill workers and an industrial hygiene assessment of their occupational environment.

Attapulgite clay, commonly called attapulgite after the principal mineral it contains, is a crystalline, hydrated, magnesium-aluminum silicate with a unique chain structure that gives it unusual colloidal and sorptive properties. It is the principal member of a group of sorptive clays known collectively as fuller's earth.(3)

Attapulgite has a wide variety of industrial applications; colloidal grades are well-known thickening, gelling, stabilizing, and thixotropic agents in products such as paint and drilling muds. Sorptive grades find use as decolorizing and clarifying agents, filter aids, floor absorbents, animal litter, pesticide carriers, components of no-carbon copy papers, catalysts, and refining aids. In addition, attapulgite has been used as a pharmaceutical carrier or product.

Attapulgite is found in economic quantities only in the Georgia-Florida area of the United States, in India, and in the Soviet Union. In the Soviet Union the mineral is commonly referred to as palygorskite. The production (mining/milling) of attapulgite clay in the United States is estimated at 900,000 tons a year.

As mined, attapulgite clay contains 70 to 80% attapulgite, 10 to 15% montmorillonite, sepiolite, and other clays, 4 to 8% quartz, and 1 to 5% calcite or dolomite. Much of the non-clay fractions are removed during processing so that commercial products can contain from 85 to 90% attapulgite.

PLANT SELECTION AND DESCRIPTION

The plant selected for study was chosen on the basis of its population size, duration of operation at its present location, adequacy and maintenance of personnel records, and because exposures, other than to attapulgite clay, were thought to be negligible and would not be an important factor in the environmental assessment.

The plant site, which included a mill and catalyst plant, was located in southern Georgia; however, the company owned substantial amounts of acreage in both Georgia and Florida. At the time of the study, there were three active strip mines, one in Florida and the other two in Georgia.

When the NIOSH study was initiated in 1976, the company employed approximately 395 people, of whom 79 were salaried, 70 were employed in the catalyst plant, 44 worked in the mines, and the remaining 202 were employed in the milling and shipment of attapulgite clay. Stratification of the workforce at the time of the study indicated a predominantly male population consisting of approximately 55 to 65% white and the rest non-white, and with both past and present workers tending to live within a 30-mile radius.

Production at the plant started around 1920 using two mills, designated #1 and #2, that produced only granular attapulgite clay. In 1933 a third mill (#3) was built to increase the production of granular clay to meet the demand for decolorization of petroleum. It was not until the early 1940's that the company started manufacturing the finer particle size clay products. In 1967 the #2 mill was revamped for the installation of a Raymond Mill, which, because of its air separation system, allowed a finer clay to be produced.

DESCRIPTION OF MINE AND MILL PROCESSES

Attapulgite clay deposits are found within approximately a 15 mile radius of the milling facility. The clay beds vary in thickness from 4 feet to more than 12 feet and may occur in two distinct layers separated by a stratum of sand calcite (limerock). Conventional open pit strip mining methods are used in which the overburden is removed from a substantial area until the clay has been exposed. Since the quality of attapulgite clay varies both laterally and vertically through its stratum, this variability is used to increase the range of production types and applications. Because of the different stratums, the clay is selectively mined and hauled to the clay shed at the mill site.

Once stored in the shed, the clay is selectively removed and fed into the mill process as illustrated in Figure 1. The clay is first conveyed to the crusher (hammermills and/or rolls), where it is reduced to granules or flakes approximately 1/2 inch or smaller. If the clay is to be extruded (extrusion improves absorptivity), it proceeds from a roll crusher to a pugmill where sufficient water is added to yield an extrudable mass. The pugmill discharge is fed to a screw-type extruder to produce an extrudate in the form of rods averaging roughly 1/2-inch in diameter. This extrudate is then dried in one of the several counter-current rotary dryers; these dryers operate over a range of 300 to 1200°F depending on the grade of extrudate being produced. For the unextrudated grades of clay, the discharge from the crusher bypasses the pugging and extruding steps and goes directly to the same dryer as the extruder clay.

Once the clay is dried, the remaining steps in the process consist of size reduction and classification. The combination of grinding roll mills and sifters yields a variety of granular product grades coarser than 100 mesh, while the undersized material is classified into a variety of fine grades. For certain products, the granular material (clay) may be recycled to the dryer for further calcination. The fine grades (100 to 325 mesh) are classified and conveyed to the finished product bins. If still finer grades are needed, the 100/325 mesh clay is passed through the Raymond Mill where it is air separated into a product which is 95% finer than 10 micrometers (μm).

Because of the diverse recycling system between all stages of milling, sifting, grinding, and drying, all waste material and dust from the baghouse collectors can be reused by reconstitution through the extruding process. After all size reduction and classification, the finished product is conveyed to a storage area where it is bagged or shipped in bulk by truck or train.

INDUSTRIAL HYGIENE EVALUATION

In 1976 an industrial hygiene survey was conducted at this plant to document dust exposures at the various attapulgite clay milling processes. No sampling was performed at the catalyst plant since attapulgite clay was not used there and the workforce was separate from that of the clay milling operations. Likewise, no airborne dust samples were collected at the mine site since exposures were felt to be minimal since the clay was mined wet.

