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DUST EXPOSURE IN ASBESTOS PROCESSING

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INTRODUCTION

Asbestos is a generic term applied to a number of fibrous crystalline silicate minerals. Although chemically they are grouped as hydrated silicates, they vary greatly in degree of hydration, complex composition of the silicate, and physical properties of the crystalline fibrous structure.

Reference was made to asbestos as early as several centuries B.C. It was not established as a mineral of industrial importance, however, until around the end of the last century. Asbestos has a wide variety of uses in modern industrial technology because of its outstanding properties of chemical resistance, fibrous structure and incombustibility. It is used in the manufacture of textiles, felts, ropes, brake linings, clutch facings, roofing and flooring materials, asbestos-cement products, gaskets, insultation materials, special papers, filters, and plastic products. These are used in practically every major industry.

Statistics from the Bureau of Mines "Mineral Facts and Problems, Bulletin 650, 1970" indicate that the United States is the world's largest consumer of asbestos, using more than one-fifth of the 3.5 million short tons of world production. Most of the asbestos production is chrysotile asbestos, but approximately 200,000 tons of the world's production each year consists of amosite and crocidolite. In 1968 the United States consumed about 23% of the total world production.

Asbestos workers have been the subject of numerous studies and review articles since asbestosis was first recognized as an occupational disease in the late 1920's; however, many questions remained unanswered concerning the clinical aspects of the disease and its etiology. Information on the prevalence and clinical characteristics of asbestosis had been derived primarily from medical studies of actively employed asbestos workers. These were supplemented by special clinical studies and autopsy data. Little definitive data regarding the nature and magnitude of concurrent environmental exposures had been obtained.

Even though an estimated 3.5 million workers are exposed annually to asbestos, this may represent only a part of a much larger emerging base resulting from advancements in industrial technology and affecting a far greater population, the rapidly expanding field of industrial fiber technology. There is evidence that respirable fibers, whether they are of natural mineral, vegetable, or synthetic origin, may behave quite differently in the lungs than particulates of the same chemical composition.

A comprehensive study was started in order to obtain data which could be utilized to accomplish the following objectives:

1. To determine the health status of the asbestos workers in this industry with special attention to diseases of the respiratory tract.

2. To determine the relationship between occupational exposure and cause of death of asbestos workers.

3. To develop medical and environmental criteria and procedures for the control of health risks identified by the study.

4. To determine which environmental factors have an adverse effect upon the health of asbestos workers in the asbestos-products industry.

The National Institute for Occupational Safety and Health (NIOSH) (formerly Division of Occupational Health) in the U.S. Public Health Service has been conducting an epidemiological study of the asbestos processing industry since 1964. This paper will confine itself to the environmental phase of this study which was designed to define the working environment of the various plants. Particular emphasis was placed on levels and nature of exposure to asbestos dust.

PRESENT EPIDEMIOLOGIC STUDY

The present epidemiologic study of the asbestos products industry was started for the following reasons:

1. The substantial changes in the size and technology of the industry have created new exposure situations in need of evaluation.

2. Over-all reductions in asbestos dust levels now make it possible to examine the relation of asbestos to asbestosis in workers with long-term lower level exposures.

3. The relationship between types and magnitudes of exposures and the occurrence of lung cancer needs to be defined.

SAMPLING METHODS

The types of samples collected in the environmental phase can be divided into four categories:

1. Bulk samples - Several pounds of each of the different types of crude fiber, bag house waste, and treating and lubricating oils used were collected at each plant.

2. Long period gravimetric samples - Several instruments for obtaining mass samples of total and respirable dust were run simultaneously in the representative area in the midst of each operation. These instruments included a high volume sampler, a Hexhlet modified to take a membrane filter, and a set of four membrane filter field monitors with and without 10 millimeter cyclone presamplers, and a membrane filter field monitor with a horizontal elutriator upstream.

3. Simultaneous impinger-filter samples - Breathing zone samples taken with an impinger and a membrane filter simultaneously were used to obtain a comparison of these methods of dust enumeration. This method of sampling was used because the initial exposure limits were based on samples evaluated with the impinger and it was hoped that a correlation existed between the methods so that a meaningful use could be made of all the past data collected. Other sets of simultaneous impinger-filter samples, with and without horizontal elutriator presamplers, were taken in general room air near specific operations.

4. Personal Samplers - Only the personal samples collected using membrane filters will be discussed because it gives a better index of airborne fiber concentration. Lynch, et al[1] found that the impinger method of sampling was very inefficient with relation to capturing fibers to be counted later. The lack of fibers in the impinger samples was not due to the absence of fibers in the air. The impinger, an impaction device, has a collection efficiency related to the aerodynamic size of particles and is not efficient for particles with falling speeds less than that of one micrometer, unit density spheres. Further, the 10X objective, light field, counting technique used does not resolve particles much smaller than one micrometer (μm). Laboratory experiments showed that the impinger passed fibers and from field sampling it is estimated that only about one out of one hundred fibers in the air as seen in electron micrographs was seen in the impinger samples.

Since it is important that any method used be able to measure that factor in the environment that is most relevant to the disease-causing mechanism and will, therefore, yield a significant correlation between health and exposure, it was determined that the membrane filter method met this criteria. Fibers have long been implicated as the causative agent in asbestosis and may be significant in cancer. Timbrell's[2] work showed that because of the peculiar aerodynamic properties of fibers (i.e., that their falling speed is dependent on diameter only when aspect ratios are greater than 10) it is possible for much larger objects (longer and heavier) to penetrate deep into the lung in the shape of fibers than in the shape of grains. This appears to be a most significant biologic property considering that the parent minerals involved (amphibole and serpentine) are not considered biologically active.

Based on methods developed in Great Britain[3], a method of collecting and counting fibers on membrane filters was developed[4]. These filters have pore sizes of 0.8 μm but are almost 100% efficient down to several hundredths of a micrometer because of surface effects. They are dissolved by means of a mounting medium which is prepared by dissolving 0.05 g of membrane filter per ml of 1 to 1 mixture of diethyl oxalate and dimethyl phthalate and has an index of refraction (ND) equal to 1.47. The samples are counted with a 4 mm objective (430X) under phase contrast illumination. By examining a suitable number of fields, it is possible to count enough fibers to make a statistically useful estimate of fibrous dust concentration. In order to collect a sample representative of airborne dust which is likely to enter the subject's respiratory system, it is necessary to position a collection apparatus near the nose and mouth of the subject (i.e., in his "breathing zone"). An exploded view of the sampler is shown in Figure 1. The sample is collected on a 37 mm millipore type AA filter mounted in an open-face field monitor. The monitor is fastened to the worker's lapel and air is drawn through the filter by means of the battery powered personal sampler pump, similar to those approved by NIOSH under the provisions of 30 CFR 74. A support pad is placed between the field monitor and the membrane filter which aids in controlling the distribution of air through the filter. Flow rate of the personal sampler pump was maintained at 1.7 liters per minute (lpm). Sample time varied from 15 minutes up to 4 hours. The majority of the samples were collected between 1 1/2 to 2 1/2 hours. Actual sampling time depended upon many variables (e.g., concentration of fibers, types of operation, amount of background material present, etc.).

