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HETA 86-038-1807
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MORRIS BEAN & COMPANY
YELLOW SPRINGS, OHIO

NIOSH INVESTIGATOR:
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I. SUMMARY

On October 29, 1985, the National Institute for Occupational Safety and Health (NIOSH) was requested to evaluate worker exposures to alumino-silicate ceramic fibers (hereafter referred to as ceramic fiber, CF) at Morris Bean & Company, Yellow Springs, Ohio,. The fibers potentially become airborne in the handling of Fiberfrax* insulation material which is used in the casting of aluminum parts. The request was prompted by changes in the manufacturers' material safety data sheets (MSDS) stating that ceramic fibers present a possible cancer hazard based on preliminary testing in laboratory animals and that at temperatures above 870°C (1600°F) these fibers can convert to cristobalite.

During a site visit conducted on January 23, 1986, air samples were collected to evaluate exposure to CF in the casting, shakeout and sand reclamation areas. Seven personal breathing zone samples ranged from 0.03 to 0.18 fibers per cubic centimeter (f/cc) and averaged 0.1 f/cc. The average for 5 area air samples was 0.40 f/cc, and these ranged from 0.06 to 0.75 f/cc. The two highest air concentrations, 0.48 and 0.75 f/cc) were from the sand reclamation area and were attributed to a malfunction in the equipment which allowed the fibers to escape through worn seals. Dimensional analysis of the fibers collected revealed that the diameters and lengths ranged from <0.25 - 4 um and 1.0 - >30 um, respectively. The majority of the fibers were of respirable size. No evidence of conversion to cristobalite was found in any of the samples.

Except for mild skin and face irritation, no health effects were reported during interviews with eight workers who handle the Fiberfrax* material. No exposure criteria have been developed that are specific for airborne ceramic fiber exposure. The fiber concentrations were well below the NIOSH recommended exposure level (REL) for fibrous glass (3 f/cc), which is for another type of man-made-mineral-fiber. It should be noted that this REL may not be appropriate for ceramic fiber exposures since ceramic fibers are more durable than fibrous glass and not cleared as well from the lung.

Insufficient data are currently available to determine the toxicity of ceramic fibers. Based on the preliminary animal test that show ceramic fibers may be carcinogenic, it would be prudent to minimize exposures. Until further epidemiologic and animal studies on the carcinogenicity of these fibers can be completed, manufacturer's recommendations for handling these materials, which are discussed in Section VIII, should be followed.

KEYWORDS: SIC 3361 (Foundries, Aluminum) Man-made-mineral-fibers, ceramic fibers, alumino-silicate fibers.

II. INTRODUCTION

On October 29, 1985, the National Institute for Occupational Safety and Health (NIOSH) received a request from Local 6931 of the United Steel Workers of America to investigate exposures of workers at Morris Bean & Company in the molding, casting and maintenance departments to ceramic fibers. Workers noticed a revision in the material safety data sheet (MSDS) for Fiberfrax* insulation materials which had changed from a cautionary statement that ceramic fibers can cause temporary skin and upper respiratory irritation to a warning that ceramic fibers pose a possible cancer hazard based on tests with laboratory animals, and that cristobolite (crystalline silica) is formed at temperatures above 1600°F.

A walk-through survey, which was conducted on December 12, 1985 to obtain information necessary for developing an industrial hygiene sampling protocol, was summarized in a NIOSH letter to union and company officials dated January 2, 1986. A followup industrial hygiene survey to measure exposures to ceramic fibers was conducted on January 21-24, 1986. On February 6, 1986, a letter was sent to the union and management which recapped the activities of the followup survey and provided specific recommendations aimed at reducing exposures. Results from the followup survey were reported in a letter on October 31, 1986. Analysis of the samples was delayed due to a backlog of samples awaiting transmission electron microscopy (TEM) evaluation.

III. BACKGROUND

Morris Bean & Company, Yellow Springs, Ohio is an aluminum foundry primarily involved with the casting of impellers and turbo-chargers from 4 inches to 60 inches in diameter. The current workforce numbers about 81 hourly and 56 salary employees. The Yellow Springs facility has been in operation since 1952. The current workforce of 137 is down from a peak of 400 in the early 1970's. Since layoffs have occurred by seniority, most hourly workers now have over 15 years service. The only major change in the facility has been the addition of sand reclamation equipment.

At various stages of the foundry processes, workers handle Fiberfrax* insulation material. The Fiberfrax*, which is manufactured by Sohio Carborundum, is handled in several different forms (blanket insulation, rigid sheeting and cylindrical risers). As this material is handled or cut by bandsaw, fibers potentially become airborne. Although only 4-5 workers actually handle the Fiberfrax*, others nearby are also potentially exposed. A make-shift local exhaust system, using furnace filters, had been made in October, 1985 for one bandsaw operation to help reduce CF exposures.

IV. EVALUATION METHODS

Twelve air samples (7 personal breathing zone and 5 area) were collected on 25 milliliter (mm) mixed cellulose ester filters at a flow rate of 500 cubic centimeters per minute (cc/min) and analyzed for fibers using transmission electron microscopy (TEM). A section was cut from each filter with a #6 cork-bore and prepared for TEM analysis via the Zumwalde-Dement procedure outlined in NIOSH Publication Number 77-204.[1] One hundred fields, having a total area of 0.7 square millimeters, were examined on each preparation. Fiber counting and sizing were performed at 10,000 x magnification. Elemental spectra were obtained for all fibers where size and orientation permitted.

