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Calspan

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FINAL REPORT

WORK PRACTICES AND ENGINEERING CONTROLS FOR CONTROLLING OCCUPATIONAL FIBROUS GLASS EXPOSURE

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I. INTRODUCTION AND SUMMARY

The man-made vitreous fibers, fibrous glass and mineral wool*, have truly become ubiquitous in our technologically oriented society. Estimates place the number of unique applications at over 35,000. One of the properties that has made these materials so useful, their fibrous structure, is now causing concern over their possible biological effects. To gather information on work practices and engineering controls that can be effectively used to control occupational exposure to fibrous glass, Calspan Corporation conducted field surveys and a literature search, and consulted with unions, trade groups, and medical experts in the field. Forty field surveys were conducted, including glass textile, glass and mineral wool manufacturers; fine fiber producers and users; glass-reinforced plastic operations; and appliance, filter, and vehicle manufacturers; as well as commercial and residential insulation installers. This report documents the results of these efforts. The following discussion presents an overview of the processes involved and enumerates the conclusions of this study.

Glass Wools

The fibrous glass wool industry began in 1938 when Owens Illionis Glass Company and Corning Glass Works formed a joint venture company, Owens-Corning Fiberglas, that spawned the glass wool industry. Originally, fiber was formed by allowing molten glass to fall through small holes in a ceramic bushing, followed by further attenuation by high-velocity gas burner or steam. Refined versions of this process, flame attenuation, are still widely used. In the 1950's, Owens-Corning Fiberglas and the Cie de St. Gobain perfected the centrifugal or rotary process. Here, a single molten stream feeds into a rotating platinum basket that distributes the glass on an outer rotating cylindrical spinner. The spinner wall is perforated with numerous small holes. The molten glass is forced through the holes forming fibers which are then attenuated 90° from their forming direction by high-velocity gas burners or air. Output of a single spinner ranges from 0.23 to 0.45 metric tons per hour (500-1000 lb/hr) and up to 5 or 6 spinners may form fiber for a line [1].

*The term mineral wools, as used in this report, includes all vitreous fiber produced from natural rock, man-made slags or minerals (and combinations of these) unless otherwise noted. Mineral wools are glassy substances with relatively variable chemical compositions as compared to "glass" wools.

Flame-attenuated wool has greater longitudinal strength because the fibers are attenuated in the same direction (away from the gas or steam blower) so that the lengths tend to align giving greater tensile strength in that direction.

As rotary-spun fibers are attenuated at the circumference of a rotating disk, fiber lengths assume random distributions. Standard building insulation produced by the flame attenuated process requires less fiber by weight (approximately 35 to 50 percent) to achieve the same thermal properties as rotary spun wools. Rotary forming processes produce more uniform fiber. As they can produce huge tonnages of wool, the rotary processes now dominate the industry.

Typically, borosilicate and low alkali silicate glasses are used for making glass fibers because of chemical durability. The surface-area-to-weight ratio of the fibers in glass wool products is so large that even atmospheric moisture could seriously weather common silicate glass fibers. The low thermal conductivity property of insulation fiberglass is achieved because the glass fibers trap stationary pockets of air. The fiberglass web in which these pockets are held minimizes heat transfer by air convection and limits it to conduction. Table I-1 lists the composition and diameter ranges of common glass fiber product types.

Mineral Wools

Commercial production of mineral wools predates glass wools by over 40 years. Production of slag wools began in England in about 1885 and was established in New Jersey before the turn of the century. The first manufacture of rock wools was begun by C. C. Hall in 1897 in Alexandria, Indiana. The industry developed slowly until after World War I and peaked during the 1950's when competition from glass wools became intense.

Modern mineral wools typically use a blend of slag waste and natural rock as raw material. Frequently some of these raw materials are transported great distances to the wool plants. Early plants used a process in which the melt stream from a cupola furnace was attenuated into fiber by a steam jet.

Table I-1

PROPERTIES RELATED TO APPLICATIONS OF GLASS FIBERS

GLASS TYPE	FIBROUS-GLASS FORMS	FIBER DIAMETER RANGE, μm	FIBER DIAMETER RANGE, in.	DOMINANT CHARACTERISTICS	PRINCIPAL USES
LOW-ALKALI LIME-ALUMINA BOROSILICATE	TEXTILES AND MATS	5.85-9.65	0.00023-0.00038	EXCELLENT DIELECTRIC AND WEATHERING PROPERTIES	ELECTRICAL TEXTILES. GENERAL TEXTILES. REINFORCEMENT FOR PLASTICS, RUBBER, GYPSUM, PAPERS. GENERAL-PURPOSE MATS
SODA-LIME BOROSILICATE	MATS TEXTILES	10.1-15.2 5.85-.65	0.00040-0.00060 0.00023-0.00038	ACID RESISTANCE	MATS FOR STORAGE - BATTERY RETAINERS, FOR CORROSION PROTECTION, WATER PROOFING, ETC. CHEMICAL (ACID) FILTER CLOTHS, ANODE BAGS
SODA-LIME BOROSILICATE	WOOL (COARSE)	7.60-15.2	0.00030-0.00060	GOOD WEATHERING	THERMAL INSULATIONS. ACOUSTICAL PRODUCTS
SODA-LIME	PACKS (COARSE FIBERS)	114-254	0.0045-0.010	LOW COST	COARSE FIBERS ONLY, FOR AIR AND LIQUID FILTERS, TOWER PACKING, AIRWASHER CONTACT AND ELIMINATOR PACKS
LIME-FREE SODA BOROSILICATE TAKEN FROM [1]	WOOL (FINE) (ULTRAFINE)	.76-5.08 0 (EST)-.76	0.00003-0.00020 0.0000-0.0003	EXCELLENT WEATHERING	LIGHTWEIGHT THERMAL INSULA-TIONS, SOUND ABSORBERS, AND SHOCK-CUSHIONING MATERIALS. ALL-GLASS HIGH-EFFICIENCY FILTER PAPERS AND PAPER ADMIXTURES

In the most typical process today the cupola stream flows into a centrifugal rotor. High velocity air or steam jets surrounding the rotor further attenuate the fiber "thrown" from the rotor. Average fiber diameters range from 3.5 to 7.0 μm and have a wider distribution of diameters than do glass wools.

Textile Fiber

In the 1930's, Owens-Corning Fiberglas began the development work leading to commercial production of continuous filament glass fiber. Textile fiber had been produced sporadically for over a century but its commercial exploitation awaited development of E glass, a low alkali, calcioalumina-silicate, and perfection of mechanical drawing equipment. By 1934 textile fiber was being drawn from multiholed bushings and collected in strands.

In 1935, the first patents were issued for room-temperature setting resins and polyesters, thus setting the stage for the development of the glass reinforced plastic (GRP) segment of the industry. Radomes for World War II aircraft were the first important commercial GRP development. Textile fiber now accounts for about 40 percent of the dollar volume of the fibrous glass industry.

Filaments ranging from 2.5 to 15 μm diameters can be produced by the textile processes. The small end of the range is produced in limited quantities for uses such as the "beta" fabric for space suits. Drapery fabrics use 4 to 6 μm-diameter fiber. The great bulk of textile fiber is used for plastic reinforcements and tire cord. Diameters of these products are in the upper range, 9 to 14 μm.

Fine Fiber

Manufacture of fine fiber glass* with nominal diameters within the respirable range (< 3.5 μm) was begun during World War II by Owens-Corning Fiberglas as a small volume operation using a flame attenuation process to produce flotation fiber as a replacement for kapok in life jackets.

*The term fine fiber, as used in this report, refers to fibrous glass products manufactured with nominal diameters within the respirable range.

Fine fiber ($<3.5\ \mu m$) offers unique benefits for such applications as high-performance thermal and acoustical insulation for space vehicles and aircraft, and for high-efficiency filtration media. In 1966 a second manufacturer, Johns-Manville, began commercial production of fine fiber. All fine fiber wool production in the U.S. is now concentrated in two plants. Produced by proprietary, highly sophisticated flame attenuation processes, fine fibers are routinely manufactured in diameters ranging down to 0.1 μm.

CONCLUSIONS AND SUMMARY

- Extensive radiographic and pulmonary function studies of workers with long-term occupational exposure to fibrous glass indicates no adverse health effects when compared to control groups.
- Mortality studies of worker populations indicate no adverse health effects.
- It is the tendency to compare the man-made inorganic fiber industry to the much older asbestos industry; however, all of the environmental data collected by investigators using fiber count techniques under phase contrast microscopy show workplace respirable fiber counts much lower than those associated with modern asbestos production. Exceptions are the fine fiber producers and users ($<3.5\ \mu m$ nominal diameter) where respirable fiber counts approach those of asbestos on occasion. The data base for fine fibers is limited.
- Animal experimentation using intrapleural and intraperitoneal injection or implantation of fibrous glass in a variety of fiber diameters has demonstrated that carcinogenicity correlates strongly with fiber diameter and that only fiber diameters $<3.5\ \mu m$ are implicated.