GENERAL CHARACTERISTICS OF PARTICULATES IN ASBESTOS PLANTS

The sources of airborne particulates in an asbestos processing plant may be classified as follows:

1. Fibrous asbestos
2. Asbestos type minerals (serpentine, antigorite, etc.)
3. Non-asbestos type minerals occurring with asbestos (magnetite, periodotile, chromite, nickel, quartz).
4. Other process materials (cotton, rayon, glass fiber, etc.)
5. Non-process materials (air pollution).

An air sample from an asbestos plant taken by any efficient sampling device and examined microscopically reveals that most particles do not appear fibrous. They resemble, in fact, the particles common in air samples from virtually any operation producing mineral dust. If such a sample is magnified several thousand diameters by electron microscopy many particles less than 0.5 micrometers (µm) in diameter are also visible. These small "air pollution" particles occur in any air sample, indoor or outdoor, and the number varies depending on time, season, community heating fuel, location of plant air inlets relative to nearby smokestacks, and general atmospheric conditions. Air pollution particles bear little if any relationship to the dust generated from asbestos processing.

However, many fibers including rayon and cotton which are identifiable by their large diameters are also observed in such an air sample. The presence of asbestos fibers is the unique characteristic of the sample. Figure 2 is a typical electron micrograph of dust from asbestos textile processing. Figure 3 is an electron micrograph at a higher magnification of extremely clean bulk asbestos treated to open the fibers.

Both Dreesen[5] and Fulton[6] reported that the usual diameter of airborne asbestos fibers was less than 0.5µm. Electron micrography confirms [illegible] fact many of the [illegible]

0.1 µm diameter. If a fiber is defined as having an aspect ratio greater than three to one, most of the fibers, by number, are short; median lengths from electron micrographs are between 1 and 2 µm.

CURRENT STANDARDS

Asbestos has been listed as one of the five target health hazards by the Occupational Safety and Health Administration of the U.S. Department of Labor. As of December 7, 1971, an emergency standard for asbestos was invoked by the federal government under the auspices of the Occupational Safety and Health Act. The standard states:

> "The 8-hour time-weighted average airborne concentration of asbestos dust to which employees are exposed shall not exceed five fibers per milliliter greater than five microns in length, as determined by the membrane filter method at 400-450X magnification (4 millimeter objective) phase contrast illumination. Concentration above five fibers per milliliter but, not to exceed ten fibers per milliliter, may be permitted up to a total of 15 minutes in an hour for up to five hours in an 8-hour day."

The National Institute for Occupational Safety and Health (NIOSH) in its "Criteria for a Recommended Standard.....Occupational Exposure to Asbestos," recommends:

> "Occupational exposure to airborne asbestos dust shall be controlled so that no workers shall be exposed to more than 2.0 asbestos fibers per cubic centimeter (cc) of air based on a count of fibers greater than five micrometers (>5 um) in length [determined by the membrane filter method at 400-450X magnification (4 millimeter objective) phase contrast illumination, ...], determined as a time-weighted average (TWA) exposure for an 8-hour work day, and no peak concentration of asbestos to which workers are exposed shall exceed 10.0 fibers/cc greater than 5 µm as determined by a minimum sampling time of 15 minutes."

RESULTS OF ENVIRONMENTAL SAMPLING

Although many different types of samples have been collected only the results of the membrane filter method will be discussed because this is the method enumerated in the existing Federal Standard on asbestos. All of the data listed are the values of fibers greater than 5 micrometers in length. All concentrations are listed as the number of fibers greater than 5 micrometers in length per cubic centimeter of air sampled (hereinafter, as fibers/cc). The results listed are based on approximately 10,000 samples that were collected and counted.

Table 1 lists the arithmetic means of the over-all asbestos concentrations by types of plants for those that were in the cohort. In some cases there were three surveys conducted, for example, in the textile and friction plants. A minimum of two surveys was conducted in each plant. The cycle on the resurveys was approximately every

2 1/2 years. This table provides an overview of the various types of plants and allows only general conclusions to be made. It can be seen that there is a definite difference in exposure levels among the various types of plants. On the surface it would appear that the insulation plants have the highest exposures, followed by the textile, friction, construction materials and cement pipe plants. The values for the insulation plants are high because two of the plants had very high values as shown in Table No. 2. This table shows the asbestos concentrations by various operations within the insulation plants. The plants are arranged according to the over-all individual plant average for all surveys conducted there. The wide variation between the highest plants and lowest plants can be attributed to the amount of controls that each plant has. It is evident that regardless of the over-all plant average the mixing operations have the highest exposure of all operations in all the plants and the inspection and packing operations the lowest. If these values are compared with the emergency standard of 5.0 fibers/cc (TWA) and 10.0 fibers/cc (peak), it can be seen that all means for all operations at the two highest plants not only exceed the TWA value but the peak value as well. Whereas the plant average for the lowest plant for all operations was equal to or less than the proposed standard of 2.0 fibers/cc.

Listed in Table No. 3 are the asbestos concentrations for the insulation plants by operations broken down according to the over-all means by survey conducted. The over-all values at each operation are high as a result of the very high values from two of the plants. There was very little difference between the results of the two surveys conducted except at the mixing operations. All other operations had similar values for both surveys. The mixing operations had the highest exposures.

Table No. 4 lists the textile plants by individual plants according to their over-all plant average for all surveys conducted. It appears that a plant which has a high over-all average will generally have a high average for each of the various operations. That is not to say that the highest averaged plant over-all will have the highest average for each and every operation, but it is true most of the time. If their values are compared with the emergency standard of 5 fibers/cc, then neither of the two highest averaged plants have any operations where the mean value is below it. The second lowest-averaged plant has two operations which fall below the emergency standard. Whereas the lowest-averaged plant has virtually every operation below the emergency standard.

The various asbestos concentrations by operations within the textile plants for each survey conducted are shown in Table No. 5. The fiber preparation, carding, spinning and twisting operations all appear to be problem areas based on the present emergency standard. Only the winding and weaving operations appear to be near the standard.