Eleven air samples (7 personal breathing zone and 4 area) for silica were collected on 37 mm PVC filters which were preceded by a 10 mm cyclone. The sampling rate, which was set at 1.7 lpm, was selected so that the material collected on the filter would represent respirable-sized particles. Each of these samples was analyzed for silica using x-ray powder diffraction (XRD). The purpose of this sampling was to determine if any of the CF had converted to cristobalite. Since silica sand was used in the molding area, any silica found on the filters could have been due to the sand and not the conversion of CF.

V. EVALUATION CRITERIA

A. Ceramic Fibers

Man-made mineral fibers (MMMF)(also referred to as man-made vitreous fibers, MMVF) generally refer to amorphous glass fibers made from molten slag, rock or glass. Four general classifications of MMMF exist; slag wools, rock wools, glass, and ceramic wools and filaments. Unlike asbestos, MMMF are amorphous, generally have a larger diameter and fracture in a transverse plane. (Asbestos fibers fracture longitudinally, producing a large number of fine fibrils.) The fibers referred to in this report are the alumino-silicate ceramic fibers, produced by melting Kaolin clay, or alumina and silica, to form alumino-silicate glasses which are "blown" or "spun" to form the fibers. They are generally used for high temperature applications and are produced in blanket, modular block, paper and textile forms.[2]

B. Inhalation and Deposition Properties of Fibers

The airways of the human respiratory system are made of a series of branching tubes which decrease in size and diameter until they dead-end at the alveoli. Alveoli are small thin-walled air sacs designed to allow quick transport of inhaled gases into the bloodstream. Along with gases, different sized particles can also be inhaled. Most particles are deposited in the nose, pharynx, or trachea. Particles deposited in the upper portions of the airway are cleared by special ciliated cells which line the air passages (mucociliary clearance). Smaller sized particles can deposit in the deeper portions of the airways, and are cleared by another form of the body's defense mechanism (alveolar clearance). Small particles are engulfed by macrophages, scavanger cells, which attempt to clear the particles from the lung by secreting powerful enzymes or by moving the particles to the lymphatic system or back up the airways. Particles which deposit in the upper airways are more likely to be removed by the lung's clearance mechanisms while smaller particles, which reach the deeper portions of the airway, are less efficiently cleared.[4]

Fibers, by definition, have a length to diameter ratio (aspect ratio) greater than 3:1. Although fiber shape might seem to preclude deposition in the deeper portions of the airway, inhaled fibers can align parallel to the airway and act aerodynamically as if they were spheres.[3] As the ratio of fiber length to diameter increases, fiber length begins to affect the properties of fiber inhalation and deposition.[4] (Nominal fiber diameter and fiber length determine fiber aerodynamic equivalent diameter. As the fiber aspect ratio increases, the ratio of fiber aerodynamic equivalent diameter to nominal fiber diameter approaches a constant which varies from 2.5 to 3.5. For example, a fiber of 1 micrometer (uM) nominal diameter and 20 uM long can have aerodynamic properties of a 3 uM spherical particle.)[3] Particles with diameters less than 3.5 uM are capable of reaching the deeper portions of the human airway.[4] In rats, fibers with a mass median aerodynamic diameter between 3 and 6 uM were capable of alveolar deposition, although at much reduced levels (1-2%).[5]

Animal studies [6,7] indicate that fibers longer than 10-15 uM may be less efficiently cleared from the lungs by macrophage mediated processes. In one study ceramic fiber clearance reached a maximum at fiber lengths of 11-15 uM and then decreased with increasing fiber length.[8]

C. Animal Studies

Concern for the carcinogenic potential of MMMF increased in the 1970's, after a number of intra-pleural (placement of glass fibers inside the pleural cavity) and intra-peritoneal injection studies compared the biological response of animals to asbestos, a naturally occurring fiberous mineral, and man-made glass fibers. Although glass fibers were much less carcinogenic than asbestos fibers, certain sized glass fibers were also capable of inducing mesothelioma. The authors hypothesized that fibrous shape and not chemical composition may determine carcinogenic potential;[9,10] fibers less than or equal to 1.5 um in diameter and greater than 8 um in length had the highest probability of inducing the mesothelioma.[9] Other studies have indicated that fiber durability may also affect carcinogenic potential.[7,8,11,12] After inhalation and deposition in the lungs, fibers which maintain their integrity for longer periods may exert greater carcinogenic effects on lung tissue.[7,8] Asbestos fibers are stable in physiologic solutions that completely dissolve glass fibers.[11] Other solubility studies have shown that ceramic fibers are more durable than mineral wool fibers, which are more durable than glass fibers.[12]

Injection studies in animals are commonly used to assess toxicological properties of chemicals and other materials. These studies can identify carcinogenic potential, however, they by-pass many defense mechanisms and do not always correlate well with typical human routes of exposure. Results from these studies can be of questionable validity when extrapolated to human populations. To overcome these limitations, researchers studying fiber carcinogenicity have exposed animals to aerosolized particles of MMMF. Several inhalation studies have not shown an association between exposure to inhaled fibrous glass and tumor production.[13,14,15] One researcher concludes that fibrous glass dust may act like an inert dust because it is rapidly removed from the lung by the lung's clearance mechanism.[14] However, in one study, malignant tumors were identified in 2% of rats exposed to aerosolized samples of glass microfibre, rock wool, and glass wool (n=48 for all three studies).[16]

Most studies that have been conducted to determine the carcinogenic potential of MMMF have exposed animals to fibrous glass and mineral wool. Ceramic fibers have only recently been included in animal toxicity studies. A recent study compared pulmonary lesions in rats and hamsters after intra-peritoneal and intra-tracheal injection of fibrous glass, mineral wool, crocidolite asbestos, andrefractory ceramic fibers.[17] After intra-tracheal exposure, only those exposed to asbestos developed primary alveolar tumors. After intra-peritoneal injection, abdominal mesotheliomas developed in 80% of the rats implanted with ceramic fibers or asbestos, but only in 32% of those implanted with fibrous glass.[17] In another CF intra-peritoneal injection study on rats, 3 of 32 rats developed peritoneal tumors, 1 mesothelioma, and 2 fibrosarcomas.[18]