- Fiber carcinogenicity, as demonstrated by animal experimentation with a variety of fibrous materials, is a function of particle form and has apparently no relationship to chemical composition. Respirability is a function of fiber diameter. Fibers with diameters $>3.5\ \mu m$ and lengths $>50\ \mu m$ are unlikely to penetrate the alveoli.

- Users and fabricators of fine fiber products are extremely limited in number. Industry estimates place fine fiber production at about only 1 percent by weight of total production. However, the survey team believes the unique properties of fine fiber as filtration media and ultra-efficient insulation will dictate increasing usage of these materials in the energy-short and ecologically concerned nation.

- While current work practices and engineering controls used by the industry are in large part adequate, their continuation and even expansion is to be encouraged because of the benefits in employee comfort and efficiency as well as the possibility that further studies may disclose risk of severe or chronic disease.

- We perceive no reason to remove fibrous glass from the nuisance dust category with the threshold limit value (TLV) set at the present 15 mg/m^3 value. However a TLV based upon fiber counts would have more meaning and perhaps justifies a separate standard.

II. RECOMMENDED WORK PRACTICES AND ENGINEERING CONTROLS

While it is beyond the scope of this report to recommend any level at which exposure to fibrous glass and mineral wool should be controlled, our survey confirmed that an extensive variety of work practices and engineering controls are used throughout the industry to reduce respiratory and dermal exposure to these materials. Skin exposure is universal throughout all segments of the industry and is discussed in Section II.a. Work practices and engineering controls that have proven effective for respiratory exposure vary considerably according to the processes performed and are therefore discussed independently.

II.a Dermal Exposure

Skin irritation can be greatly reduced by proper personal hygiene practices. Employers should instruct all new employees on the irritating properties of fibrous glass and mineral wool and provide proper facilities and supplies so that employees may practice good hygiene. Among the practices found effective in the industries surveyed are:

- Long-sleeved shirts and long trousers should be worn. Clothing should fit loosely at the neck and wrists. Caps are effective.
- When fiber accumulates on skin areas, workers should be instructed not to remove the material by rubbing, brushing, or blowing with compressed air. Instead, dust should be rinsed off with warm water, followed by a gentle washing using a mild soap.
- Work clothing should be changed daily and workers should be instructed on proper laundry procedures, i.e., that fiber-laden clothing should be washed separately from other items.

- Medical screening should be used to detect those potential employees that are dermatographic or who have chronic skin conditions.
- Barrier creams which provide a substantial reduction of irritation for some workers should be made available.
- For on-site operations such as residential and commercial insulation installation, materials should be provided at readily accessible locations so that workers can practice good personal hygiene. If water cannot be made available, waterless soap and paper towels will provide a partial solution.
- As part of new employee orientations, the mechanical nature of the "itch" should be explained and the above personal hygiene measures detailed.

II.b Respiratory Exposure

II.b.1 Basic Manufacturing and Production Formation and Packing by Manufacturer

Bonded Wools

Because of the volume of process air drawn through the formation chambers for fibrous wool products, excessive dust is not a "hot end" problem in any of the basic mineral or glass wool processes. These products are typically edge trimmed and chopped, cut, or sawed to final dimensions after oven curing the binder system. Commonly, local exhaust systems are used to capture dust at these points and occasionally to remove unbonded "lint" from the product. In some plants, these vent through cyclone dust collectors which are effective for gross dust such as the >7.5 μm-diameter dusts associated with onset of dermal irritation in most people, but are almost completely ineffective in removing respirable fiber.

Packing processes where mechanical pressure is applied to reduce product volume would be expected to be dusty; however, this is not substantiated by environmental data.

Among the practices and controls that can be used to control excessive dust levels are:

- Use of well-designed and maintained local exhaust systems with proper capture velocities at product trim points. Consideration of the inefficiencies of cyclones for capture of the respirable fraction of airborne fiber should be made in the selection of dust collection systems.
- A common deficiency is in disposal of collected dusts. Poorly designed equipment or inadequate procedural directions to workers servicing equipment and removing accumulated dust can result in a secondary dust hazard. Procedures and equipment should be designed with full consideration of ultimate disposal so that dust carefully collected within the plant does not become airborne again during transport to a dump site. All containers for receipt of dust or haulage must be covered. Conveyors and screw augers used for dust removal from plants should be completely enclosed.
- Prevent waste from accumulating along product lines as workers remove out-of-specification material from conveyors. Conveniently placed bins encourage proper disposal and prevent trampling underfoot.
- Housekeeping is best accomplished with power vacuum cleaners since most dust is captured by this method. For periodical major housekeeping efforts when overhead structures are cleaned and vacuuming is not feasible and a dustier process must be used, workers should wear respirators.
- Higher-density products such as pipe insulation and high-temperature block are usually formed on subsidiary lines by hot-pressing uncured fiber. Typically, product trimming is accomplished by band sawing. Well-designed and serviced local exhaust systems are effective in reducing dust levels.

Loose Fiber and Pouring and Blowing Wools

Loose industrial fiber and pouring and blowing wools are produced by both glass and mineral wool industries. In the glass wool plants, blowing wools tend to be largely a reclamation product, formed from other scrap products. In many mineral wool plants, loose fiber is often a major product for uses such as acoustical tile by secondary manufacturers or a loose insulation. This production of loose fiber by mineral wool producers is often a dusty operation. Environmental data indicates extremely low respirable fiber counts for both mineral wool loose fiber products and scrap reclamation from both glass and mineral wool producers. However, if dust levels are excessive, the following practices are of merit:

- Enclose conveyors, surge bins, tumble screens, shaker tables, rotating screens and product blenders.
- Similarly, chopping stations where scrap is reclaimed for blowing wool should be enclosed.
- Good housekeeping appears to be a major contributor to maintaining low dust levels in mineral wool plants.
- Pneumatic-bag fillers also produce considerable amounts of dust, a problem compounded by the close presence of workers. Properly designed annular local exhaust systems surrounding the filling beak appreciably reduce this problem. Ram ejectors, where a measured weight of wool is compressed within an enclosure and then forced into the bag, or the screw-type filling machine are appreciably less dusty.
- Reclamation processes where scrap glass textile fiber is blended with glass wool after carding and garnetting are excessively dusty and require enclosure and well designed local exhaust and dust collection systems.

Textile Fiber Production and Manufacture

Because of the continuous nature of the textile fiber and because of the application of water-soluble binder systems immediately after the fiber is drawn from the bushing, airborne fiber counts are low (<1.0 fiber/ml) in formation areas even in plants producing the finest continuous glass fiber (averaging 3.5 μm). Spinning, weaving, twisting, plying and chopping operations to which fiber strand is subsequently subjected as it is processed into finished fabrics, yarns, rovings, woven rovings, or various matted (rather than woven) fabrics, also show extremely low fiber counts. In addition, high purity demands placed on these materials for some applications place a premium on good housekeeping.

Dust reduction techniques that have proven effective are local exhaust systems with typical capture velocities in the 100-250 fpm range. Typically, these vent through bag filters or precision drum rotary filters.

II.b.2 Product Installation

- For installation of dry mineral and glass wools in confined spaces such as attics, workers should be furnished reusable or single-use, negative-pressure respirators approved under 30 CFR 14 (Bureau of Mines Schedule 21B). Wool is charged into most blowing systems by pouring the bagged material into a hopper. Moving fingers within the hopper loosen the compressed wool. Typically this hopper is housed in a van. Hopper-charging can be a dusty operation and 30 CFR 14 respirators should be furnished and their use encouraged.
- Trampling of scrap and trims underfoot appears to be a significant contributor to airborne dust levels. Administrative controls that provide worthwhile reductions include furnishing plastic bags mounted on stands for workers to place trims in as they are cut. When filled the bags are tied securely and placed in the trash.

- Dust levels from self-adhering mineral fibers such as are applied by spraying for acoustical, fireproofing and thermal insulation (asbestos-replacements) can be controlled by prompt cleanup. As the cement-coated fiber is water-wetted at a mixing nozzle as it is sprayed, the installers face little airborne hazard although using an approved 30-CFR-14 respirator would be a good practice. The chief dust producing practice is cleanup of oversprayed areas or materials that drop during application. If cleanup is prompt while the fiber is still wetted, no fiber becomes airborne. If the material is dried, considerable dust can evolve. An effective measure is to stagger the work hours so that the cleanup crew remains after the sprayers finish so that the material is not allowed to dry. Waste should be bagged and securely tied for final disposal. Final cleanup should be by vacuuming.