The average concentrations for the friction plants are listed by the over-all individual plant average in Table No. 6. When considering the mean values of the various operations with respect to the emergency standard of five fibers/cc, it is apparent that [illegible] plant hasn't any operations which are below the standard. The second highest averaged plant has four operations which are just slightly above the emergency standard and two operations which are below it. The two lowest averaged plants have mean values for all the operations below the emergency standard. When comparing these two plants using the proposed standard of two fibers per cc, it can be seen that the second lowest plant has two operations which have mean values below and two operations which are reasonably close to the proposed standard, whereas, the lowest averaged plant has four operations which have mean values below the proposed standard and two of which are reasonably close to it.

Table No. 7 has the arithmetic means by operations for all the friction plants surveyed according to the three surveys conducted at these plants. There appears to be a certain amount of flucuation among the various operations for each survey, with the overall means being highest in the mixing, grinding and sanding, and cutting and drilling operations.

The concentrations by operations for the construction material plants are listed according to over-all individual plant average in Table No. 8. The range of values is small. The reason that the value of the average of all samples for the mixing operation is higher than either value listed is that there was another plant in the cohort which had a high value. That plant was not listed because it had low values for the forming and finishing operations which brought the over-all plant average below the highest plant.

There were only two surveys conducted in the construction materials plants (Table No. 9). There was a decrease in mean values in all operations between the original survey and the resurvey. Only the mixing operations during the original survey exceeded the emergency standard of five fibers/cc.

Results for the cement pipe plants are in Table No. 10. Only one of the arithmetic means of the asbestos concentrations by operations exceeds the emergency standard of five fibers/cc - that, in coupling finishing. This high mean value is the result of one sample with an extremely high concentration. Since there was no immediate apparent reason for suspecting that it was not a valid sample, it was included. However, it should be pointed out that all other operations at that plant and all operations at the other plants have concentrations that are relatively low. Based on the proposed standard of two fibers/cc, there was only one operation, mixing, in the two lowest averaged plants which exceeded that standard.

Table No. 11 lists the asbestos concentrations by operations for the cement pipe plants according to the surveys conducted at each plant. There were only two surveys conducted at each plant. All mean values for the resurvey were below those from the original survey. All operations in cement pipe plant have mean values which are below the emergency standard of 5 fibers/cc.

SAMPLING METHODS EVALUATION

A special study was conducted to evaluate the possible variations between: 1) different sampling positions, and 2) repeatability between adjacent samples. In the past, it was standard operating procedure to ascertain whether a worker was right-handed or left-handed, and then the field monitor would be hung from his left lapel and right lapel, respectively.

The first phase of this study consisted of having a worker simultaneously wear two samplers with one field monitor positioned at his left lapel, and one at his right lapel (left-right paired samples). The pumps were hung on the worker's belt and the hoses put over his shoulders and attached to the field monitors on each lapel.

Table No. 12 lists the results of the left-right paired samples that were collected simultaneously on each worker. There were a total of 23 pairs of samples collected (46 total samples). The results were tabulated according to which side had the higher concentration, no matter how small. The total number of samples listed on this table is 22 rather than the 23 pairs which were collected since one pair of samples had the same concentration. The fact that an equal number of samples had higher concentrations on each side does not of itself tell the complete story, since it doesn't show the variability in the differences. A more complete evaluation can be realized if a range of differences is calculated. This was accomplished by subtracting the lower concentration value from the higher concentration value. Where the right side had the higher concentration, the range of differences was from less than 0.1 fibers/cc up to 1.0 fibers/cc, with a mean difference equal to 0.3 fibers/cc. Where the left side had the higher concentrations, the range of differences was from less than 0.1 fibers/cc up to 1.1 fibers/cc, with a mean difference equal to 0.5 fibers/cc. Thus, it is evident that even the differences (which are minimal) are reasonably uniform regardless of which side had the higher value.

The second phase of this study was conducted similar to the first phase in that two samples were collected simultaneously from an individual worker. Instead of hanging the field monitors one on each lapel, the field monitors were hung side-by-side on the same lapel. The results of the side-by-side paired samples that were collected simultaneously are listed on Table No. 13. For identification purposes the field monitor located closer to the center of the worker was called the inside sample, and conversely, the other was referred to as the outside sample.

There were a total of 85 paired samples collected for this phase of the study. The total number of samples shown on Table No. 13 is 84. This is the result of one pair of samples having the same concentration for each sample. The distribution on these samples shows that 38 of the samples had higher concentrations on the inside filter, whereas, 46 had higher concentrations on the outside filter. The binomial probability test was applied to the data and the results indicated that this distribution of 38 and 46, for the inside and outside samples, respectively, could have easily occurred by chance. There is no significance in the number of samples on the outside which had higher concentrations as compared with those on the inside.

A check of the range of differences for the samples that had a higher concentration on the inside filter would reveal values of less than 0.1 fiber/cc up to 1.5 fibers/cc. The mean of these differences was 0.4 fibers/cc. Where the 46 outside samples had higher concentrations than the inside, the range of differences varied from less than 0.1 fibers/cc to 4.9 fibers/cc. The variation between the high values of each side, 1.5 to 4.9, appears to be relatively large. This is the result of one pair of samples. The mean of the differences is only 0.6 fibers/cc for the outside samples in contrast to 0.4 fibers/cc for the inside samples. The difference here is not significant.

This phase of the study, the side-by-side paired samples, was also instituted to determine what the variation in the sampling procedure was for samples that had values close to the proposed standard of 2.0 fibers/cc. The side-by-side paired samples were arbitrarily broken down into three separate groups:

1. Samples with mean concentrations less than 1.5 fibers/cc,

2. Samples with mean concentrations between 1.5 and 2.5 fibers/cc; and

3. Samples with mean concentrations greater than 2.5 fibers/cc.

The results of the first group (samples with mean concentrations less than 1.5 fibers/cc) are shown in Table No. 14. There was an even distribution in the number of samples that had higher concentrations on either side, 28 and 27. The range of differences is the same, 0.2 fibers/cc, which is 10% of the proposed standard of 2.0 fibers/cc.

The breakdown for the mean concentrations for these samples which had values between 1.5 and 2.5 fibers/cc is shown in Table No. 15. There were 11 samples collected on the outside which had higher concentrations as compared with 5 samples collected on the inside. The outside samples had a higher range value, 1.6 fibers/cc, than did the inside samples, 0.9 fibers/cc. The mean of the differences was the same for both types of samples - 0.6 fibers/cc.