A total of 200 airborne dust samples were collected in the mill; 150 of these were personal breathing zone samples collected for the determination of respirable and total dust time-weighted average (TWA) concentrations. In addition, for each of the job categories, a representative number of personal samples were randomly selected for free silica determinations. The remaining 50 airborne dust samples were general area samples collected at various mill processing operations. These samples were analyzed for free silica and trace metals (cadmium, cobalt, chromium, iron, manganese, nickel, and zinc) as well as subjected to electron microscope characterization. In addition to the airborne samples, settled dust samples were also collected from different areas of the mill and analyzed in the same manner as the airborne samples.

Samples of airborne respirable and total dust were collected at a flow rate of 1.7 liters per minute on 37-mm diameter, pre-weighed, MSA Type FWS (polyvinyl chloride) filters. Total dust samples were collected open-faced with respirable dust samples collected using 10-mm nylon cyclone pre-separators. Total dust samples were also collected for trace metal analysis on 37-mm diameter, pre-weighed, Millipore Type AA (cellulose ester) filters. Likewise, at various milling operations, total dust samples were collected on Millipore Type AA filters and analyzed by transmission electron microscopy (TEM) utilizing selected area electron diffraction (SAED) and energy dispersive spectroscopy X-ray analysis (EDS) for characterization of particle morphology and chemical composition.(4)

Free silica analysis was performed using X-ray diffraction as specified by the NIOSH Method P&CAM 109.(5) Trace metal analyses for Cd, Co, Cr, Fe, Mn, Ni, and Zn were accomplished by atomic absorption spectroscopy on selected air and settled dust samples using the NIOSH Method P&CAM 173.(6)

INDUSTRIAL HYGIENE RESULTS

Tabular summaries of time-weighted average (TWA) exposures by job category for free silica and respirable and total mass dust samples (attapulgite) are given in Table 1. All TWA concentrations for respirable dust were below the Occupational Safety and Health Administration (OSHA) standard (5 mg/m^3), however, some TWA concentrations for total dust exceeded the Mine Safety and Health Administration (MSHA) standard (10 mg/m^3). Since there were no specific occupational health standard for attapulgite clay the standards for inert or nuisance dusts were considered applicable.

All TWA free silica exposures calculated for each job category were within acceptable limits recommended by NIOSH.(7) Some individual personal respirable samples indicated free silica exposures exceeding the NIOSH recommended TWA standard of 0.05 mg/m^3. However, these concentrations may be questioned since the free silica results on each sample was reported near the lower detection limit of the analytical method (0.02 microgram per filter).

All airborne samples in which trace metal analyses were performed indicated levels comparable to the lower detection limit of the analytical method. These low values were substantiated by the trace metal analysis conducted on settled dust samples as indicated in Table 2. Iron was the only trace metal found in any appreciable quantity (1.0 - 2.4%).

Exposure data for total and respirable personal dust samples, respectively, were grouped to determine exposure parameters for specific job types as illustrated in Tables 3 and 4. The rationale for these groups was based on three distinct areas of the mill where the attapulgite clay was felt to have different constituents. Group A represents workers who were exposed to the initial process in milling the clay; in most instances, the clay was still in a wetted state. Group B workers were primarily exposed to the clay after it had been dried and had undergone grinding and milling. Most of the workers in Group C were exposed to the clay once it had been milled and separated by size for bagging or bulk shipment.

As noted in Tables 3 and 4, geometric mean dust concentrations were substantially lower for Group A workers (1.75 mg/m^3 total and 0.45 mg/m^3

respirable). For Group B, geometric mean exposures were 15.90 mg/m^3 total and 1.60 mg/m^3 respirable. Group C had geometric mean total and respirable exposures of 11.92 mg/m^3 and 1.15 mg/m^3, respectively.

A random selection of total dust samples that were representative of all milling processes was chosen for particle characterization by TEM. Samples were observed at 17,000-50,000X magnification and all indicated similar particle morphology with individual clay fibers ($\geq$ 3:1 aspect ratio) being more numerous on samples collected near the dryers and at the Raymond Mills. Typical photo-micrographs of airborne attapulgite are illustrated in Figures 2-4.

Both SAED and EDS were performed on observed fibers for definitive attapulgite identification; likewise a mine sample of the clay and a reference standard sample obtained from the Smithsonian Institute were analyzed in the same manner to further substantiate the presence of attapulgite in the airborne samples. Illustrated in Figure 5 is an EDS spectrum of attapulgite obtained from a cluster (5 µm diameter) of attapulgite fibers. This spectrum of Mg, Al, Si, and trace Fe helped to substantiate the cluster as attapulgite clay. No other types of fibrous ($\geq$ 3:1 aspect ratio) minerals were observed in either the airborne or mine samples.