These studies also exposed animals to aerosolized ceramic fiber particles. In the first study, one of 70 Syrian hamsters developed a mesothelioma after 10 months of CF inhalation exposure, none of the Osborne-Mendel (OM) rats developed tumors.[17] By comparison, none of the asbestos inhalation-exposed hamsters developed tumors, although, 3 of the 57 asbestos exposed OM rats developed primary tumors (1 mesothelioma, 2 bronchoalveolar tumors). None of the animals exposed to fibrous glass developed tumors. Fibrosis developed in 22% (12) of the CF exposed rats, but only in one of the CF exposed hamsters. By comparison, only 2%-7% of rats (n ranged from 52 to 70) exposed to four types of fibrous glass developed fibrosis. In the second study, 8 of 48 Wistar Rats developed pulmonary neoplasms after inhalation exposure to CF. The tumors were identified as malignant histiocytomas and carcinomas with squamous histological patterns.[18] Generation of fiber aerosols resulted in unusually shaped fibers and a large quantity of non-fibrous particulates. Concern has been expressed by industry representatives that the dust cloud may have been contaminated by metal particulate matter abraded from the blades used in the dust generator and may have contributed to the development of lesions.[19]

D. Epidemiologic Studies

Many epidemiological studies have been conducted on workers exposed to MMMF, although none of them have studied ceramic fiber exposures. The studies on MMMF have not identified a consistent dose or duration of exposure association between fibrous glass exposure and cancer. In particular, two large historical cohort studies have been conducted.[20,21] Saracci[20] studied 25,000 workers in 13 European glass-wool and rock-wool plants, while Enterline[21] studied at 16,000 workers in 17 American glass, rock, slag-wool, and continuous filament plants. In both studies, lung cancer rates were elevated after 30 years from the time of first employment (SMR=192 and 138 respectively), however, no consistent association was detected between duration of employment or type of fiber exposure and cancer mortality. Since the increases in lung cancer rates are more prominent for certain segments of the MMMF industry (mineral wool), Saracci hypothesizes that 30 years ago environmental exposures and conditions in these segments of the MMMF industry may have been very different from today.[22] Neither study addressed smoking habits or the presence of other environmental substances likely to affect worker health. Results of other epidemiologic investigations in the MMMF industry have recently been reviewed.[22]

Despite all the studies conducted on workers exposed to fibrous glass and mineral wool, no epidemiological studies have been conducted on ceramic fiber producer or user industry populations. Extrapolating from the health effects observed in the studies performed on fiberous glass and mineral wool to CF exposures, may not be appropriate because parameters affecting fiber carcinogenic potential--fiber dimension and rate of dissolution, may not be comparable. Under experimental conditions, the rate of ceramic fiber clearance from the lung was much slower than the rate for mineral wool clearance. Unlike mineral wool and fibrous glass, ceramic fibers are more durable and do not undergo dissolution in the lung.[8]

E. Conversion of Ceramic Fibers to Cristobalite (free silica)

Silica is the most common mineral found in the earth and commonly appears in crystalline form as quartz. Besides quartz, other crystalline and amorphous forms of silica are found. After heating, naturally occurring free silica can undergo conversion to crystalline tridymite and then to crystalline cristobalite.[25]

Inhalation of respirable particles of crystalline free silica can produce silicosis, a disabling form of pulmonary fibrosis characterized by the presence of nodulation in the lungs.[23] Three forms of silicosis have been identified; chronic silicosis developing after 30 to 40 years of low dose occupational exposure; accelerated silicosis developing after 4 to 8 years of high exposure and generally seen in sand blasters; and acute silicosis, a rare form of the disease occurring after 1 to 3 years of heavy exposure.[24] Smoking habits and respiratory infections can accelerate the development of the disease.[25]

Conversion of ceramic fibers to crystalline silica, (cristobalite) has been reported to occur at 1000°C (1742°F)[(26)], and 1150°C (2012°F)[(27)]. In the latter study, conversion to mullite (an aluminum-silicate) occurred rapidly while subsequent conversion to cristobalite required 2 weeks at sustained temperatures. A recent study of two types of alumino-silicate CF, Kaowool* and Fiberfrax*, confirmed that fiber conversion to cristobalite may require sustained temperatures over a period of days to weeks. Both brands of CF converted to mullite within a few hours, although only Fiberfrax*, with higher levels of titanium, sodium and potassium oxides, subsequently converted to cristobalite. The authors suggest that oxide impurities may aid the conversion of mullite into cristobalite.[28]

Removal of ceramic fiber insulation from high heat furnaces may present the greatest potential for exposure to fibers that have converted to cristobalite. Furnace insulation can be in service for many hours at temperatures over 1000°C. In a recent study of CF used in furnaces, cristobalite formation was estimated to occur at 920°C (1700°F).[29] Air and bulk samples collected during insulation removal identified cristobalite at levels up to 15% to 20% of the sample. The insulation was exposed to temperatures which ranged from 270°C to 1350°C (500°F - 2550°F), with exposure times ranging from 100 hours to 470 hours.[29]

VI. RESULTS

Airborne fiber concentrations (Table 1) ranged from 0.03 to 0.18 f/cc for the personal breathing zone samples and averaged 0.1 f/cc. The average for the 5 area air samples was 0.37 f/cc and these ranged from 0.06 to 0.75 f/cc. The two highest air concentrations (0.48 and 0.75 f/cc) were from the sand reclaim areas and were the result of a leaky seal in the machinery.