Table No. 16 presents the data for those samples with mean concentrations greater than 2.5 fibers/cc. The inside samples totaled 6, with a range of differences between 0.1 and 1.5 fibers/cc. The outside samples, of which there were 7, had a range of differences between 0.1 and 4.9 fibers/cc. Since this group includes all samples whose mean concentrations are greater than 2.5 fibers/cc it would be expected that a wider variation would occur between ranges of difference and means of differences because of the larger values involved. The "high" value of 1.5 fibers/cc for the inside samples was the result of a sample whose mean concentration was 4.7 fibers/cc. Whereas the "high" value of 4.9 fibers/cc for the outside samples resulted from a sample with a mean concentration of 12.3 fibers/cc. The mean of differences for the inside samples was 0.7 fibers/cc, whereas the outside samples had a value of 2.0 fibers/cc. Once again, these values are influenced by several high sample concentrations which, as expected, had higher differences between paired samples.

SUMMARY

There is a wide variation among types of plants as well as among individual plants within a given type. This is a result of many factors, including, but not limited to: different processing methods (e.g., spinning and weaving operations in textile plants as opposed to wet processes in the cement pipe plants); use of different types of asbestos (e.g., long fibers vs. short fibers); good housekeeping practices vs. bad housekeeping practices; properly designed and operated control systems; and modern machinery vs. antiquated machinery. Whereas a number of plants have mean concentrations at most operations which exceed not only the proposed standards but also the existing emergency standard, there is a significant number of plants which have values for most operations that do meet this criteria. There are a number of controlled plants as evidenced by their ability to meet the lower proposed standard.

An evaluation of the special study based on all the samples collected would indicate that there isn't any appreciable difference between samples that were collected on either the right or left sides or between samples that were collected side-by-side, especially for the samples that had low concentrations. As the concentrations got higher on the side-by-side samples, there might be a tendency for the outside sample to collect a higher concentration sample than the inside sample. When the proposed standard becomes law, the variation at the higher concentrations becomes moot.

CONCLUSIONS

The results of environmental surveys of the various asbestos plants reveal that dust concentration as measured by the membrane filter method are generally below the existing emergency standard. Due to the natural variability of the environment, categories of significantly different dust measurements must be broad. There are currently available methods by which dust concentrations to asbestos dust can be maintained at or below the existing standard as evidenced by the number of controlled plants in this study.

Based on the limited number of samples collected and analyzed during the special phase of this study, it would appear that position of the field monitor on the worker has no influence on the resulting concentration. There is little variability between samples collected side-by-side, especially at the lower concentrations.

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TABLE NO. 1

ASBESTOS CONCENTRATIONS BY TYPES OF PLANTS

Arithmetic Means

(Fibers >5µm in length per cc)

Type of Plants	Original Survey	First Resurvey	Second Resurvey	Over-all
Textile	4.4	9.6	9.0	7.6
Friction	4.9	2.4	4.9	4.3
Cement Pipe	2.6	1.7	-	2.2
Construction Materials	4.0	1.3	-	3.2
Insulation	13.9	12.9	-	13.4

TABLE NO. 2

ASBESTOS CONCENTRATIONS BY OPERATIONS

INSULATION PLANTS

Arithmetic Means

(Fibers>5µm in length per cc)

Operation	Over-all Individual Plant Average				
	Highest Plant	Second Highest Plant	Second Lowest Plant	Lowest Plant	Average of all Samples
Mixing	58.9	25.3	11.2	2.0	26.0
Forming	23.2	25.6	3.3	0.3	13.8
Finishing	34.9	27.1	5.1	0.8	16.0
Inspection & Packing	10.9	13.0	4.0	0.4	5.8
Means	26.2	13.5	4.9	0.5	11.8

TABLE NO. 3

ASBESTOS CONCENTRATIONS BY OPERATIONS

INSULATION PLANTS

Arithmetic Means

(Fibers>5µm in length per cc)

Operations	Original Survey	Resurvey	Over-all
Mixing	32.4	18.9	26.0
Forming	12.3	15.8	13.8
Finishing	16.2	15.8	16.0
Inspection & Packing	6.1	5.6	5.8
Means	13.9	12.9	13.4

TABLE NO. 4

ASBESTOS CONCENTRATIONS BY OPERATIONS

TEXTILE PLANTS

Arithmetic Means

(Fibers>5µm in length per cc)

Operation	Over-all Individual Plant Average				Average of all Samples
	Highest Plant	Second Highest Plant	Second Lowest Plant	Lowest Plant	
Fiber Preparation	15.6	27.9	5.7	5.2	12.1
Carding	32.7	20.4	4.4	4.3	11.1
Spinning	12.6	6.8	6.7	3.6	8.7
Twisting	12.9	9.0	8.3	3.1	7.7
Weaving	12.5	6.6	2.9	2.6	4.9
Means	14.2	9.9	4.5	3.4	7.3

TABLE NO. 5

ASBESTOS CONCENTRATIONS BY OPERATIONS

TEXTILE PLANTS (8)

Arithmetic Means

(Fibers>5µm in length per co)

Operation	Original Survey	First Resurvey	Second Resurvey	Over-all
Fiber Preparation	8.4	11.4	15.0	12.1
Carding	5.3	15.5	13.3	11.1
Spinning	4.6	12.1	9.0	8.7
Twisting	4.1	8.5	9.6	7.7
Winding	4.6	4.5	5.3	5.0
Weaving	3.1	5.8	6.3	4.9
Means	4.4	9.6	9.0	7.6

TABLE NO. 6

ASBESTOS CONCENTRATIONS BY OPERATIONS

FRICTION PLANTS

Arithmetic Means

(Fibers>5µm in length per cc)

Operation	Highest Plant	Second Highest Plant	Second Lowest Plant	Lowest Plant	Average of all Samples
Mixing	11.8	4.1	3.7	1.4	5.3
Forming	7.1	5.5	1.4	2.5	3.6
Hot Pressing	8.7	2.5	1.3	1.4	3.4
Grinding & Sanding	8.6	5.7	2.6	2.4	4.8
Cutting & Drilling	8.7	5.6	2.2	1.8	4.4
Inspection & Packing	7.7	5.8	3.4	1.7	3.8
Means	8.5	4.5	2.1	1.7	4.0

TABLE NO. 7

ASBESTOS CONCENTRATIONS BY OPERATIONS

FRICTION PLANTS

Arithmetic Means

(Fibers>5μm in length per cc)