- Few applications in which the man-made fibrous minerals are installed as insulation by manufacturers of such products as appliances, vehicles, or mobile homes require special procedures because of dust levels. Such manufacturers, for economic reasons, often minimize handling by ordering material prepared to the exact dimensions or form required for their product, thus reducing handling and incidently dust-producing manipulation. In industries where material is received in bulk, typically the insulation is sheared in a central preparation shop where local exhaust could be used to control any excessive dust levels. In the appliance industry, handling of insulation for self-cleaning ovens produces some worker complaints about "fly." These appliances utilize a high-temperature cycle to "burn off" oven spatters. For this application, special binder formulations with no lubricant are used. The lower binder content apparently makes the product dustier to handle. Because of its higher temperature stability, mineral wool is required for high-temperature

(>450°F) applications such as boilers, chemical plants, power plants, etc. Installers working in these areas complain of excessive dust while forming the material around ducts and pipes. Some manufacturers prescore high-density board for this application so that it bends more readily, a practice claimed to reduce the dust levels appreciably.

Shipboard Applications

The man-made fibrous minerals are replacing asbestos in some shipboard applications. In addition to the dust problems associated with installation in confined spaces, periodic refurbishment of ships requires removal and replacement of old insulation ("tear-out"). Destruction of binder systems by heat and age embrittlement creates dust problems. Among the procedures and practices that could be used are:

- Pre-fabrication of material in shops under adequate local exhaust to reduce cutting and fitting in confined quarters.
- Prewetting of materials to be torn out.
- Isolation of areas where "tear-out" is taking place with curtains and portable partitions.
- Exclusion of all personnel not involved in the operation in the "tear-out" areas.
- Use of portable exhaust blowers and dust collectors with sucker hoses or 30-CFR-14 respirators if ventilation equipment cannot be used.
- Immediate disposal of scrap fiber in plastic bags or other containers not requiring re-handling of loose scrap. Vacuuming of dusts.

II.b.3 Glass Reinforced Plastic (GRP) Product Manufacture

In GRP plants, worker exposure to fibrous glass dusts occurs in three areas -- in mat, woven roving and glass cloth preparation areas where roll fabrics are cut to the proper shape for the product being produced, in sprayup areas where roving is chopped in 1-1/2 to 2-inch fibers simultaneously with application of catalyzed resins, and in finishing areas where flashing is removed and imperfections ground. Sprayup does not create a dust problem because the fiber is wetted by the gun and because the monomers used with the resin, frequently styrene, require downdraft or sidedraft local ventilation for worker protection. Good practices and controls are:

- Perform cutting operations on perforated downdraft tables. Provide plastic bags for immediate collection of small remnants to prevent foot trampling. Capture velocities should be about 200-250 fpm.
- Bandsaws in finishing areas should be equipped with local exhaust systems. Portable sabre saws are also available with high-velocity, low-volume capture attachments.
- Grinding should be performed within a properly designed and adequately serviced sidedraft or downdraft booth. Small parts may be finished on exhaust tables. For large assemblies such as tanks, extractor hoods are available for portable disc sanders and grinders. Typical effective slot velocities are 10,000 to 25,000 fpm.

II.b.4 Fine Fiber Production and Use

For any operation where excessive fine fiber dust levels are encountered, the following techniques are of use:

- Where loose fine fiber is charged into either paper-making pulpers or acid leaching tanks to form refractory fiber, 30-CFR-14 respirators are recommended. In paper making, a procedure of simply fitting all pulpers with lids, charging the pulper with the rotor nonoperational, and then adding water and beginning the pulping process after closure of the lid is effective in reducing dust levels.

- Slitting and sawing operations, where fine fiber papers are trimmed to final product dimensions, should be equipped with properly designed and well maintained slot exhaust systems, vented through dust collectors.

- For manufacturers packing fine fiber into filtration media, workers pleat or form the fiber on tables. If excessive dust is a problem, these operations should be performed on down-draft tables with capture velocities of about 200-250 fpm. Trim and waste should be immediately placed into plastic bags or other containers not requiring re-handling of loose scrap to avoid trampling underfoot.

- All subsequent forming and cutting of refractory materials manufactured from fine fiber should be done under adequate local exhaust systems.

- Environmental sampling indicates low fiber counts in primary manufacturing facilities. However, to maintain these low fiber counts, great attention should be paid to housekeeping.

III. BIOLOGICAL EFFECTS OF EXPOSURE TO FIBROUS GLASS

This section summarizes the reported biologic effects of exposure to fibrous glass. The present body of research, discussed in detail subsequently, supports the following conclusions:

- Epidemiological studies have not shown chronic bronchitis, pulmonary fibrosis, bronchogenic cancer or mesothelioma to occur at any statistically significant variation from control groups. However, most studies have been of "survivor" groups, and only a relatively few studies have exhaustively traced persons who have left the industry or died.

- Most reports of adverse pulmonary or cancerous human reaction are of either isolated cases or complications without sufficient data to isolate the causative factor.

- Cutaneous irritation is mechanical in nature, typically transitory and sensitization probably does not occur. Fibers with diameters >7.5 μm are the chief offenders.

- Animal studies clearly demonstrate that fibrous glass is carcinogenic in vivo. The dosage levels and methods of administration have been chosen to indicate the mechanism of action and thus are extremely remote from those that humans might experience. Carcinogenicity of this material has been attributed to particle shape (fibrous nature) and not to chemical composition.

III.a Animal Studies

In animal experiments, Stanton and Wrench [2] demonstrated that carcinogenicity of asbestos and fibrous glass both seem largely related to structural shape of these materials rather than to any carcinogenic contaminant or chemical property of the materials themselves.

Seventeen materials were compared using a direct intrapleural injection technique. The four glass fibers used were: Pyrex filtration wool (5-12 μm) nominal diameter); short fiber insulation wool of a type produced 20 years ago (1-35 μm diameter) and both a urea-formaldehyde resin coated and an uncoated Code AAA fiber (nominal diameter 0.22 μm). All were reduced in a Spex mill to fiber lengths of 1-20 μm. Mean diameters of the two coarser fibers were 5-10 μm; the AAA Code fiber diameters ranged from 0.06-3 μm. The coarser fiber induced 4 mesotheliomas among 91 rats; the Code AAA fiber 5 among 28 and the uncoated AAA, 3 among 26. In addition to the statistically significant higher mesothelioma incidence rate among rats injected with the finer fiber, pleural fibrosis was higher among these animals.

Milling to reduce crocidolite to submicroscopic fibrils reduced mesothelioma incidence, suggesting that particle form was the important factor in mesothelioma incidence.

In an extension of this work, Maroudas, O'Neill and Stanton [3] suggested that fiber length was as important as diameter and that fibers must be more than 20 μm in length in order to induce neoplasia.

For intrapleural and peritoneal injection, Davis [4] prepared two borosilicate glass fiber types (0.05 and 3.5 μm average diameters) each by two different methods, hand milling and flotation, to separate long (~200 μm) fibers and by mechanical reduction until most fiber were $<$ 20 μm.

All samples produced granulomas within the pleural cavities. Reaction, however, was markedly different. Whereas, long-fiber samples produced massive fibrosis, the short-fiber samples produced minimal fibrosis of a small, discrete type. Long-fiber samples did not produce granuloma in the pleural cavity. Peritoneal tumors did develop in 12% of the rats injected with 10 mg of glass (~200 μm long, 0.05 μm in diameter) and 17% of the mice injected with 25 mg of glass (~200 μm long, 0.05 μm in diameter). From this work Davis concluded that fibrous glass in the pleural and peritoneal cavities behaves similarly to asbestos, but generally does not cause the lung fibrosis attributed to asbestos because it initially kills fewer macrophages.

Botham and Holt [5,6], exposed guinea pigs for 24 hours to an atmosphere containing a high concentration of submicrometer-diameter glass fibers or powdered glass of the same composition. The animals were then progressively sacrificed so that clearance mechanisms and cellular changes might be progressively noted.

Botham and Holt found that many fibers and particles clear within a week after inhalation but that other particles are retained in alveolar phagocytes. Meanwhile, red blood cells escape from capillaries into alveoli and an iron-containing material appears in alveolar macrophages.

Some of the intracellular glass fibers became coated with this material within days of inhalation; powdered glass particles did not become coated. Subsequent development of glass fiber bodies follows the sequence demonstrated earlier for asbestos by Botham and Holt, being slower than the chrysotile bodies but more rapid than other varieties of asbestos.