To determine fiber size characteristics, 15 airborne total dust samples were randomly selected from those collected within the mill. Measurements (diameter and length) made at 20,000X magnification on approximately

460 fibers indicated fiber lengths of 0.1 to 2.5 μm with a geometric mean of 0.52 μm, and diameters of 0.02 to 0.1 μm with a geometric mean of 0.06 μm as illustrated in Table 5. In addition, fiber aspect ratios (length to diameter) ranged from approximately 10:1 to 250:1. It was noted during TEM analysis that fibers had an affinity to agglomerate into jagged particles ranging in diameter from 0.5 to 5.0 μm. This characteristic is shown in Figures 2 and 3.

INDUSTRIAL HYGIENE DISCUSSION

The exposure data from the industrial hygiene study indicated TWA total dust concentrations for milling and bagging operations to sometimes be in excess of the MSHA standard (10 mg/m^3). However, because of the mobility of the employees within many of the job categories, these high dust concentrations were not indicated by the TWA's for many of the workers. Likewise, all personal TWA respirable dust concentrations were below the OSHA standard of 5 mg/m^3. Airborne free silica concentrations for respirable samples were found to be within acceptable limits, since the analysis for quartz indicated levels near the lower detection limit of the method.

When job types were grouped together (Tables 3 and 4), there appeared to be a considerable difference in exposures between those workers who handled the clay when wet (Group A) and those who handled it when dry (Groups B and C). Only a small difference in exposures was observed between Group B and C; this difference probably reflects the mobility and location overlap of these 2 groups of workers.

EPIDEMIOLOGIC STUDY

To delineate any fatal health hazards in the attapulgite industry, a retrospective cohort mortality study was undertaken. This study consists of characterizing the cause-specific mortality rates of all males who worked at the Englehard Mineral and Chemical Attapulgite facility for at least one month between January 1, 1940 and December 31, 1975. These people were identified from microfilm copies of company personnel records. The vital status determination as of December 31, 1975 of each of these 2302 employees was attempted based on information from the Social Security Administration, Internal Revenue Service, Bureau of Motor Vehicles, and state vital statistics offices. As a result of this intensive followup program, less than 6% of the study group were lost to followup. Death certificates were obtained for all but 30 of approximately 300 persons known to have died. The underlying cause of death was coded by a qualified nosologist, so that comparability would be assured when comparing the age, race and cause specific mortality rates of the attapulgite workers with those of the United States male population. To date, one of the major problems in the study has been the lack of racial information on a substantial proportion of the cohort. We are trying to obtain these data from the Social Security Administration since they were not available through the company.

When completed, the study will describe mortality patterns by duration of work at the facility and by work area. The facility has been characterized into major areas for purposes of analysis. These correspond to administrative areas used by the company: mining, milling, shipping, catalyst plant, and maintenance.

Because of previous studies of asbestos and other fiber exposed groups, major a priori emphasis will be placed on investigating lung and digestive system cancer and nonmalignant respiratory diseases such as emphysema and chronic bronchitis. However, all causes of death will be examined.

Before interpreting the results of this cohort mortality study, one must consider the statistical power of the study. The statistical power of a study is the probability we have of detecting a given risk if it in fact exists. As seen in Table 6, if the risk of death due to respiratory system cancer, degestive system cancer, or nonmalignant respiratory disease is twice that of the U.S. population, then we have a 97% chance of finding a statistically significant excess in this study. If the risk of death due to each of these causes is 1.5 times that of the U.S. population then we have only a 61-62% chance of detecting it. Similarly if the relative risk is only 1.2, then we have 20-21% chance of detecting it.

The plant studied had fairly rapid turnover, thus many short term workers. If there is a chronic health problem usually we would expect to find it in longer term workers. We also know that occupationally induced cancer usually takes over 10 years to develop. Therefore, if we limit our study to workers who worked at the plant for at least 5 years and look at their risk only after 10 years since their first exposure at the plant, we have much smaller number of people. In fact, as can be seen in Table 7 we have very little chance of detecting either a 1.2 fold or 1.5 fold relative risk.

Review of Animal Studies

In animal studies performed by Pott with chrysotile asbestos, it was concluded that the fiber shape and size were more important factors in carcinogenesis than the chemical composition.(8) In a later animal study by Pott, et.al. tumorigenic effects were demonstrated with various fibrous minerals.(9) One of the fibrous dusts, palygorskite, when injected into the pleural cavity of rats, was equivalent in carcinogenicity to chrysotile asbestos. A mineralogical study performed by Huggins has shown that attapulgite and palygorskite are structurally and chemically the same except that palygorskite tends to occur in a mineral habit with longer fiber lengths (>2 μm).(10)

In another animal study by Davis, a series of mineral dusts were injected into the pleural cavities of mice to test their relative fibrogenicity.(11) The degree of cellular granulomatous adhesions which were found between the lungs, diaphragm, and chest wall were dependent upon particle size and morphology. The highest degree of fibrosis within the granulomata was demonstrated using long fibrous minerals. The amount of fibrosis decreased with shorter fibers and particles.