Operation	Original Survey	First Resurvey	Second Resurvey	Over-all
Mixing	3.4	2.8	9.2	5.3
Forming	5.1	2.2	2.4	3.6
Hot Pressing	4.9	1.7	2.7	3.4
Grinding & Sanding	5.6	3.5	4.6	4.8
Cutting & Drilling	4.8	1.8	5.3	4.4
Inspection & Packing	5.0	1.5	3.2	3.8
Means	4.9	2.4	4.9	4.3

TABLE NO. 8

ASBESTOS CONCENTRATIONS BY OPERATIONS

CONSTRUCTION MATERIAL PLANTS

Arithmetic Means

(Fibers>5μm in length per cc)

Operation	Over-all Individual Plant Average		Average of all Samples
	Highest Plant	Lowest Plant	
Mixing	4.6	3.6	5.9
Forming	4.8	1.1	2.2
Finishing	-	4.3	3.4
Means	4.7	2.4	3.1

TABLE NO. 9

ASBESTOS CONCENTRATIONS BY OPERATIONS

CONSTRUCTION MATERIALS

Arithmetic Means

(Fibers>5µm in length per cc)

Operation	Original Survey	Resurvey	Over-all
Mixing	6.8	3.4	5.9
Forming	2.6	1.3	2.2
Finishing	4.8	0.9	3.4
Packing	2.6	0.2	1.9
Means	4.0	1.3	3.2

TABLE NO. 10

ASBESTOS CONCENTRATIONS BY OPERATIONS

CEMENT PIPE PLANTS

Arithmetic Means

(Fibers>5µm in length per cc)

Operation	Over-all Individual Plant Average				
	Highest Plant	Second Highest Plant	Second Lowest Plant	Lowest Plant	Average of all Samples
Mixing	4.9	3.5	4.2	1.6	3.4
Pipe Forming	2.0	1.4	0.5	1.1	1.9
Pipe Finishing	2.9	3.2	0.8	0.8	1.6
Coupling Finishing	9.5	2.9	1.1	1.1	2.5
Means	3.2	2.6	1.1	1.0	1.8

TABLE NO. 11

ASBESTOS CONCENTRATIONS BY OPERATIONS

CEMENT PIPE PLANTS

Arithmetic Means

(Fibers>5µm in length per cc)

Operation	Original Survey	Resurvey	Over-all
Mixing	4.4	2.2	3.4
Pipe Forming	2.0	1.6	1.9
Pipe Finishing	1.7	1.4	1.6
Coupling Finishing	3.3	1.7	2.5
Means	2.6	1.7	2.2

TABLE NO. 12

SAMPLING METHODS EVALUATION

Left-Right Paired Samples
Collected Simultaneously

Side with Higher Concentration	Number of Samples	Mean of Differences Fibers>5µm/cc		Mean of Differences Fibers>5µm/cc
		Low	High	
Right	11	<0.1	1.0	0.3
Left	11	<0.1	1.1	0.5

TABLE NO. 13

SAMPLING METHODS EVALUATION

Side by Side Paired Samples
Collected Simultaneously

Position with Higher Concentration	Number of Samples	Range of Differences Fibers>5µm/cc		Mean of Differences Fibers>5µm/cc
		Low	High	
Inside	38	<0.1	1.5	0.4
Outside	46	<0.1	4.9	0.6

TABLE NO. 14

SAMPLING METHODS EVALUATION

Side by Side Paired Samples
Collected Simultaneously

Samples with Mean Concentrations
Less than 1.5 Fibers>5µm in Length per cc

Position with Higher Concentration	Number of Samples	Range of Differences Fibers>5µm/cc		Mean of Differences Fibers>5µm/cc
		Low	High	
Inside	28	<0.1	0.7	0.2
Outside	27	<0.1	0.8	0.2

TABLE NO. 15

SAMPLING METHODS EVALUATION

Side by Side Paired Samples
Collected Simultaneously

Samples with Mean Concentrations
Between 1.5 and 2.5 Fibers >5μm in Length per cc

Position with Higher Concentration	Number of Samples	Range of Differences Fibers >5μm/cc		Mean of Differences Fibers >5μm/cc
		Low	High	
Inside	5	<0.1	0.9	0.6
Outside	11	<0.1	1.6	0.6

TABLE NO. 16

SAMPLING METHODS EVALUATION

Side by Side Paired Samples
Collected Simultaneously

Samples with Mean Concentrations
Greater than 2.5 Fibers >5μm in Length per cc

Position with Higher Concentration	Number of Samples	Mean of Differences Fibers >5μm/cc		Mean of Differences Fibers >5μm/cc
		Low	High	
Inside	6	0.1	1.5	0.7
Outside	7	0.1	4.9*	2.0