Powdered glass inhalation produced less severe capillary seepage. Fewer giant cells formed and so red blood cells and intracellular glass particles were cleared more readily as junctions between respiratory and terminal bronchioles remained open.

The similarities in effect between asbestos and glass fiber were concluded to be due to the fibrous nature of the materials; the differences in effect between powdered glass and fiber were assigned to the difference in physical form of the inhaled particle.

Inhalation chamber experiments conducted by Gross et al. [7] subjected rats and hamsters to an airborne fibrous glass dust environment for a period of two years. Dust concentration was maintained at about 100 mg/m^3. Phase contrast microscopy determined that fiber diameters averaged 0.5 μm and were narrowly distributed. Length ranged from 5 to 20 μm. Dust content was 70 to 76 percent fibrous. Three inhalation chambers were used--one with uncoated fiber, another with resin-coated fiber typical of glass wools and the third with a starch binder which is characteristic of textile fiber. Exposures were for six hours daily, five days a week, for 24 months. The animals, consisting of 30 rats and 30 hamsters, were permitted to live out their lives after completion of dust exposure, except for five rats and five hamsters from each chamber which were killed for sampling after six- and 12-month exposures, respectively.

Gross et al. observed no major abnormalities attributable to fibrous glass dust. Microscopic tissue reactions consisted of macrophage reactions localized in alveoli clustered around respiratory bronchioles and alveolar ducts. Glass fiber deposited in the lungs of the rats and hamsters was not found to be associated with fibrosis or atelectasis. Dust foci in the lungs of animals that survived the longest after exposure were less numerous and smaller than foci of animals sacrificed during or shortly after the study, suggesting pulmonary clearance.

In addition, glass fibers in the same diameter and length ranges, and with the same coatings (and no coating), were intratracheally injected into an additional 210 animals which were then allowed to live out their lives. Results were similar to those observed in the animals used in the inhalation experiment with the exception that dust foci in the injected animals were smaller than those of the inhalation study and that a somewhat greater incidence of bland pleural fibrosis was reported.

Using fine glass fibers of two size distributions (median diameter 0.12 μm, median length 1.7 μm with only 2% longer than 20 μm and median diameter 1.8 μm, median length 22 μm and 10% longer than 50 μm), Wagner et al. [8], used intrapleurally injected rats in experiments to determine carcinogenicity. Mesotheliomas only occurred in the group injected with the finer fiber (0.12 μm) with 12 percent of the group being affected. In addition seven of this 32-rat group displayed marked hyperplasia.

The incidence of mesotheliomas arising from intrapleural injection of various materials was investigated using identical techniques by Wagner, Berry, Timbrell and Skidmore [8,9]. These results are summarized below:

Material	Percentage of rats with mesotheliomas
SFA chrysotile	66
UICC crocidolite	61
UICC amosite	36
UICC anthophyllite	34
UICC chrysotile (Canadian)	30
UICC chrysotile (Rhodesian)	19
Glass fibre code 100 (0.2 μm dia.)	12
Ceramic fibre	10
Glass powder	3
Glass fibre code 110 (1.8 μm dia.)	0

Pott, Huth and Friedrichs [10,11] conducted a series of intraperitoneal injection studies on rats using varying dosages of fine glass fiber and fibrous and granular minerals. Again tumor development indicated fibrous structure as the causative agent.

In a recent test series, Potts et al. [11] used two sizes of fine fiber at varying dosage levels -- type MN104 in which 50% of the fiber diameters were <0.2 μm and 50% of the fiber lengths were ≤ 11 μm, and type MN112 where 50% were <1 μm in diameter and 50% were ≤ 28 μm in length. Tumor production in rats was roughly proportional to dosage with nearly 90% of the tumors being mesotheliomas. An injection series with NMRI mice developed comparable tumor rates in most cases but hamsters and guinea pigs failed to develop tumors. (These species also failed to develop tumors from injection of chrysotile.)

Schepers and co-workers, in over 30 years of research [12-20], have investigated fibrous glass physiological effects using techniques ranging from biopsy and necropsy of human subjects to animal experiments studying the biological activity of glass fiber by cutaneous, subcutaneous, intravenous intraperitoneal, intratracheal and inhalation methodologies. Three intratracheal series were performed using glass wool with mean diameters < 3 µm (many < 1), 3 and 6 µm and lengths ranging from 20 to 50 µm. Schepers concluded that the large fibers were relatively inert; however, smaller diameter fibers produced areas of focal atelectasis but no fibrosis.

In one inhalation series, guinea pigs were exposed to 6 µm-diameter fibrous glass at concentrations of approximately 5 mg/m^3 for 20 months and to fibrous glass with a maximum diameter of 3 µm at concentrations of 1 to 2.5 mg/m^3 for another 20 months. Conclusions were that the fibers were not fibrogenic, but that the biological effect was not entirely that of an inert material as focal atelectasis and bronchiolar damage was noted.

In another series of prolonged animal inhalation experiments with a variety of glass-reinforced plastics (polyesters) and filler dusts, Schepers [16] found little pulmonary reaction and noted no neoplasm formations.

III.b Human Studies

A recent mortality study of employees of the oldest US glass wool plant by NIOSH [21] indicated no excess of malignancy of any kind. The only category of disease showing a possibly significant excess was in "other respiratory diseases of a non-malignant nature exclusive of influenza and pneumonia." The majority of the 17 cases in this category listed emphysema or cor pulmonale on the death certificate with only 5 of the 17 having any mention of fibrosis. The likelihood of exposure to free crystalline silica or coal dust could not be excluded in any of these cases. No excess of bronchogenic or gastro-intestinal cancer or mesothelioma was uncovered.

Gross, Tuma and de Treville, [22] conducted a post-mortem study of the lungs of 20 fibrous glass workers with occupational exposures rated from slight to severe and with exposure durations from 16 to 32 years. The control group was 26 urban dwellers without apparent occupational exposure.

No significant difference was found between the groups as to average total dust per gram of lung or the average dimension of fibers within the lung. No relationship between the fibrous glass workers' duration or severity of exposure and lung fiber count was found.

Histopathologic changes were also evaluated. As both groups exhibited basic parallelism, the investigators concluded that no specific disease or tissue alteration attributable to fibrous glass could be found and that the fibrous glass workers' lungs were "the seat of no more diseases of the lung" than were those of the control group. The exception to the second conclusion was the presence of three lung-involved malignancies among the glass workers. Only one was reported as primary in the lungs and it occurred in a heavy cigarette smoker.

Wright [23] analyzed a group of 1389 employees with 10 or more years exposure in manufacturing fibrous glass for roentgenographic abnormalities that might be associated with an airborne fibrous glass environment. No recognizable abnormal pattern was observed. Wright found that the frequency of the various radiologic abnormalities appeared to concur with the general population with no significant difference based on the severity of worker exposure.

Using the same fibrous glass factory studied by Wright, [23], Gross et al. [22], the team of Nasr, Ditchek and Scholtens [24] examined chest roentgenograms of 2,028 workers. The group included 1,832 production workers and 196 office employees. Of the group, 19 percent had an employment duration greater than 25 years, 33 percent more than 20 years, 50 percent more than 15 years and 63 percent had more than 10 years exposure. All diagnoses were made blind; the investigators were not supplied worker age, exposure or employment duration data.

About 16 percent of the workers were found to have radiographic abnormalities with the most prevalent being increased lung markings, abnormal aorta, emphysema and abnormal heart. However, no significant difference in the prevalence of abnormalities between the production workers and office employees was found.

Summarizing California occupational disease records for two discrete periods in the 1960's, Milby and Wolf [25] reported 66 cases of adverse respiratory reaction to fibrous glass inhalation. Based on the reporting physician's diagnosis or reported patient complaints, the major manifestations were bronchitis (64% of all case reports), pharyngitis (38%), rhinitis (30%), asthma (9%), laryngitis (6%) and sinusitis (5%).

Carpenter and Spolyar [26], in a study published in 1945, evaluated chest roentgenograms of 84 workers with a minimum of seven years occupational exposure to mineral and slag wools. Maximum exposure was 29 years and the average 14 years. Of the 84, one employee, with a previous employment history with refractory-brick batch, exhibited silicosis; the remainder were reported negative for pneumonoconiosis. However, 43 employees had exaggerated linear markings. Working with a control group drawn from the plant's office force and similarly distributed in age to the studied workers, the investigators concluded that the exaggerated linear markings were "community related."