The precise fiber dimensions required to observe pathologic responses have been impossible to determine experimentally because of the difficulties encountered in producing fibers of specific size.(12) However, the results from some of the more recent studies suggest that long thin fibers play an important role in eliciting a biological response. In one fiber implantation study reported by Stanton, et.al. it was concluded that fibers less than 1.5 μm in diameter and longer than 8.0 μm in length may be the most important for production of pleural sarcomas.(13)

Review of Human Studies

Few human epidemiologic studies to date have been able to differentiate the pathologic responses in man with regard to fiber types and dimensions. However, Bignon, et.al. attempted to determine the size characteristics of chrysotile and amphibole asbestos fibers retained in the human respiratory system.[14] Measurements were made of lung washing fluid obtained by broncho-alveolar lavage and sputum collected from alive people, and of respiratory tissues (lung parenchyma, parietal pleura, and mediastinal lymph nodes) sampled at autopsy. The results indicated that the intra-alveolar fibers were shorter (mean 3.3 µm) than fibers found in lung parenchyma (mean 4.9 µm). Fibers encountered in mediastinal lymph nodes were shorter (mean 2.5 µm) and of amphibole type, whereas fibers encountered in the parietal pleura were the shortest of all (mean 2.3 µm) and had the smallest diameters (mean 0.06 µm). All fibers encountered in the different sites of the respiratory system were found to have diameters less than 0.25 µm and with mean lengths less than 8 µm.

Bignon et.al. studied two individuals - one was exposed to airborne attapulgite and had lung fibrosis, and the other, had ingested a drug containing attapulgite, and tested both for the retention of attapulgite in their bodies.[15] The lung washing fluid from the individual exposed to airborne attapulgite demonstrated retention of attapulgite fibers in the alveolar spaces, whereas, a concentration of 300,000 fibers/ml were observed in the urine of the other case individual. The significance of this latter case was that attapulgite can pass through the human gastro-intestinal mucosa, and interact with organs not directly in contact with the outside environment.

DISCUSSION AND INTERPRETATION

Of concern is the potential of attapulgite clay to separate into individual fibrous structures which may be respirable when airborne. These fibers have diameters less than 0.1 μm and maximum lengths of 2.5 μm. Although the respirability of airborne fibers is not clearly understood, it is thought to be mainly dependent on the fiber diameter. Timbrell's[16] work suggests that the two major mechanisms of fiber deposition in the upper airways (gravitational settling and inertial deposition) are chiefly dependent upon particle aerodynamic diameter. Fibers with densities less than 3.5 g/cm^3 and diameters less than 3.5 μm may escape deposition by these two mechanisms and penetrate deeply into the lungs of humans. Airborne fibers observed in this study satisfy both the density and fiber diameter requirements and would therefore be considered potentially respirable.

It would appear that when the attapulgite fiber size data from this study are compared to the fiber dimensions which are thought to produce biological responses in animals, only the small diameter (<1.5 μm) appears to match the criteria. However, all the observed attapulgite fibers had lengths less than 2.5 μm and, when compared to the animal study results, they would be considered to have a lesser potential for producing a biological response. In contrast to the animal studies, the studies by Bignon, et.al.[14,15] suggests that because of fiber size similarities observed for chrysotile and amphibole asbestos, and attapulgite, the potential exists for attapulgite fibers to be retained in the human body. As illustrated in Table 8 the asbestos, fiber size data tabulated by Bignon et.al.[14] for tissue sites indicates that a size selective process may take place in which the smaller (length) fibers are transported within the body and deposited at other sites (i.e. parietal pleura, lymph nodes). Likewise, this contention of fiber transport is supported by Bignon et.al.[15] in which attapulgite fibers were observed in urine.

It is unknown at this time if the inhalation or ingestion of attapulgite clay is harmful. However, if attapulgite fibers have the potential to migrate and deposit within the body it would appear prudent that continued research be conducted to determine if chronic health effects may occur.

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TABLE 1

SUMMARY OF TIME-WEIGHTED AVERAGE EXPOSURES BY JOB TITLE

	Job Title	Respirable Mass Free SiO_2 mg/m^3	Total Mass Free SiO_2 mg/m^3	Dust Concentrations Respirable Mass mg/m^3	Dust Concentrations Total Mass mg/m^3
	0200 Stationary Samples (Milling Operations)	—	—	9.90*	15.94
Group A	0201 Crane Operator	<0.030*	<0.030*	0.16	0.52
	0202 Hammer Mill Oper.	<0.031	<0.033*	0.41	0.46*
	0203 Pugmill Oper.	<0.028	<0.122	1.40	6.45
	0204 Dryer Oper.	<0.028*	—	0.57	—
	0205 Dryer Oiler	<0.030*	0.030*	0.74	6.57*
	0206 Crusher Oiler	<0.029*	0.029*	0.52	1.90*
Group B	0207 Miller No. 1	<0.029	0.084*	1.15	21.47*
	0208 Miller No. 2	<0.028*	—	2.10	15.54*
	0210 Raymond Miller	<0.028*	—	1.42*	9.12*
	0213 Screen Oper.	<0.027	0.110*	3.24	22.34
	0300 Stationary Samples (Bagging Operations)	—	—	2.04	12.62
Group C	0301 Lead Person	<0.074	0.248*	1.01	9.78*
	0302 Shipper	<0.031	0.145	1.72	16.30
	0303 Laborer	<0.029	0.183	1.90	22.51
	0305 Bag Press Oper.	<0.029*	—	0.72*	

Note: (*) Represents one sample
(—) No sample collected

Lower limit of detection for SiO_2 was 0.02 mg per filter

NIOSH recommended time-weighted average standard for free silica in respirable dust is 0.050 mg/m^3.