Figures 1 through 5 graphically show the results of the second phase of the fiber analysis which determined the diameter and length of the fibers counted in 5 of the 12 samples. All of the fibers sized were less than 4 um in diameter and were predominantly (96%) less than 2 um. Fiber lengths varied from 1 to >30 um; 88% were less than 20 um.

There was no evidence of a conversion of ceramic fiber to cristobalite.

VII. DISCUSSION

Determination of the toxicity of MMMF has primarily relied on data from animal experiments and epidemiologic studies. Animal experiments have attempted to determine the toxicity of fibers by controlling exposure variables such as type and dose of fiber exposure. The validity of extrapolating results of animal studies to human populations is an important limitation to these studies. Epidemiologic studies have attempted to quantitate the risk of developing respiratory disease based on occupational exposure to these fibers. The limitations of both approaches are discussed in more detail in another publication.[30]

No epidemiologic studies have investigated the health effects of worker exposure to ceramic fibers. Studies of ceramic fiber exposures in production plants have identified a range of average airborne fiber concentrations, 0.01 - 3.4 fibers/cm^3.[31] The concentrations of airborne ceramic fibers detected in this study (0.03 to 0.75 f/cc) are below standards currently in effect for fibrous glass (3 fibers per cubic centimeter of air having a diameter equal to or less than 3.5 micrometers (um) and a length equal to or greater than 10 micrometers), determined as a time-weighted average (TWA) concentration for up to a 10-hour work shift in a 40-hour workweek.[1] There are no exposure criteria that specifically apply to ceramic fibers.

All airborne fibers had diameters less than 4 micrometers (um) and were predominantly (96%) less than 2 um. Eighty-eight percent of the fibers were less than 20 um in length and within a respirable size range.

Two animal studies have identified tumor production after long-term inhalation exposure to aluminum silicate fibers. Differences in experimental methodology, constituents of the dust clouds, animal species, and types of tumors, make comparison of results between the studies difficult. Tumor development after inhalation exposure to glass and rock wool fibers has also been reported. Current evidence suggests that fiber size and durability, rather than chemical composition, may determine carcinogenic potential.

Increased durability of ceramic fibers relative to the other forms of MMMF may play a role in their toxic potential. Ceramic fibers do not undergo dissolution as readily as glass fibers under laboratory conditions,[12] and are not as readily cleared from the lungs.[8] The need for further evaluation of the fibrogenic and carcinogenic potential of aluminum silicate ceramic fibers and glass fibers is warranted.

Ceramic fiber production is growing but remains a small proportion (1%) of the total MMMF industry. It is estimated that only 600 workers are currently involved in CF production in the U.S.[19] Many more workers are exposed to CF in user industry occupations. However, most user industry workers may not be an appropriate cohort to study because their duration and type of fiber exposure are difficult to define. Also, these groups of workers are potentially exposed to other agents. Cancer does not usually develop until 20 to 30 years after exposure to a carcinogen. Workers at Morris Bean & Company are not suitable exposure groups for epidemiological studies due to the small number of workers exposed.

Animal studies sponsored by the Thermal Insulation and Manufacturers Association are being conducted to examine the intra-pleural, intra-tracheal, and inhalation toxic potential of four types of CF in exposed hamsters and rats. The results from this chronic toxicity study are not expected until 1989. While further animal studies are being performed, a suitable cohort of workers with a sufficient latency period to ceramic fibers (15 to 20 years) should be investigated.

There was no evidence from the data collected in this study of conversion of ceramic fibers to cristobalite. Presumably, the Fiberfrax* material does not reach high enough temperatures for long enough periods.

On the basis of available toxicity data, it would be prudent to minimize exposures to ceramic fibers through the use of engineering controls and personal protective equipment and good work practices.

VIII. RECOMMENDATIONS

1. In each situation where the Fiberfrax* material is used and not readily controlled by exhaust ventilation, consider if its use is really necessary. If it is, consider alternative substances or methods that will eliminate MMMF exposure where possible. For example, the handling of the blanket Fiberfrax* in the melt service areas is particularly troublesome since fibers are generated and engineering control in the form of exhaust ventilation is not readily adaptable.

2. Any stationary operation where the Fiberfrax* material is cut, such as the bandsaws in the molding and melt service areas, should be equipped with local exhaust emptying to the outside of the building and should have a minimum of 100 fpm capture velocity at the face of the hood. The exhaust configuration should handle the bandsaw table and the area beneath the table. While the recently installed filtering equipment on the bandsaw used for cutting the riser sleeves is marginally effective in its capture of table top emissions (evidenced by smoke tube testing) the actual capture velocities ranged from 20-40 fpm. Also it is very unlikely that the filtering system, consisting of 3 furnace type filters in series followed by a standard terminal bag filter such as might be used in a carpentry shop, would remove the respirable size fibers that are too small to be seen by the naked eye. Perhaps one, centrally located bandsaw could be set up with the proper exhaust and shared by all who cut the risers and board material.

3. For those situations where local exhaust cannot be effectively used to control exposures to the fibers, or as a temporary interim measure until local exhaust are installed and tested, protective equipment should be used to minimize exposures to the fibers. The protection measures you have instituted should be considered a minimum and anyone handling the Fiberfrax* should follow those guidelines. The only exception would be that half-mask respirators with high efficiency filters (HEPA) should be used as a minimum.