Theodos [27] reported on 312 limited intercostal lung biopsies of patients with diffuse infiltrative lung diseases. These histologic reports were reviewed in conjunction with the patients' occupational history to evaluate whether a pneumoconiosis could be either the primary or a contributing factor. Of the total, one case, that of a laundry worker, was a fibrous glass pneumoconiosis. The patient had been employed for 12 years as a mangle operator. Glass fibers were identified by phase microscopy. It was postulated that the patient's exposure was from ironing fibrous glass fabrics.

Murphy [28] reported in 1961 the case of a worker, occupationally exposed to fibrous glass insulation from old hot water heaters, who developed hemoptysis, weight loss and a cough. Pathological examination indicated the presence of glass fiber in the lung; however, the symptoms were not ascribed specifically to fibrous glass and no exposure index was given.

An epidemiological and physiological study by the Industrial Health Foundation [29] drew a sample of 232 workers from a fibrous glass plant population of about 2,400 to investigate for respiratory system abnormalities. The sample group was categorized into three age groupings and three exposure severity groups for Latin square statistical analysis. The group was subjected to a chronic bronchitis questionnaire, a chest roentgenogram and to pulmonary function tests. The study concluded that no evidence existed to support the hypothesis that dusty jobs were less healthy than those with minimal exposure or to suggest adverse bioeffects of dust exposure.

Hill [30] in 1971 compared a group of 70 fibrous glass wool manufacturing employees with a mean of 19.75 years occupational exposure to a control group closely matched as to age, height, weight and area of residence. Independent readings of randomly mixed, unidentified roentgenograms were performed by two teams of radiologists. Pulmonary function was also determined and a respiratory history elicited by questionnaire. No evidence of respiratory hazard was found.

In a follow-on study five years later, Hill recontacted 53 of the original 70 study members. Roentgenograms revealing pleural thickening in some of the cases, led to a review of the original control group. Pleural thickening was also noted. Hill found the percentage of pleural thickening to be equivalent in each group.

Both the sample and control groups were drawn from a narrow geographic range. Pathologists of the area were queried as to occurrence of mesotheliomas. All reported cases were associated with asbestos exposure.

Schepers [31] questioned whether pathological fibrous glass envolvement in humans may be frequently overlooked, citing: 1) most investigators believe that glass fiber is relatively harmless and therefore fail to search for it; 2) the difficulty of identification within tissue using ordinary microscopy, and 3) the low probability of correct fiber orientation (horizontal plane). He pointed out that even if glass fiber is known to be present in experimental animals and can be identified by chemical analysis, it rarely is possible to identify such fibers microscopically.

He reported identifying more than a dozen cases of lung disease in which fibrous glass played either a primary or contributing role and stated that, "The discovery of even a few human cases with glass in the lung tissue is like finding the tip of a gigantic iceberg."

Bjure, Söderholm and Widmisky [32] evaluated cardiac and pulmonary function in 6 workers who had been exposed to glass wool and rock insulation wool and 8 asbestos workers. The exposure period ranged from 7 to 30 years. Clinical, radiologic, electrocardiographic, hemodynamic, and spirometric investigations were made.

The wools did not cause any detectable functional impairment in workers with a similar exposure. Those exposed to asbestos showed a marked restriction in dynamic lung function, a reduced diffusing capacity, and, in three out of eight subjects, a pathologically raised pulmonary artery pressure at rest or during exercise.

III.c Cutaneous Effects

Cutaneous effects from fibrous glass are a universal worker complaint throughout the industry from basic manufacture to secondary users and installers. New workers are particularly affected, complaining of an itching or prickly sensation of the arms, face or neck. As universal as the complaint is the appearance of "hardening" phenomena in the majority of workers; discomfort largely disappears within a week or two. Workers often report a return of the condition particularly during hot and humid weather.

Glass "itch" is the most common reason given for terminating employment in the industry. Possick, Gellin and Key [33] reported new worker turnovers of approximately 10 percent in the fibrous glass industry attributable to skin irritation. Most cases of dermatitis associated with fibrous glass are caused by direct contact with glass fiber, although the lubricants and coating agents used in the manufacturing process contribute to some degree to the frequency of dermatitis. Small, imperfectly formed glass fibers, known as slugs, are a major cause of skin irritation in workers directly handling glass wool.

In general, turnover rates reported to the Work Practices survey team agreed with those reported by Possick et al. However, one mineral wool plant reported a turnover of over 1000 percent in three years among production employees. Here, the high rate was partially attributed by management to higher paying job opportunities at other local industries. Frequently workers insist that hardening is never a complete process and that irritation is continuous to some varying degree. Some of the survey plants reported that women, particularily fair skinned women, appear slightly more sensitive than men. Plants without medical programs often cite high employee turnover as a major reason why such programs are not economically feasible.

Disabling dermatitis from glass fibers is rare [33,34]. Frequently those experiencing discomfort do not display erythema or develop papules. A psychological component of the problem exists. Workers installing fibrous glass hood liners in an auto assembly plant experience discomfort;

workers at another stage who install a vegetable fiber acoustic pad which replaces one formerly made of fibrous glass, also experience the "itch."

Cutaneous reactions have been rather extensively investigated [33,35-42]. Preponderant conclusions are:

- Irritation is mechanical in nature and cutaneous sensitization probably does not occur.

- Reactions are basically transitory and are related largely to fiber diameter and secondarily to fiber length.

- Large-diameter, short fibers are the primary offenders. Fibers having a diameter of 7.5 µm or more produce irritation in most people; those measuring 3.75 µm or less have little, if any, effect. Fibers between these ranges have a moderate potential for irritation.

- The mineral fiber industry is a poor occupational choice for those with chronic skin conditions or who are dermatographic.

The work of Heisel and associates [35-37] is particularly appropriate to this study. This work is summarized below.

Two groups of subjects were tested by Heisel and Mitchell [35] to determine: (1) if dermatitis from glass fibers was caused by mechanical irritation rather than by specific sensitivity, and (2) whether the degree of irritation might vary with the coarseness of fibers contacted. Patch tests, rubbing tests, and sensitization tests were performed using cut-short fibers and unbroken long fibers.

The tests included a group of 50 female subjects who had no known previous contact with glass fibers and a group of 92 employees of a fibrous glass manufacturing plant. Four rabbits were also subjected to the tests.

Unbroken long fibers produced no reaction in any of the test subjects in either the patch tests or the rubbing tests. In all tests using short-cut fibers, it was found that the degree of reaction was directly related to the diameter of the fiber. The largest-diameter fiber (18-19 μm nominal), P code, used in the patch tests produced the greatest reaction, while the smallest fiber, AAA Code (0.50-0.75 μm) produced essentially no reaction. Again, the largest-diameter fiber (38.1 μm diameter) used in the rubbing tests produced the greatest reaction; the finer fiber the least. Animal reactions corresponded to those of the human subjects.

Since the results of the sensitization tests were negative and only one subject in each of the test groups had severe reactions (both exhibited marked degrees of dermographism), it was concluded that cutaneous reactions to glass fibers are caused largely by mechanical irritation from sharp broken ends penetrating the epidermis.

Heisel and Hunt [36] further studied cutaneous effects using beta (2.5-3.8 μm average diameter) and C (3.8-5.0 μm average diameter) fiber and fabrics. Rubbing, patch, and use tests were performed on a group of 50 subjects. No reaction was observed to beta fabric and only 2 subjects (4%) noted any irritation when the coarser C fabrics were used.

Laundering tests involving 102 subjects in a double-blind study were also performed. Approximately two-thirds of the subjects wore underclothing which had been washed with the beta and C fabrics and with coarser DE (6.25 μm-nominal) fabric typical of most fibrous glass draperies. Both continuous and textured fabric varieties were used. One-third of the group acted as controls. These tests produced virtually no reaction to underclothing washed with beta- and C-fiber fabrics after 48 hours of continuous wear. Underclothing washed with the DE-fiber, however, elicited considerable complaints from the test subjects. The textured DE-fiber fabric caused more irritation than its continuous fiber counterpart (because of the tendency of textured fabric to release lint more freely). Female subjects were slightly more sensitive than male subjects.

Ash tests were performed on swatches of underclothing used in the laundering tests and on lint obtained by filtering the water in which fibrous glass fabrics were washed (after three successive rinses). Microscopic examination revealed numerous glass filaments in every instance. The investigators concluded that: (1) coarse fiberglass materials such as drapes should not be washed in a machine normally used for washing clothing, (2) fiber diameter less than 4.5 μm do not appear to irritate human skin either as lint or fabric, and (3) reaction by fiber diameters > 5.3 μm were mild, transitory and mechanical in nature.