TABLE 2

SUMMARY OF THE TRACE METAL ANALYSES
SETTLED DUST SAMPLES

Sample Location	Trace Metals (ppm)						
	Cadmium	Cobalt	Chromium	Iron	Maganese	Nickel	Zinc
#1, Near Bagging Operation at Raymond Mill	1.3	3.0	105.0	18000.0 (1.8%)	443.0	52.0	72.0
#2, Same Area As #1	0.9	6.0	103.0	15100.0	240.0	24.0	74.0
#3, Settled Dust Behind Dryers	1.7	38.0	66.0	21500.0	481.0	1190.0	80.0
#4, Settled Dust underneath Hammer Mill	4.0	9.0	64.0	10000.0	689.0	17.0	60.0
#5, Settled Dust at Pugmill	2.4	6.0	76.0	16100.0	460.0	165.0	84.0
#6, Settled Dust at Bagging Operation Number 3 Mill	1.7	16.0	113.0	21000.0	322.0	20.0	107.0
#7, Same Area As #6	3.2	25.0	113.0	23600.0	438.0	25.0	94.0

TABLE 3

SUMMARY RESULTS
TIME-WEIGHTED AVERAGE TOTAL DUST EXPOSURES BY JOB TYPE

Job Type	Number of Samples	Range (mg/m^3) Low-High	Arithmetic Mean (mg/m^3)	Std. Dev.	Std. Error	Geometric Mean (mg/m^3)	Geo. Std. Dev.	95% Lower Confidence Limit	95% Upper Confidence Limit
Group A rane Operator, Pub-ill Operator, Dryer iler, and Crusher)iler	6	0.44-12.26	3.75	4.77	1.95	1.75	3.95	0.41	7.29
Group B iillers No. 1 and 2, Raymond Miller, and Screen Operator	5	8.81-37.95	18.58	12.02	5.38	15.90	1.85	7.42	34.06
Group C Lead Person, Shipper and Laborer	27	1.19-43-82	16.31	12.46	2.39	11.92	2.41	8.41	16.88

TABLE 4

SUMMARY RESULTS
TIME-WEIGHTED AVERAGE RESPIRABLE DUST EXPOSURES BY JOB TYPE

Job Type	Number of Samples	Range (mg/m^3) Low-High	Arithmetic Mean (mg/m^3)	Std. Dev.	Std. Error	Geometric Mean (mg/m^3)	Geo. Std. Dev.	95% Lower Confidence Limit	95% Upper Confidence Limit
Group A Crane Operator, Pug-mill Operator, Dryer Oiler, and Crusher Oiler	11	0.14-2.74	0.79	0.93	0.28	0.45	2.95	0.22	0.93
Group B Millers No. 1 and 2, Raymond Miller and Screen Operator	11	0.49-5.07	1.98	1.37	0.43	1.60	2.03	0.96	2.65
Group C Lead Person, Shipper and Laborer	66	0.14-7.90	1.59	1.43	0.17	1.15	2.26	0.94	1.41

TABLE 5

SUMMARY OF AIRBORNE ATTAPULGITE FIBER SIZE DATA
AS DETERMINED BY ELECTRON MICROSCOPY (20,000X)

Fiber Measured	Micrometers (μm)						
	Range	Arithmetic Mean	Count Median	Geometric Mean	Geometric Standard Deviation	LCL 95%	UCL 95%
Diameter	0.01 - 0.25	0.09	0.07	0.06	2.39	0.05	0.08
Length	0.1 - 2.5	0.77	0.4	0.52	2.50	0.44	0.63

NOTE: 460 Fibers sized from 10 airborne total dust samples

TABLE 6

ATTAPULGITE MORTALITY STUDY:
PROBABILITY OF DETECTING VARIOUS RELATIVE
RISKS FOR SELECTED CAUSES OF DEATH†
ENTIRE COHORT OF MALES

Cause of Death	Relative Risk		
	1.2	1.5	2.0
Respiratory System Cancer	20%	61%	97%
Digestive System Cancer	20%	61%	97%
Nonmalignant Respiratory Disease	21%	62%	97%

† $\alpha = 0.05$ one sided

TABLE 7

ATTAPULGITE MORTALITY STUDY:
PROBABILITY OF DETECTING VARIOUS RELATIVE
RISKS FOR SELECTED CAUSES OF DEATH†
MALES WITH ≥ 5 YEARS EXPOSURE AND
≥ 10 YEARS TIME AFTER FIRST EXPOSURE

Cause of Death	Relative Risk		
	1.2	1.5	2.0
Respiratory System Cancer	12%	30%	67%
Digestive System Cancer	13%	34%	73%
Nonmalignant Respiratory Disease	12%	31%	69%