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XI. DISTRIBUTION AND AVAILABILITY OF REPORT

Copies of this report are currently available upon request from NIOSH, Division of Standards Development and Technology Transfer, Publications Dissemination Section, 4676 Columbia Parkway, Cincinnati, Ohio 45226. After 90 days, the report will be available through the National Technical Information Service (NTIS), 5285 Port Royal, Springfield, Virginia 22161. Information regarding its availability through NTIS can be obtained from NIOSH Publications Office at the Cincinnati address. Copies of this report have been sent to:

1. Morris Bean & Company, Yellow Spring, Ohio
2. United Steel Workers of America, Local 6931
4. OSHA, Region I

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

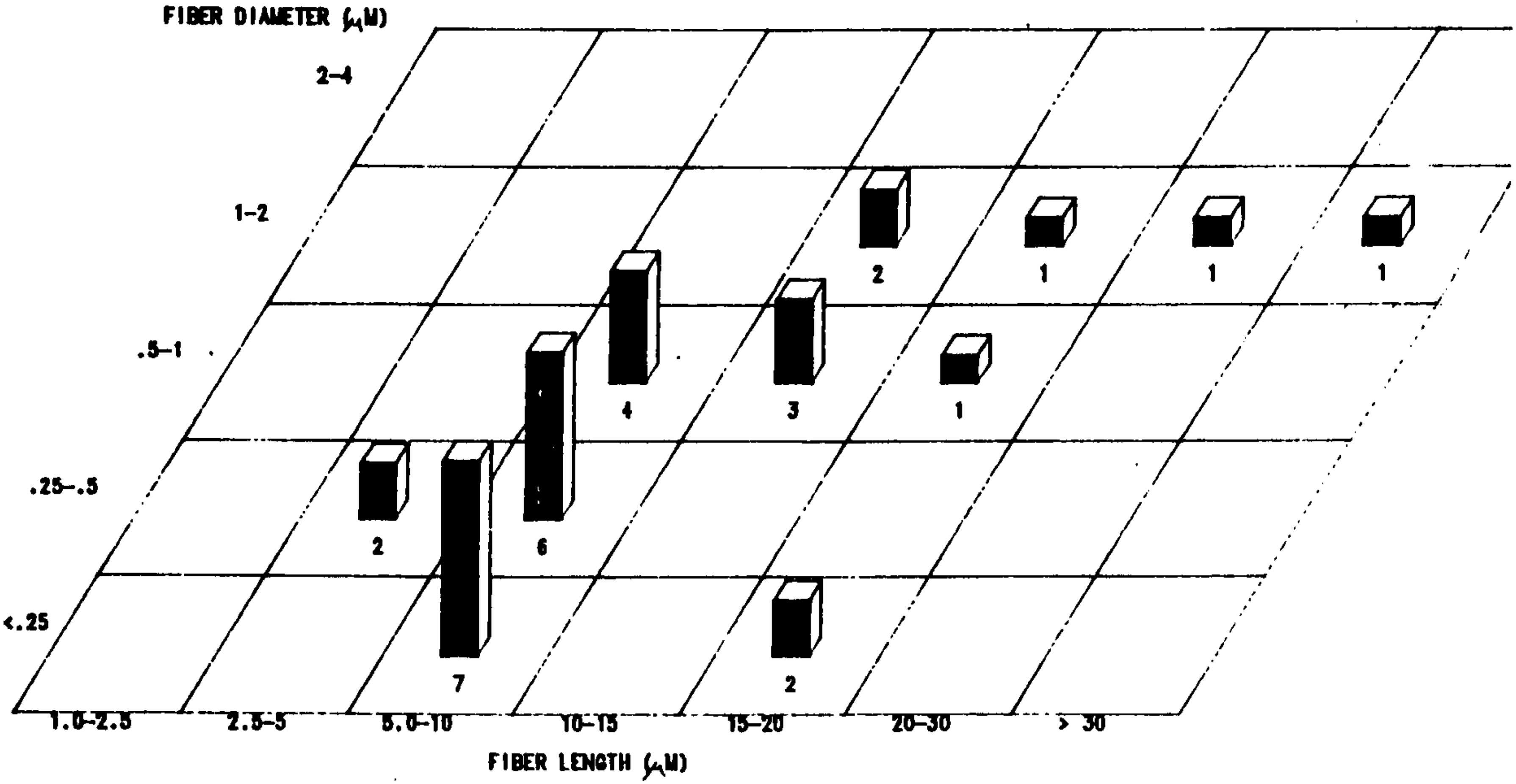
TABLE I
Airborne Fibers (MMMF)[1]

Morris Bean Company
HETA 86-038
January 23, 1986

JOB/LOCATION	Sample Type[2]	Sampling Time	Sample Volume (L)	Fiber Concentration[3] f/cc	Comments
Molder/Leader	PBZ	0745-1510	208	0.05	
Molder	PBZ	0745-1510	208	0.08	
Molder/Slinger	PBZ	0745-1510	208	0.03	
Melt SVCS.,Low Pres.	PBZ	0815-1459	187	0.04	
Melt SVCS., Laddle	PBZ	0815-1516	196	0.18	
Bandsaw, Mold	A	1313-1348	18	0.27	During cutting of risers
Bandsaw, Laddle	A	0830-1440	185	0.30	
Dry Mix Area	A	1230-1450	70	0.06	
Shakeout Operator	PBZ	1608-1814	64	0.13	
Shakeout Operator	PBZ	1610-1816	64	0.17	
Sand Reclaim,[4] Low	A	1645-1907	71	0.48	3 feet above floor
Sand Reclaim,[4] High	A	1645-1907	69	0.75	On catwalk
Blank	-	-	-	ND	
Blank	-	-	-	ND	

(1) MMMF = Man-made-mineral-fiber
(2) PBZ = Personal Breathing Zone; A = Area
(3) f/cc = fibers per cubic centimeter of air
(4) Sand reclaimer was malfunctioning; there were major leaks causing the fine reclaimed sand to become airborne.