IV. THE WORK ENVIRONMENT

It is only recently that data on the occupational exposure of workers to the man-made fibrous minerals have been collected on a sufficiently scientific basis to allow drawing conclusions about levels encountered in the industry.

Because of aerodynamic effects, cyclone and elutriator pre-samplers fail to collect representative samples of fibrous materials (Bien and Corn [43]). These difficulties led the Public Health Service [44, 45] to develop a fiber count technique during work on asbestos and airborne mineral fiber. These techniques, paired with a simultaneous total airborne dust concentration sampling, are currently widely used [45, 46, 47, 48, 49, 50] for environmental fibrous glass determination.

The fiber-count sample is collected on a 37-mm Millipore type AA filter mounted in an open-face cassette. The sampler is mounted in the worker's breathing zone and air is drawn through the filter with a battery-powered personal sampler pump at a rate of 2.0 lpm. Fibers are then counted and sized by area fields defined by a calibrated Porton reticle using phase contrast microscopy at about 430X. The number of fields counted to obtain a statistically satisfactory sample varies between researchers but ranges from 20 to 50. Total fiber concentration, or some subset defined by diameter for a given fiber length, is reported as fibers/milliliter. Submicron-diameter fibers are counted either by phase-contrast microscopy using oil-immersion objectives or by electron microscopy.

Total dust concentrations are typically determined on a 37 mm membrane filter at a 2 lpm sampling rate, desiccated, reweighed and the airborne particulate, expressed as mg/m^3, calculated from the sampled volume of air.

Studies involving basically similar techniques are summarized for comparison in Table IV-1 for primary manufacturers, Table IV-2 for secondary manufacturers and users, and Table IV-3 for fine fiber producers and users.

This environmental sampling, subsequently discussed more fully, supports the following conclusions:

- Total airborne fibrous glass dust concentrations in all segments of the industry are low, typically less than a quarter of the proposed 10 mg/m^3 threshold limit value.
- Fiber counts, too, are extremely low (except for fine fiber operations discussed subsequently), typically less than 1 fiber/ml.
- Fiber counts and dust concentrations are strongly consistent across the industry from firm to firm and from basic manufacture, through secondary operations to installation.
- The great bulk, typically more than three-quarters, of airborne fibers fall within the respirable diameter (≤ 3.5 μm) range.
- Fine fiber operations (nominal diameter ≤ 3.5 μm) demonstrate fiber counts an order of magnitude higher than other fibrous glass operations. Of course, almost all airborne fiber falls within the respirable diameter range.

However, even the order-of-magnitude larger fiber counts in fine fiber operations are low [45,51]. Dement [51] cautions that comparison to asbestos counts is misleading as:

> "The presently accepted method of counting only those asbestos fibers greater than 5 micrometers in length with the optical microscope at about 400X magnification sees only approximately 1 to 4 percent of the actual asbestos fibers present." Therefore, even at the 1976 OSHA standard of 2 fibers > 5 μm

Table IV-1

OCCUPATIONAL EXPOSURE SUMMARY – PRIMARY MANUFACTURERS

EXPOSURE	DATA SOURCE	MEAN FIBER CONCENTRATIONS (fiber/ml)	NO. OF SAMPLES	BASIS FOR INCLUSION IN FIBER COUNT	MEAN TOTAL DUST CONCENTRATION (mg/m^3)	NO. OF SAMPLES
CENTRIFUGAL-FORMING GLASS WOOL BUILDING INSULATION (4 PLANTS)	[46]	0.08	54	DIAMETER $\leq$ 10 μm	1.44	39
CENTRIFUGAL-FORMING GLASS WOOL APPLIANCE INSULATION (2 PLANTS)		0.05	35	DIAMETER $\leq$ 10 μm	0.81	17
GLASS WOOL PIPE INSULATION FORMATION (3 PLANTS)		0.10	16	DIAMETER $\leq$ 10 μm	1.74	19
SCRAP RECLAMATION-GLASS POURING WOOLS (4 PLANTS)		0.07	26	DIAMETER $\leq$ 10 μm	1.44	19
FLAME ATTENUATED FORMING-GLASS INSULATING WOOLS (2 PLANTS)		0.37	16	DIAMETER $\leq$ 10 μm	0.69	17
OTHER MANUFACTURING OPERATIONS – PRODUCT FAB, PACK, ETC. 3 PLANTS (mg/m^3); 4 PLANTS (f/ml)		0.08	26	DIAMETER $\leq$ 10 μm	0.63	41
CENTRIFUGAL-FORMING GLASS WOOL (6 PLANTS)	[47]	0.15	63	TOTAL FIBER COUNT	1.66	59
CENTRIFUGAL-FORMED GLASS WOOL PACKING AND FAB		0.16	246	TOTAL FIBER COUNT	2.02	259
SCRAP-RECLAMATION-GLASS POURING WOOLS		0.11	37	TOTAL FIBER COUNT	1.09	37
BONDED GLASS MAT FORMATION (AN ATTENUATION OF TEXTILE BUSHING FIBER)	[47]	0.22	18	TOTAL FIBER COUNT	1.12	13
FLAME-ATTENUATED GLASS WOOL FORMATION (INCLUDES WOOLS WITH NOMINAL FIBER DIAMETERS OF 1-4 um)		0.38	8	TOTAL FIBER COUNT	1.33	35
CONTINUOUS GLASS TEXTILE FIBER FORMATION		0.20	6	TOTAL FIBER COUNT	2.99	18
GLASS TEXTILE YARN FABRICATION		0.37	205	TOTAL FIBER COUNT	1.19	228
STABLE (CARDED) GLASS FIBER FORMATION (1 PLANT)		0.35	2	TOTAL FIBER COUNT	5.49	10
STABLE FIBER FABRICATION (1 PLANT)		0.20	1	TOTAL FIBER COUNT	2.25	7
GLASS WOOL INSULATION MANUFACTURE (METHOD OF FORMATION NOT SPECIFIED) (4 PLANTS)	[45]	0.37	(NR)	TOTAL FIBER COUNT	0.32	(NR)
CONTINUOUS GLASS TEXTILE FIBER FORMATION (1 PLANT)		0.20	(NR)	TOTAL FIBER COUNT	0.06	(NR)
GLASS TEXTILE FIBER – SPINNING AND TWISTING		0.33	(NR)	TOTAL FIBER COUNT	0.16	(NR)
GLASS TEXTILE FIBER – WASTE RECOVERY		0.33	(NR)	TOTAL FIBER COUNT	0.11	(NR)

NR = NOT REPORTED

Table IV-1
OCCUPATIONAL EXPOSURE SUMMARY – PRIMARY MANUFACTURERS (Cont.)

EXPOSURE	DATA SOURCE	MEAN FIBER CONCENTRATIONS (fiber/ml)	NO. OF SAMPLES	BASIS FOR INCLUSION IN FIBER COUNT	MEAN TOTAL DUST CONCENTRATION (mg/m^3)	NO. OF SAMPLES
PLANT A – GLASS WOOL (PERSONAL)	[48]					
FLAME ATTENUATED FIBER ROLLUP		0.12	4	TOTAL FIBER COUNT	3.5	4
RIGID DUCT MANUFACTURE		0.07	3	TOTAL FIBER COUNT	2.3	3
FILTER PACKER		0.10	10	TOTAL FIBER COUNT	4.8	1
BOND MAT ROLLUP		0.12	2	TOTAL FIBER COUNT	2.1	2
SCRAP RECLAMATION		0.08	2	TOTAL FIBER COUNT	3.4	2
MOLD AND PIPE MANUFACTURE		0.12	4	TOTAL FIBER COUNT	3.6	4
WOOL PLANT SELECTOR PACKER		0.12	4	TOTAL FIBER COUNT	3.1	4
PLANT A – GLASS WOOL (ENVIRONMENTAL)						
ACOUSTIC TILE PLANT		0.11	3	TOTAL FIBER COUNT	1.2	3
FLEXIBLE DUCT FORMATION		0.12	2	TOTAL FIBER COUNT	2.0	2
FILTER FIBER FORMATION		0.13	4	TOTAL FIBER COUNT	3.0	4
BONDED MAT PLANT		0.06	2	TOTAL FIBER COUNT	0.7	2
TEXTILE MAT FORMATION		0.17	4	TOTAL FIBER COUNT	2.3	4
SCRAP RECONDITIONING		0.13	2	TOTAL FIBER COUNT	3.2	2
WAREHOUSE		0.06	2	TOTAL FIBER COUNT	1.5	2
FLAME ATTENUATED FIBER FORMATION		0.07	2	TOTAL FIBER COUNT	1.3	2
WOOL PLANT – HOT END		0.09	4	TOTAL FIBER COUNT	2.3	4
PLANT B – GLASS WOOL AND TEXTILE FIBER (PERSONNEL)	[48]					
FIBER FORMATION, WINDING		0.07	6	TOTAL FIBER COUNT	2.6	6
HOT FIBER HANDLING – CHOPPED, BONDED MAT		0.15	3	TOTAL FIBER COUNT	1.0	3
HOT FIBER HANDLING – HELIX FORMATION		0.76	2	TOTAL FIBER COUNT	2.4	2
MICROFIBER FORMATION – COLD END		0.17	3	TOTAL FIBER COUNT	0.6	3
MICROFIBER FLETING AND LEACHING		0.74	3	TOTAL FIBER COUNT	0.9	4
FILTER TUBE MANUFACTURE – SOCKING STATION		2.40	2	TOTAL FIBER COUNT	2.8	2
FILTER TUBE MANUFACTURE – SAW OPERATOR		1.39	2	TOTAL FIBER COUNT	1.2	2
PLANT B (ENVIRONMENTAL						
TEXTILE FIBER ROVING, WEAVING, CHOPPED STRAND MANUFACTURE		0.09	5	TOTAL FIBER COUNT	1.1	5
BONDED MAT, HELIX FORMATION		0.05	3	TOTAL FIBER COUNT	0.7	3
MICROFIBER FORMATION – HOT END		0.04	1	TOTAL FIBER COUNT	0.1	1
CHOPPED MAT FORMATION		0.02	2	TOTAL FIBER COUNT	0.2	2
FILTER TUBE FORMATION		0.15	2	TOTAL FIBER COUNT	0.7	2
BONDED MAT FORMATION		0.03	2	TOTAL FIBER COUNT	0.5	2