† $\alpha = 0.05$ one sided

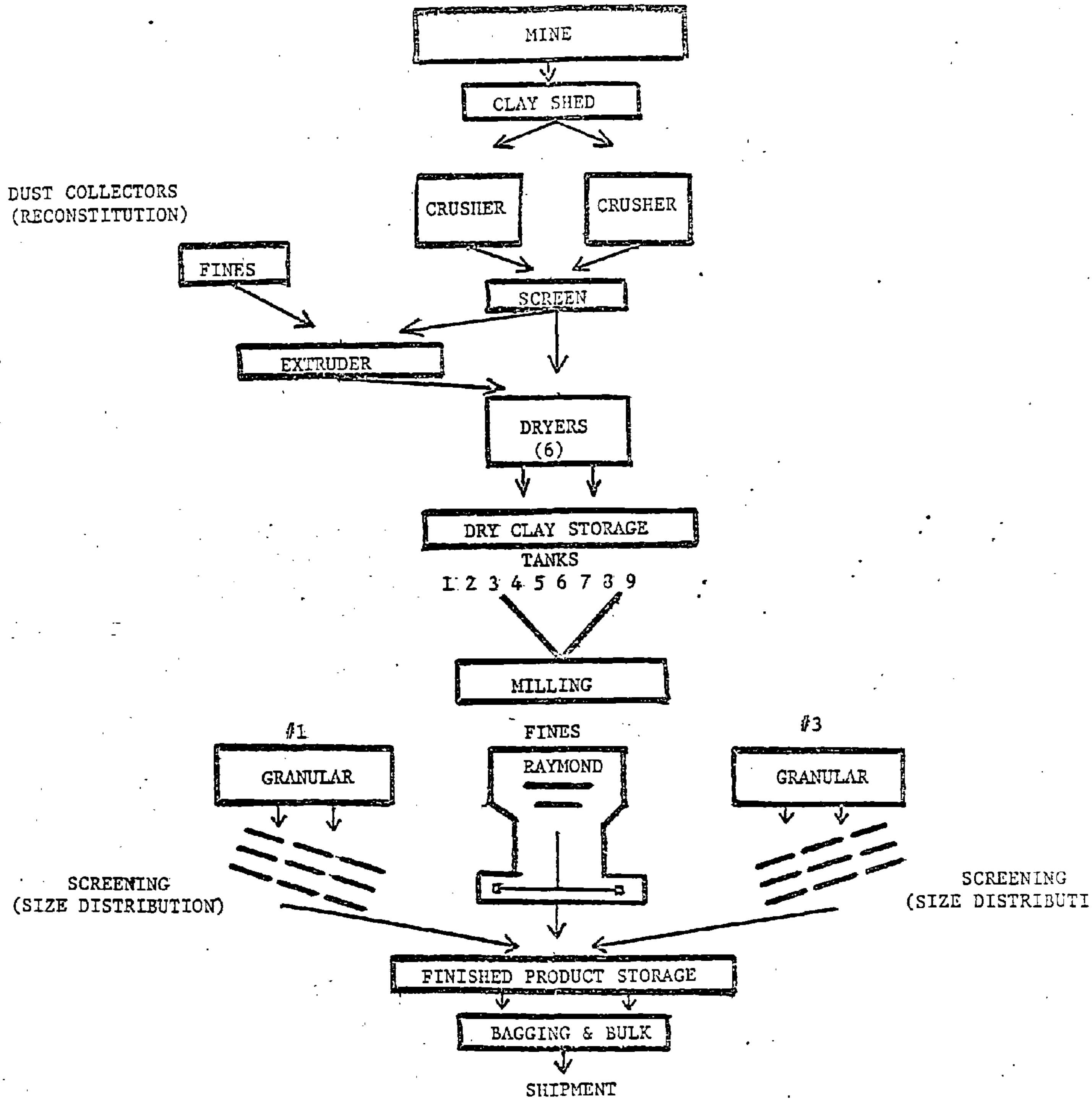
TABLE 8

COMPARISON OF FIBER SIZE DATA

	Sample Type	Mean (Micrometers) Diameter	Mean (Micrometers) Length	Comments
Bignon et al. 1979 Human Observation	Attapulgite: France - Bulk	0.06	0.80	All Fibers < 5 µm Length
	Attapulgite: Spain - Bulk	0.06	~0.80	All Fibers < 5 µm Length
NIOSH - 1980	Attapulgite USA - Airborne	0.09	0.77	All Fibers < 5 µm Length
Bignon et al. 1977 Asbestos Fiber Retention in Humans	Asbestos Fibers: Lung Wash Fluid	0.13	3.0	
	Sputum	0.16	5.0	
	Lung Parenchyma	0.13	4.9	~30% > 5 µm Length ~15% > 8 µm Length
	Parietal Pleura	0.06	2.3	~20% > 5 µm Length ~ 5% > 8 µm Length
	Lymph Nodes	0.16	2.5	~12% > 5 µm Length ~ 3% > 8 µm Length
	Alveolus	0.13	3.3	~18% > 5 µm Length