*Sample Concentration = 12.3 fibers >5μm in length per cc

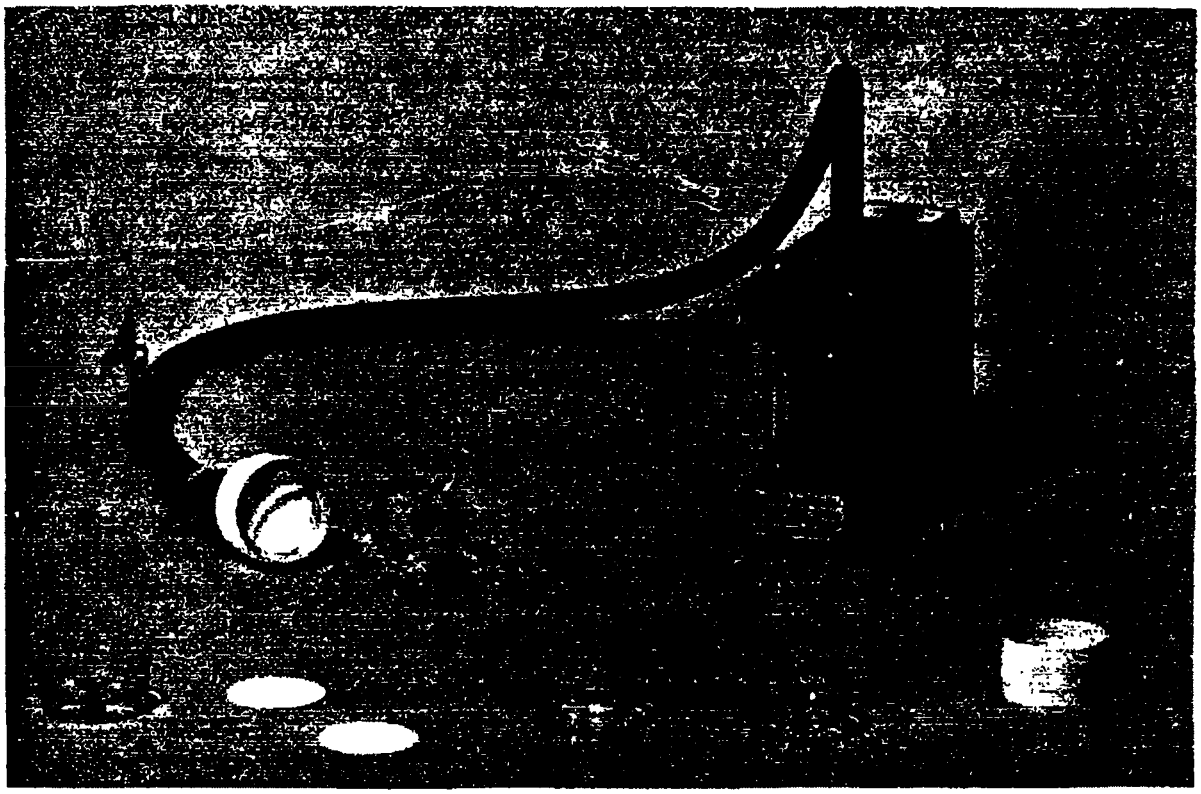

FIGURE 1