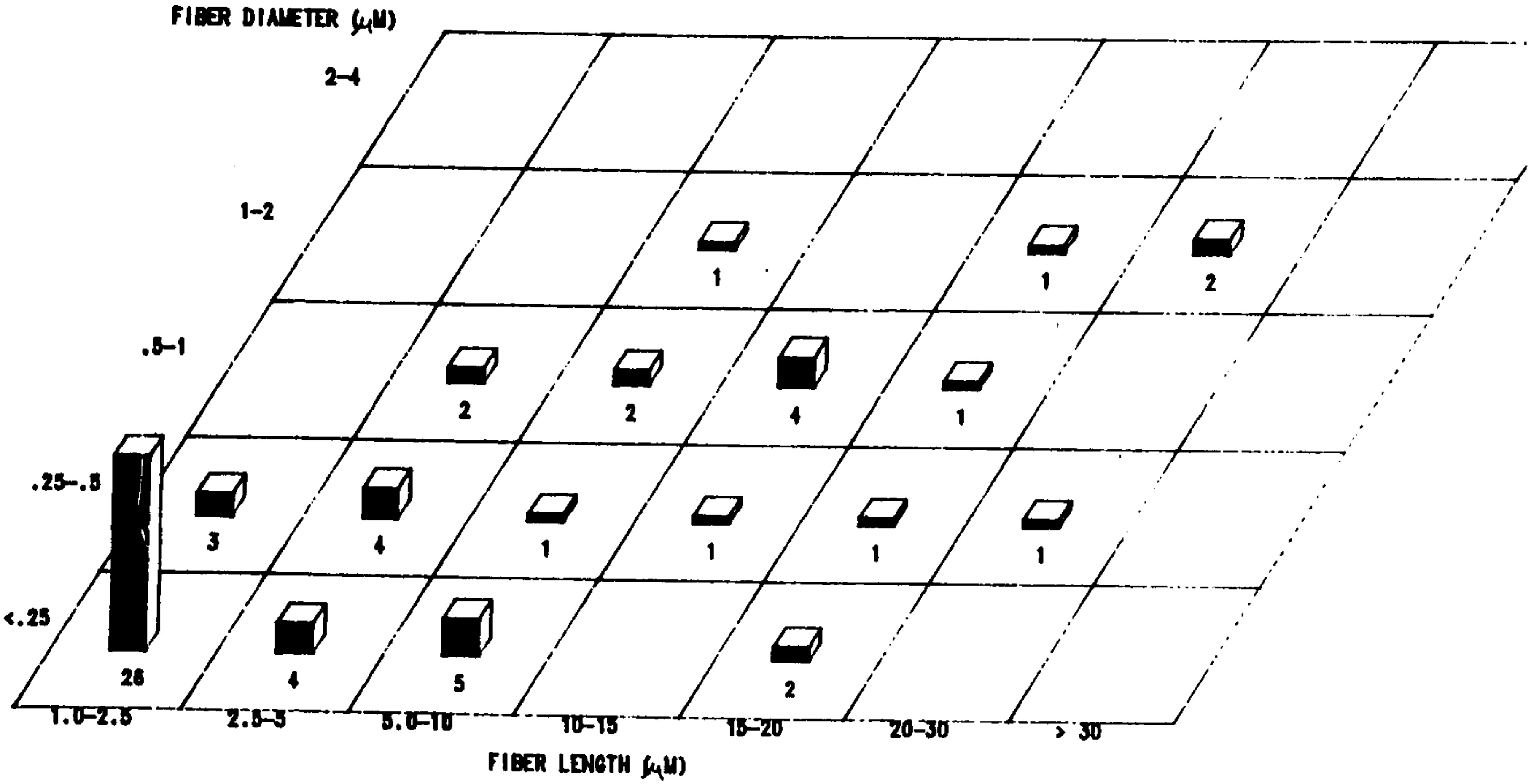
FIGURE 1
FIBERFRAX®, DURABOARD: ALUMINUM CASTING
MORRIS BEAN
JANUARY, 1986



TOTAL FIBERS COUNTED: 30
AIRBORNE FIBER CONCENTRATION: 0.08 F/CC

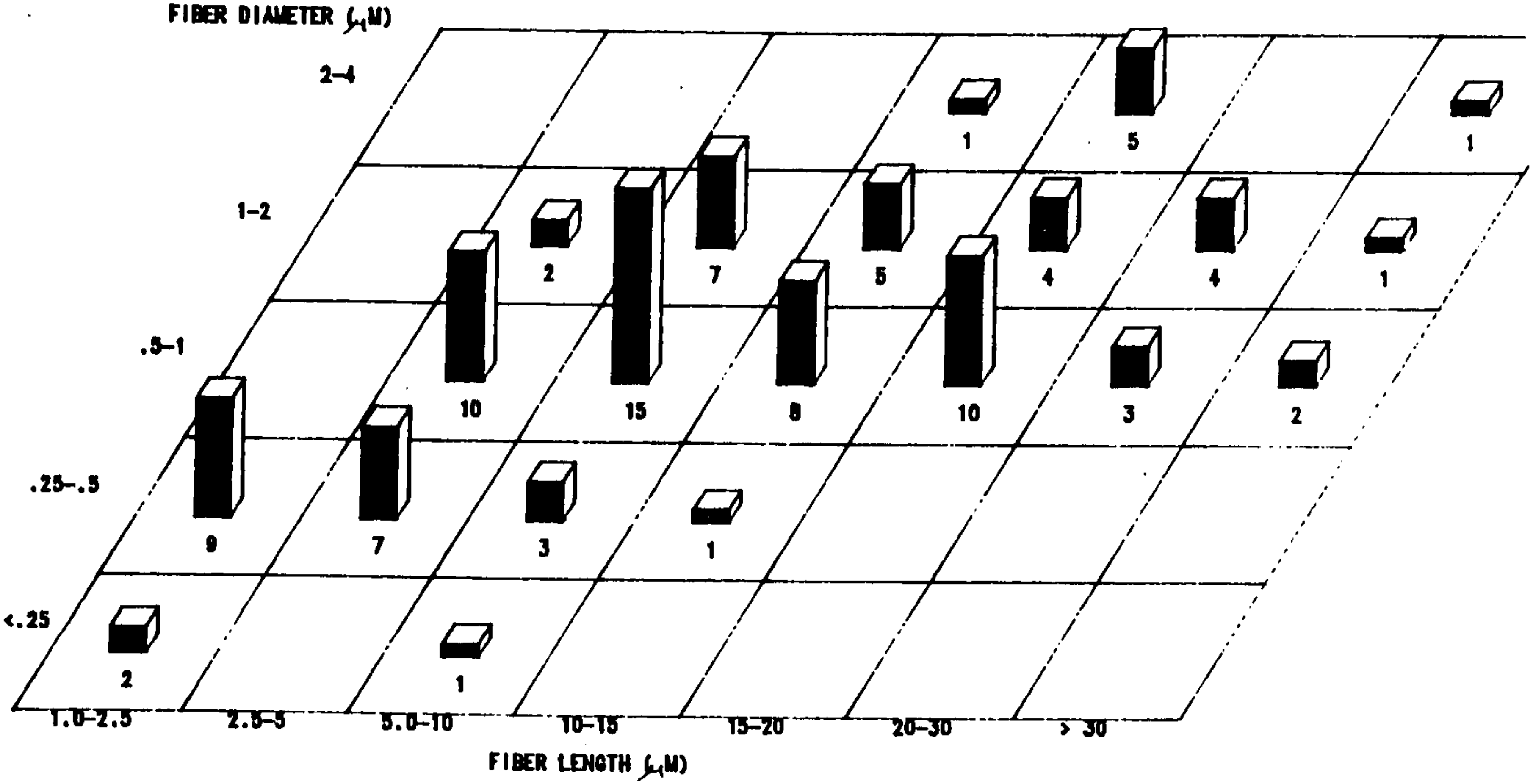