Table IV-2

OCCUPATIONAL EXPOSURE SUMMARY – SECONDARY MANUFACTURERS

EXPOSURE	DATA SOURCE	MEAN FIBER CONCENTRATIONS		BASIS FOR INCLUSION IN FIBER COUNT	MEAN TOTAL DUST CONCENTRATION	
		(fiber/ml)	NO. OF SAMPLES		(mg/m^3)	NO. OF SAMPLES
FIBROUS GLASS REINFORCED PLASTICS						
PLANT A	[46]					
SPRAY-UP		0.07	7	≤10 um	1.13	7
FLASHING REMOVAL & FINISH		0.03	3	≤10 um	3.55	3
NON-CORROSIVE PRODUCTS PLANTS – SEVERAL USING SPRAY-UP, FILAMENT WINDING AND HAND LAYUP – DATA NOT DIFFERENTIATED BY JOB CODES	[47]	0.12	38	TOTAL FIBER COUNT	3.49	43
PLANT C	[48]					
MOLDED GLASS REINFORCED PLASTIC PRODUCTS FINISHING AND TRIMMING (PERSONNAL)		0.15	5	TOTAL FIBER COUNT	3.9	5
PLANT C (ENVIRONMENTAL)	[48]					
MAT CUTTING		0.17	3	TOTAL FIBER COUNT	3.3	3
		0.17	4			
LARGE REFORM AREA		0.17	4	TOTAL FIBER COUNT	1.3	4
SMALL PREFORM AREA		0.14	4	TOTAL FIBER COUNT	2.4	4
PANEL DEPARTMENT		0.09	8	TOTAL FIBER COUNT	2.6	8
CUSTOM MOLDING		0.16	8	TOTAL FIBER COUNT	2.2	8

Table IV-3

OCCUPATIONAL EXPOSURE SUMMARY – FINE FIBER PRODUCERS AND USERS

EXPOSURE	DATA SOURCE	MEAN FIBER CONCENTRATIONS		MEAN TOTAL DUST CONCENTRATION	
		(fiber/ml)	NO OF SAMPLES	(mg/m^3)	NO. OF SAMPLES
FINE FIBER MANUFACTURERS	[46]				
PLANT 1					
PRODUCTION AND BULK HANDLING		1.0 (0.1-1.7)	5	0.4 (0.1-1.1)	5
PLANT 2					
PRODUCTION AND BULK HANDLING		9.7 (0.9-33.6)	54	0.7 (0.2-2.0)	25
FABRICATION AND FINISHING		5.3 (0.3-14.3)	24	0.3 (0.1-0.7)	13
HIGH EFFICIENCY FILTER AND CRYOGENIC PAPER MANUFACTURE	[46]				
PLANT 1					
FIBER MIXING		5.8 (4.7-6.9)	2	NT	
TRIMMING/FOLDING		1.9 (1.6-2.1)	2	NT	
PLANT 2					
FIBER BLENDING		21.9 (8.9-44.1)	3	NT	
FIBER TRIMMING		10.6	1	NT	
AIRCRAFT INSULATIONS MANUFACTURE	[46]				
PLANT 1					
BULK FIBER HANDLING		1.2 (0.4-3.1)	13	0.6 (0.2-1.4)	8
FABRICATION AND FINISHING		0.8 (0.2-4.4)	15	0.4 (0.2-0.9)	10
PLANT 2					
BULK FIBER HANDLING		14.1 (3.2-24.4)	3	NT	
FABRICATION AND FINISHING		2.1	1	NT	

NT = NOT TAKEN

in length per milliliter, the actual <u>total fiber concentration</u> will probably be 50 to 200 fibers/ml. In comparison, with phase-contrast counts of fibrous glass, one is essentially counting "all" the fibers which are present though it is necessary to use higher magnification with the small-diameter fibers. Obviously, even with the highest concentration found by these studies, actual fiber concentrations are far below those present even in a well-controlled asbestos plant."

IV.a Environmental Surveys

NIOSH [46] in 1972-73 conducted environmental surveys of respiratory exposure to fibrous glass in four wool insulation plants, six producers and users of fine fiber, and a glass-reinforced plastic-products plant.

Again, fiber-count samples were collected on Millipore type AA membrane filters at 2 lpm sampling rate with counting and sizing by phase contrast microscopy at 430X. For fine fiber, where most diameters are less than 1 μm, either oil-immersion objectives at 1000X or transmission-electron micrographs at total of about 16000X are used.

Simultaneously, a second sampler was used to collect a gravimetric total-airborne-dust sample.

In the four plants producing wools for typical insulation applications such as thermal insulation for residential and commercial use, appliance insulation, ceiling tile, pipe insulation, duct liner and so forth, fiber concentrations were extremely low--with the plant with the highest average having a 0.1 fibers/ml count. This data represent 146 samples taken in both wool-forming and product-manufacturing areas. Both centrifugal and flame attenuation processes are represented. Total airborne dust averaged about 1.1 mg/m^3 across all plants, with the highest sample being 14.5 mg/m^3. Typically, fiber sizing showed the great majority of fibers to fall within the respirable range. As also reported by Corn [48], only a small fraction (2-7 percent) of fiber lengths were ≤ 5 μm.

In the glass-reinforced plastics plant surveyed, exposure to glass fiber exists in the spray application of chopped glass strand and in finishing where excess material is removed by grinding. Fibers/ml averaged 0.07 in laminating areas and 0.03 in finishing operations. Average total dust was 2.0 mg/m^3 for all operations and median fiber diameter was 5 μm with 35 percent of the count being within the respirable diameter range.

Fine Fiber

The six facilities producing or using fine fiber include both manufacturers of this speciality product, two plants making high-efficiency and cryogenic filter papers, and two producers of high-temperature, high-efficiency thermal insulation.

As shown in Table IV-3, total dust concentrations were low, averaging less than 1.0 mg/m^3 with the greatest single sample being 2.0 mg/m^3. However, mean airborne fiber concentrations by plant, ranged from 1.0 to 21.9 fibers/ml with the highest single sample being a 44.1 fibers/ml value recorded during blending operations where bulk filter is charged into a paper-making process. Across all 123 samples taken at the six facilities, the mean value was 6.7 fibers/ml. These values are orders of magnitude higher than those reported by any of the investigators conducting fiber counting at conventional-diameter fiber producers, or secondary manufacturers.

Dement [46] observed that at the six plants, a great majority of airborne fibers had diameters less than 0.5 μm (40-85 percent) and that 4 to 45 percent of the airborne fibers were less than 5.0 μm in length. The length distribution contrasts with the 2 to 7 percent of airborne fiber less than 5.0 μm that Dement observed at large-diameter wool manufacturers.

Dement also found the airborne-fiber-length distributions of both fine fiber manufacturers closely approximated those encountered in a typical amosite-asbestos-insulation producer.