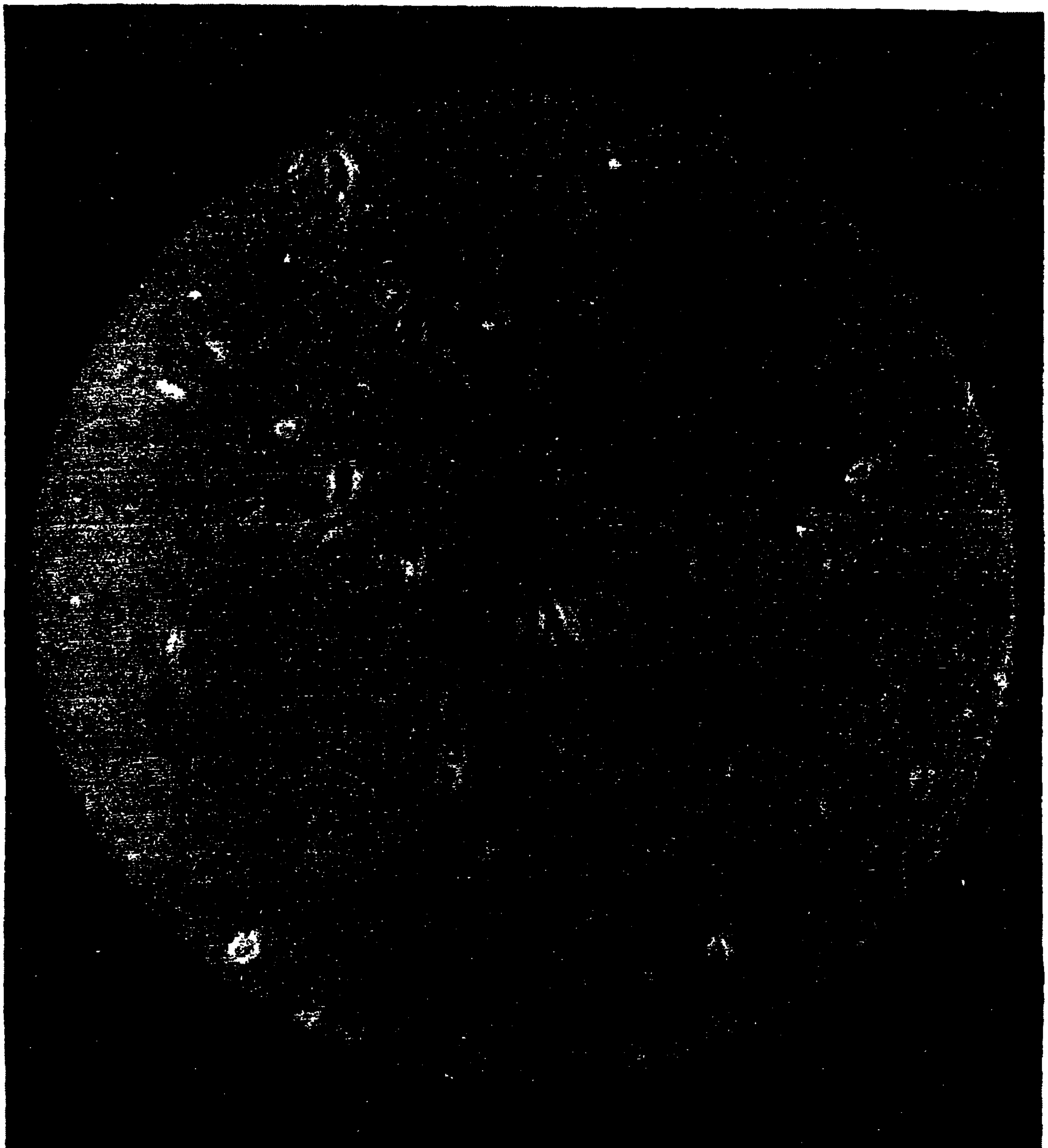

FIGURE 2

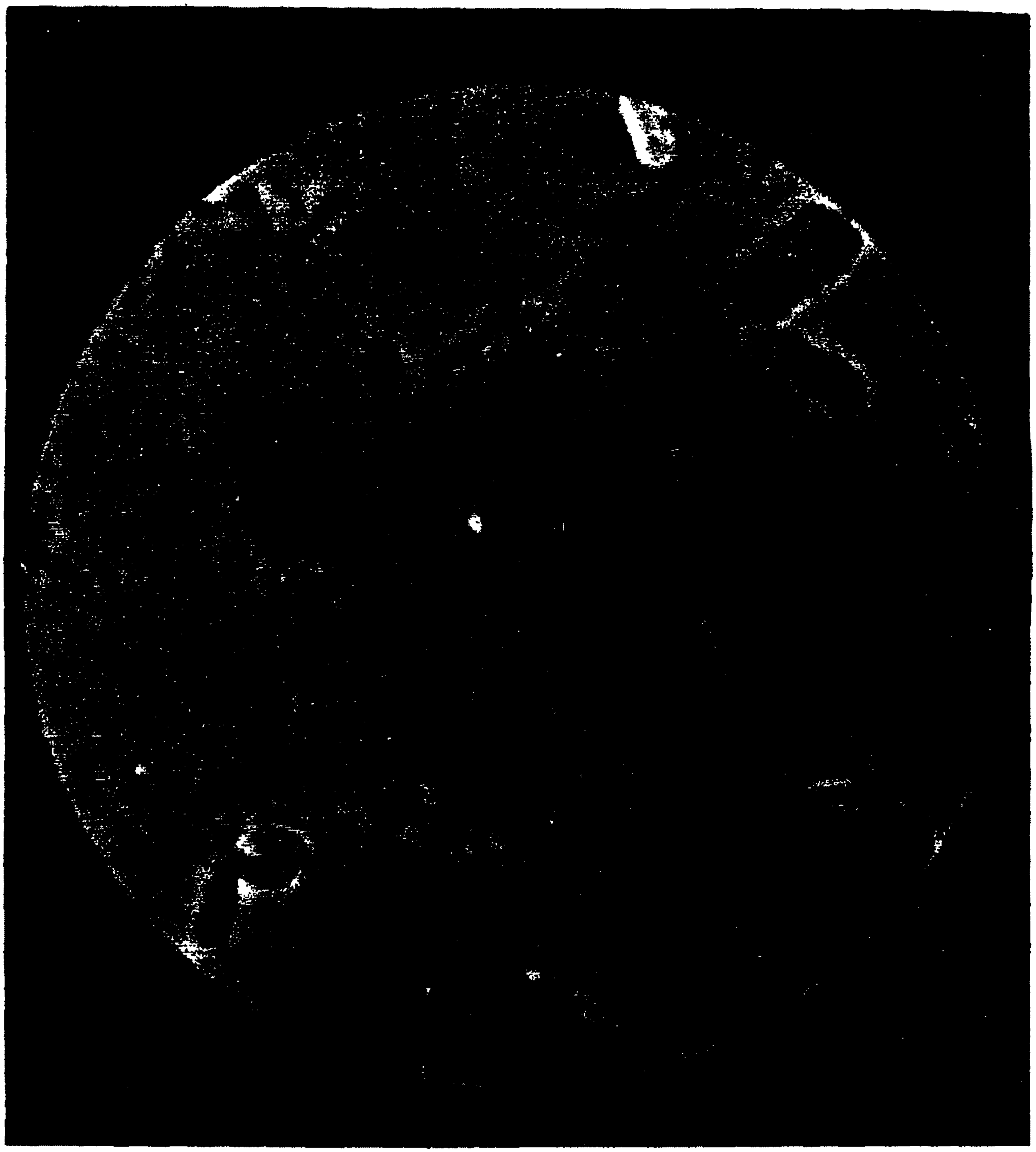

FIGURE 3

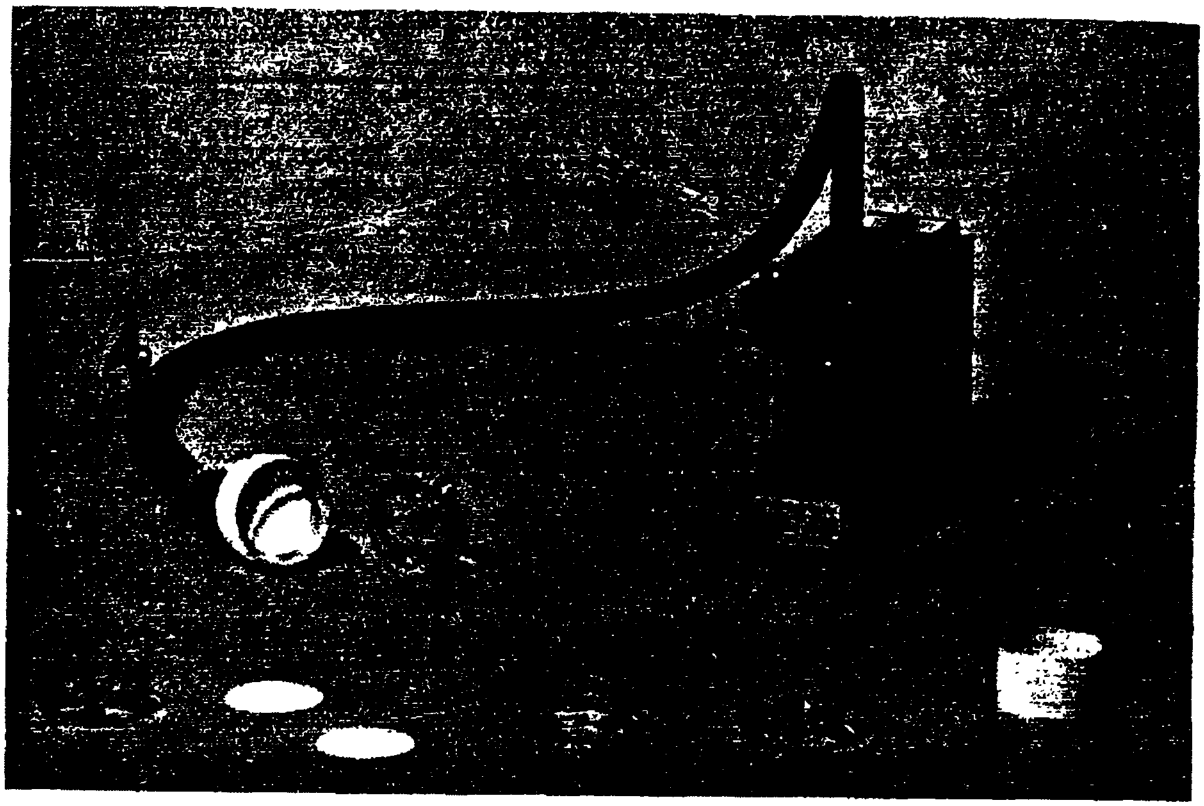