BEST AVAILABLE COPY

FIGURE 1



PROCESSING FLOW SHEET FOR
ATTAPULGITE CLAY

FIGURE 2

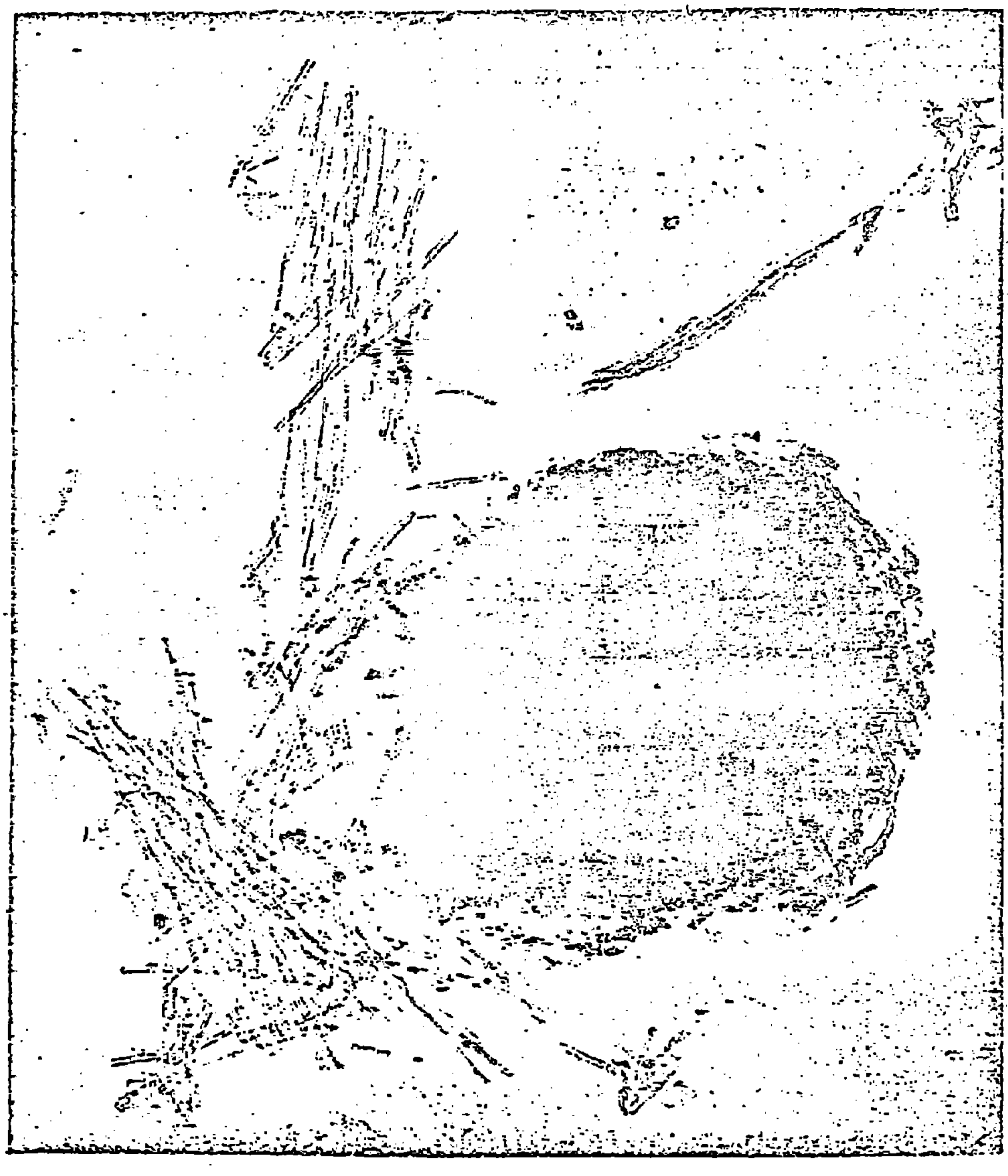
BEST AVAILABLE COPY

ATTAPULGITE
20,000X MAGNIFICATION

1 MICRON

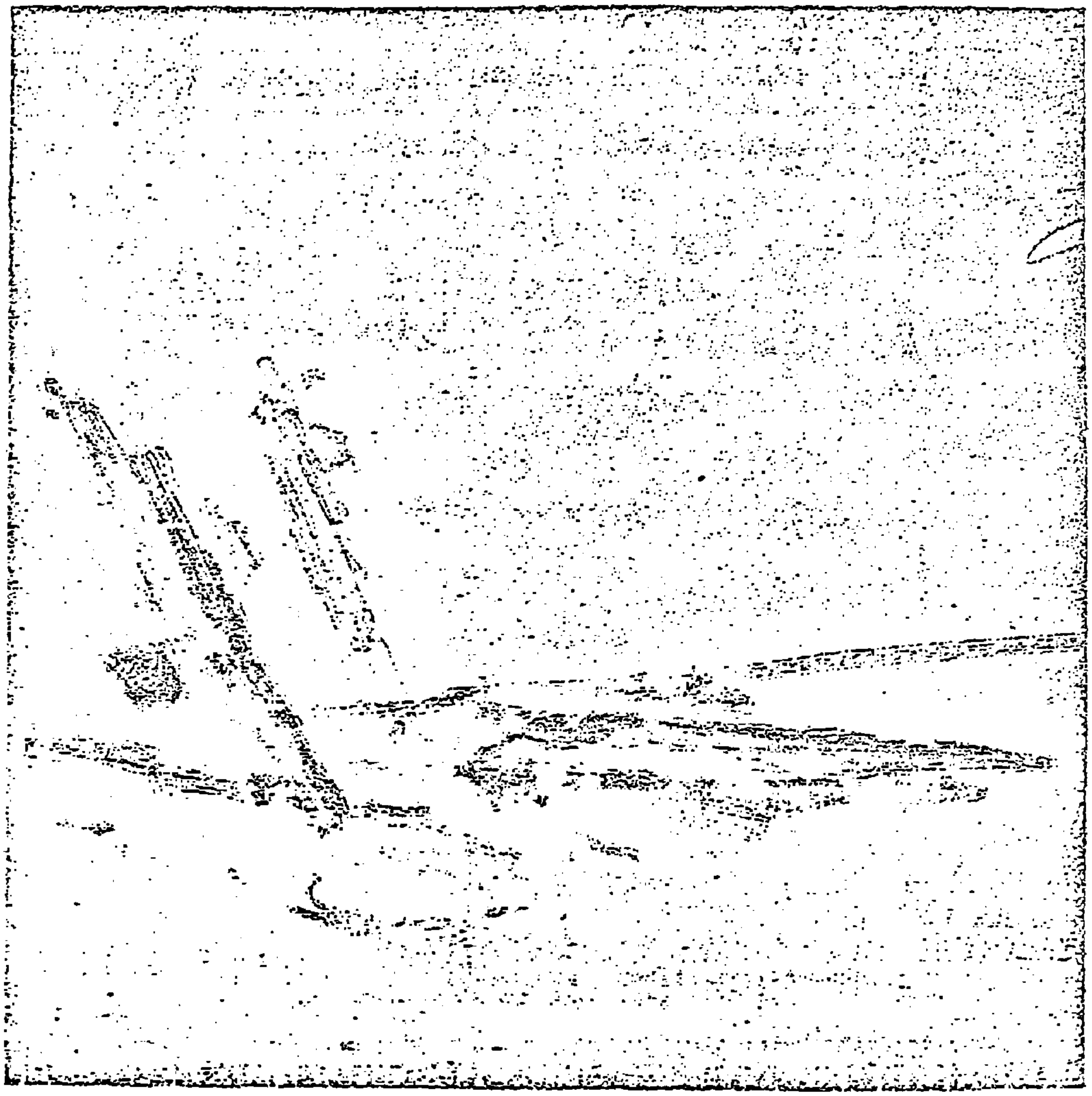