FIGURE 2

FIBERFRAX®, DURA BLANKET: MELT SERVICES, LADDLE
MORRIS BEAN
JANUARY, 1986



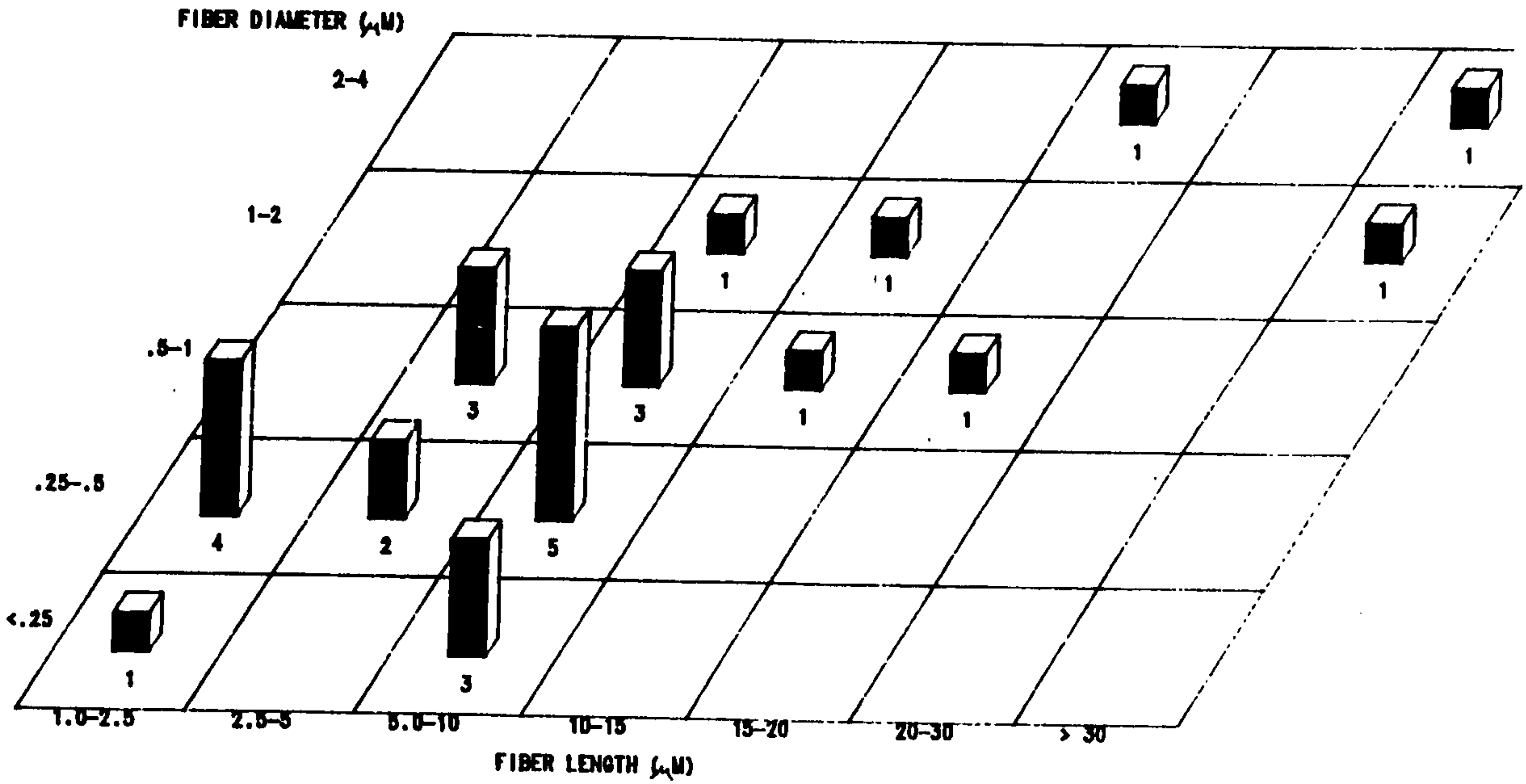
TOTAL FIBERS COUNTED: 64
AIRBORNE FIBER CONCENTRATION: 0.18 F/CC