FIGURE 1

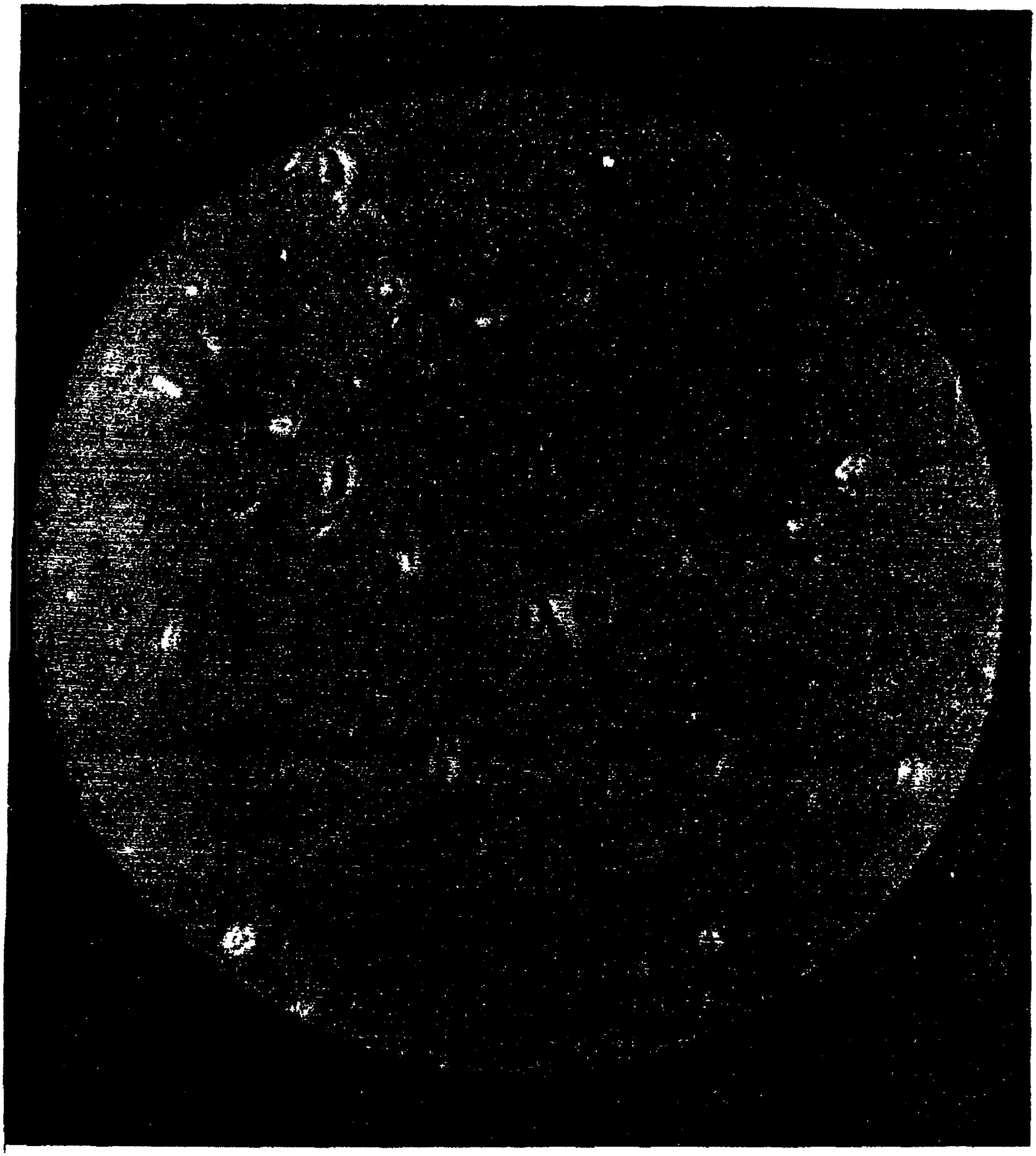

FIGURE 2

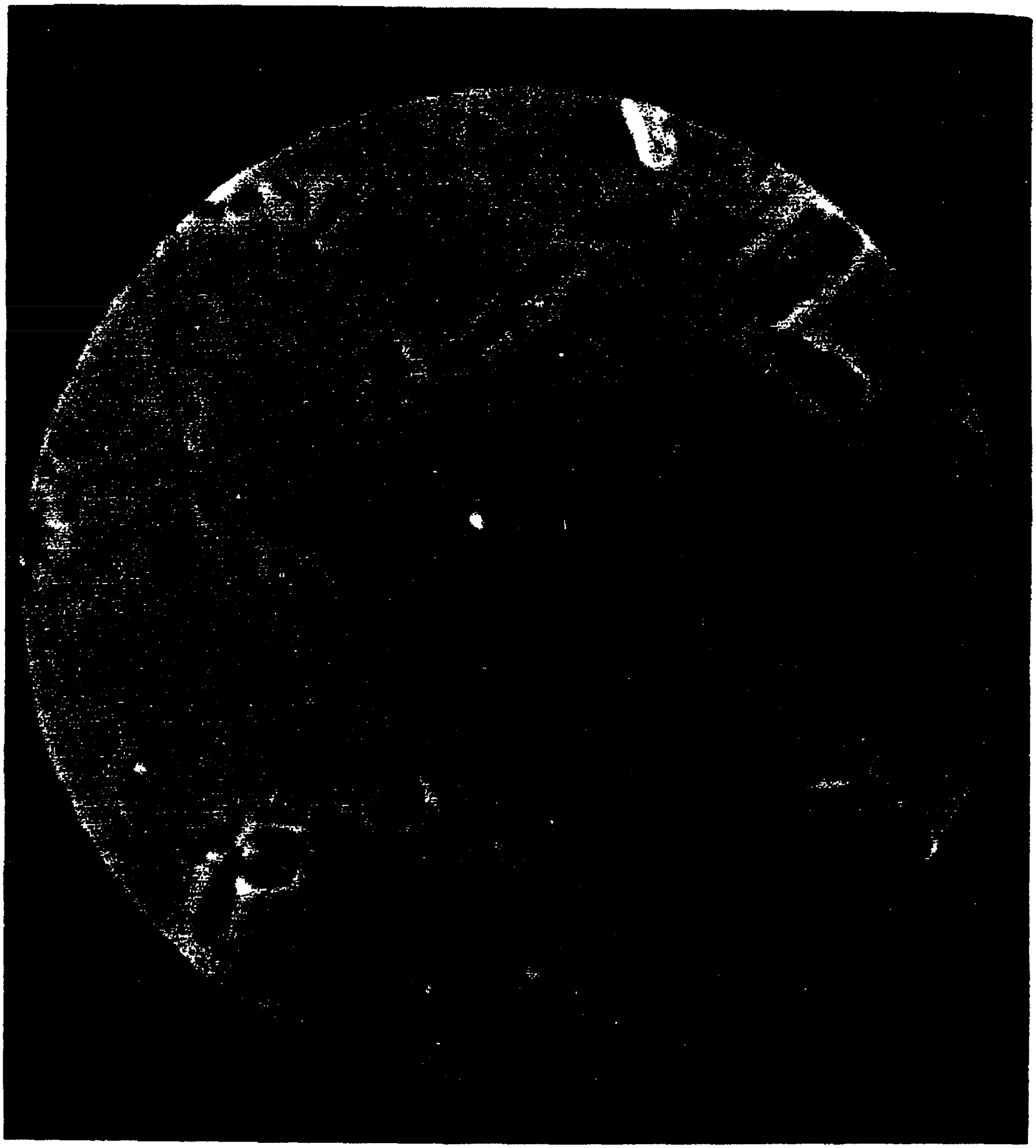

FIGURE 3