FIGURE 3

BEST AVAILABLE COPY



ATTAPULGITE
17,000X MAGNIFICANTION
1 MICRON

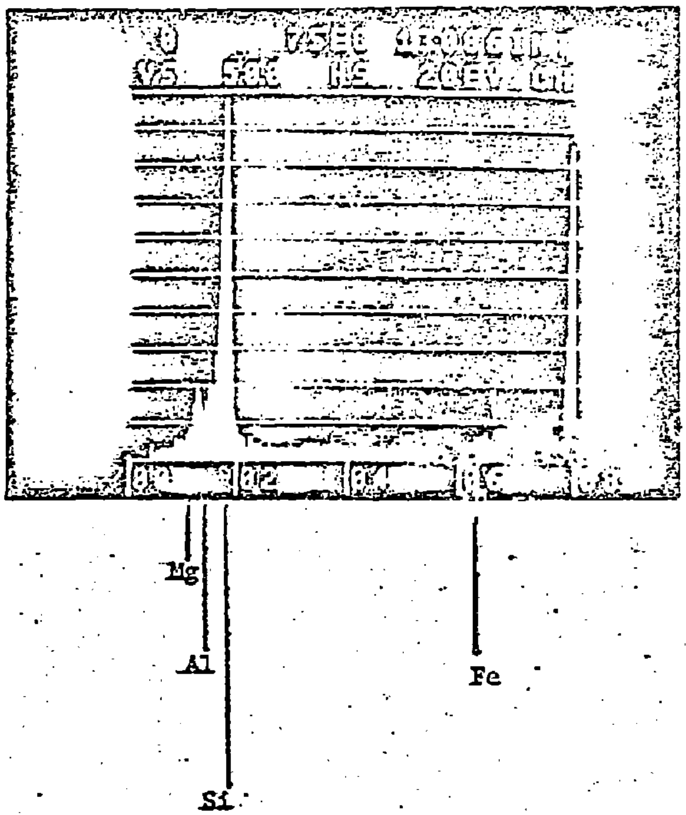
FIGURE 4



ATTAPULGITE
50,000X MAGNIFICATION

0.5 MICRON

FIGURE 5



ATTAPULGITE
X-RAY SPECTRA