FIGURE 3
FIBERFRAX®, DURABOARD: BANDSAW, MELT SERVICES
MORRIS BEAN
JANUARY, 1986



TOTAL FIBERS COUNTED: 101
AIRBORNE FIBER CONCENTRATION: 0.30 F/CC

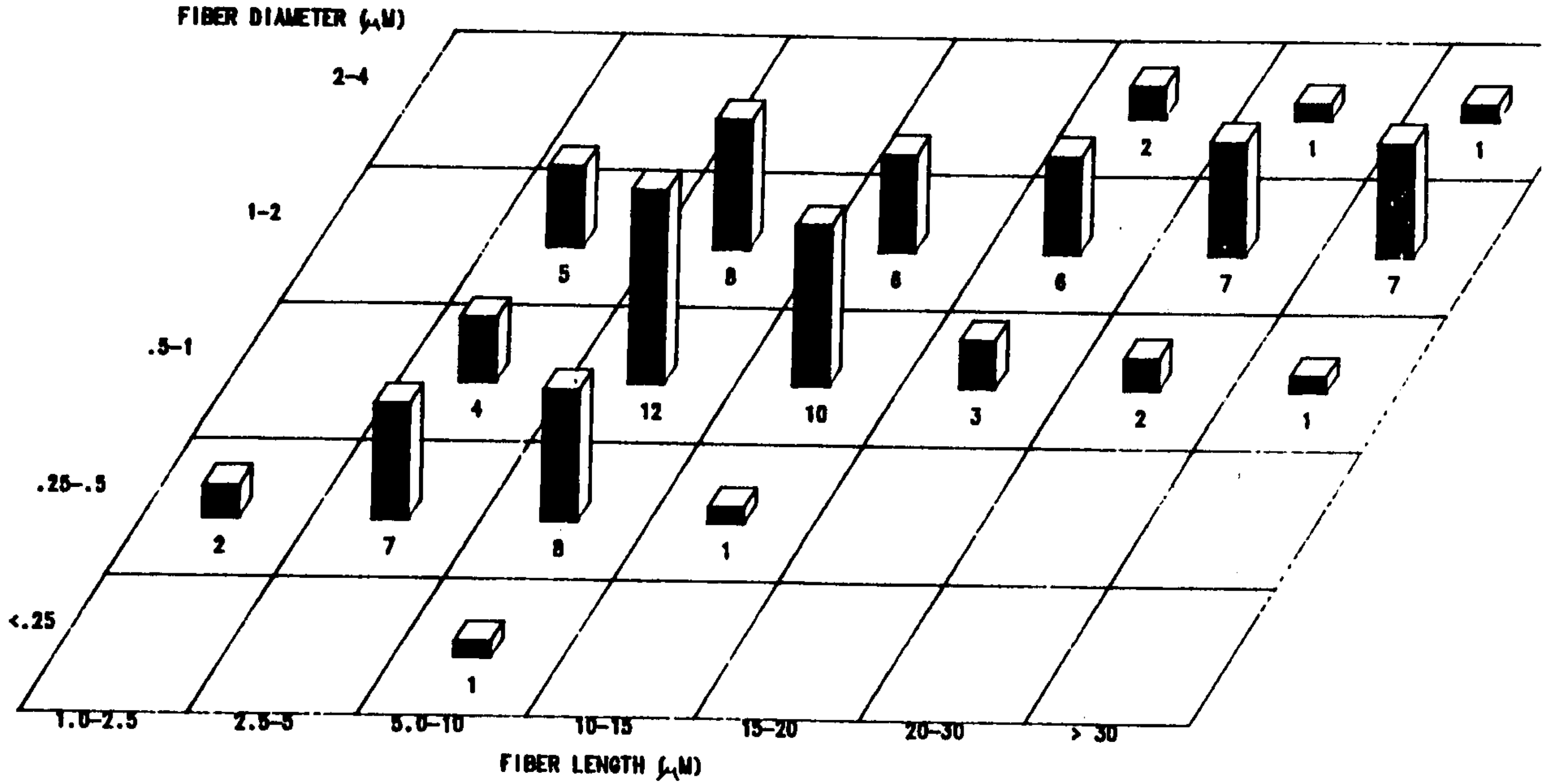
FIGURE 4
FIBERFRAX®, DURABOARD: SAND RECLAIM, LOW
MORRIS BEAN
JANUARY, 1986



TOTAL FIBERS COUNTED: 27
AIRBORNE FIBER CONCENTRATION: 0.48 F/CC

FIGURE 5

FIBERFRAX®, DURABOARD
MORRIS BEAN: SAND RECLAIM, HIGH
JANUARY, 1986



TOTAL FIBERS COUNTED: 95
AIRBORNE FIBER CONCENTRATION: 0.75 F/CC