Other Surveys

Konzen [47] reported results of fiber counts and total-airborne-dust-concentration sampling conducted since 1970 at 15 plants of one corporation. The operations covered included six glass wool plants, five textile-fiber plants, and four manufacturing fibrous, glass-reinforced plastic products. In summary, Konzen's data showed:

- Airborne fiber counts averaged <0.4 fiber/ml.
- Less than 2% of the total particulate was fibrous.
- About 80% of the airborne fiber fell within the respirable (≤ 3.5 µm) range.
- The concentration of respirable fiber in manufacturing processes is "remarkably consistent without apparent influence from geographical location of the plant, time of year, climatic conditions, method of manufacture or nominal diameter of the parent material." [47]
- No apparent relationship between total dust and airborne-fiber concentration.
- Total dust concentration across 709 samples averaged less than 2.0 mg/m^3.

In paired total-dust concentration and fiber-count sampling of two large, multi-product glass wool plants (including one manufacturer of fine fiber) and a glass-reinforced plastics manufacturer, Corn [48] reported average total-airborne-fiber counts using phase-contrast microscopy of 0.11 (0.01-0.33); 0.43 (0.01-4.50) and 0.15 (0.04-0.28) $fiber/cm^3$ for the three plants respectively. Median total dust concentrations for the three plants were 2.6 (0.7-6.0), 0.8 (0.1-5.2) and 2.8 (0.2-6.8) mg/m^3.

Fiber counts using an electron microscope technique were also made on the 125 samples and the fiber was categorized by length $<$ 1 µm or length $>$ 1 µm. Fibers were also grouped by length using phase-contrast microscopy into two ranges, under and over 5 µm. The results show a rapid trail off in the shorter fiber lengths with counts being observed in the $<$ 1 µm-length category in only 10 of the 125 samples and in 23 of the $>$ 1 µm-length category.

In an investigation of the work environment of insulation workers, Fowler, Balzer and Cooper [49], conducted field evaluations and collected membrane filter samples at light-job sites. As with the other studies described in this section, the sampling technique used a Millipore type AA membrane filter and fibers were counted at 430X using phase-contrast microscopy.

Fiber counts ranged from 0.5 to 8 fibers/ml with a median of 1.3 fibers/ml and mean of 1.8 fibers/ml. Cumulatively, about 60% of both the breathing zone and area samples had diameters within the respirable range. The majority of computed gravimetric concentrations were less than 1.0 mg/m^3.

The authors, in discussing the difficulty in estimating a typical exposure, noted that the portion of the working day that insulators actually work with fibrous glass varies from less than 10 percent to nearly 100 percent depending upon the employer and type of construction.

In the first study utilizing fiber counting as a technique to assess fibrous glass environmental exposures, Johnson, Healey, Ayer and Lynch [45], conducted membrane filter sampling at four wool and one textile plant. Fiber counts were made by phase-contrast microscopy at 430X using the procedure developed by Edwards and Lynch [44] for asbestos.

Mean total respirable fiber counts averaged across the four wool plants forming areas was 0.25 fiber/ml (0.02-2.95) and 0.10 (0.0-0.19) fiber/ml for the textile plant. Mean total respirable samples from the spinning, twisting and waste recovery areas of the textile plant were 0.72 (0.03-12.67) fiber/ml. The maximum respirable dust concentration found in any of the forming or subsequent processing sections of all plants was 1.74 mg/m^3 with all mean values falling below 0.46 mg/m^3.

A comparison of this data was made with fiber concentrations in asbestos textile plants (after dust control measures had been implemented). Exposures in the asbestos industry are on the order of 20 times those of the fibrous glass industry.

IV.b The Duct-Erosion Problem

One of the more controversial aspects of fibrous glass exposure is whether air transmission systems lined with fibrous glass are subject to erosion. In 1946, the use of fibrous glass to line the inside of metal ducts for acoustic damping was initiated [52]. In 1960, glass duct board entered the market. This material has a foil or paper backing and is strong enough to allow grooving and folding of the board into the air duct proper. Circular, wire-reinforced duct is also widely used.

Cholak and Schafer [52] in 1967 measured the eroding effect of a moving air stream on the fibrous glass duct liner and duct materials in a laboratory setup typical of heating and air conditioning systems. The test subjected fibrous glass duct material or duct sections to velocities of 3000 fpm (25% higher than the highest flow rate normally associated with air distribution systems) for a period of 136 hours per test. Outdoor air was used continuously; no attempt was made to control the air temperature or humidity. Materials were installed, cut and formed in a manner typical of such systems.

Tests were conducted using seven different types of rigid duct-board material, two different forms of flexible fibrous glass, and 16 types of fibrous glass duct. In each test: (1) outside air was drawn through a filter box; (2) air was passed through a flow nozzle 2 feet downstream to provide a flat velocity profile; (3) a damper assembly provided a flow-rate control; (4) air was then passed through a 12-foot section of egg crate construction with 2-in. square openings; (5) an 8-foot transition section was then provided with an entrance side for the test section to slide over; and (6) the test section of straight run was connected to a three-piece 90-degree elbow.

Membrane filter sampling was conducted at two locations in the test setup - near the inlet beyond the filter box and at the outlet. Three-μm, 104-mm diameter, type WS Millipore filters were used with an isokinetic

1/2-in. diameter flow nozzle located in the center of the air stream. No detectable weight of glass was collected for any of the test materials. Fiber counts were made by phase-contrast microscopy at 200 and 900X. Only one fiber was observed among all the downstream samples in the tests of any of the materials. (Although a 3-μm pore filter was used, a normal distribution of fiber diameters should have resulted in some count even if most of the fine fiber escaped detection.) This test series did not indicate whether fibrous glass-lined air transmission systems are more subject to erosion after age embrittlement.

To counter this deficiency, Cholak and Schafer [53] undertook in 1969 a field study of six air transmission systems. These systems had been installed for an average of six years. Techniques were basically the same as in the earlier study with inlet and downstream sampling, particulate collection on 3-μm pore size filters with analysis by phase-contrast microscopy at 200 and 900X. Additional samples were collected on adhesive tape and by wall wiping.

The authors were unable to identify glass fiber in any of the downstream filter analyses but did observe fiber on tape at both inlet and outlet in a single case. Analyses of the settled dust showed glass fiber in all cases but the concentration was typically higher at the inlet than at the outlet. They concluded that no evidence of erosion existed.

Balzer, Cooper and Fowler [54] in 1971 conducted membrane filter sampling on-site of actual air transmission systems lined with fibrous glass duct. Fiber counts were made using the Edwards and Lynch [44] method. Their results showed a decrease in the concentration of glass fiber as the air passed through the systems, both in the number of glass fibers and the relative portion of fibers to the total dust mass. The authors did not preclude erosion, but felt that any erosion was more than offset by deposition and entrapment of the fibers in the fibrous glass ducts. Glass fiber concentrations within the buildings correlated more closely with ambient outdoor concentrations than with those of air exiting from the supply systems. The glass fiber concentrations in the ambient air in the air supply systems and the building areas were extremely low (mean of 0.0002 filter/ml). The author concluded that properly designed, constructed and maintained air transmission systems do not add glass fiber to the air.

In another study, Balzer [50] reporting on fiber analysis and counting of 37 membrane filter samples collected from 1968-1971 from 13 transmission systems found a mean concentration 0.0004 fiber/ml using combined light and electron microscopy.

This study also analyzed 36 ambient air samples and 40 occupational samples collected during the installation of fibrous glass insulation. Fiber concentrations for the ambient air averaged 0.003 fiber/ml; the occupational samples mean was 0.4 fiber/ml. The ambient samples, with higher average fiber concentration than the air transmission systems, were collected at sites in California ranging from urban to the Sierra Mountains and predictably showed a much greater standard deviation than those from the ventilation systems. About 60 percent of the fibers from the ventilation systems had diameters $< 3\ \mu m$, compared to 15 percent for the occupational samples and 40 percent for the ambient.

V. SUMMARY OF CURRENT-PRACTICES SURVEYS

All fibrous glass and mineral wools are manufactured by a few basic processes, although there are many subtle variants from plant to plant. These can all be resolved into three fundamental ways of putting large amounts of mechanical energy into the molten raw material stream to cause it to form filaments that are subsequently air-cooled into fiber. These ways are throwing, blowing or pulling.

Under the category of throwing are several centrifugal fiberization techniques in which a stream of molten glass, slag, or rock is introduced into a rapidly rotating disk, drum or basket. The melt flows radially outward to the lip of the rotating member (or to the holes, in the case of basket types) from which droplets are rapidly thrown as soon as the centrifugally loaded mass of each droplet exceeds the surface and viscoelastic forces within the melt. The combination of these forces and the aerodynamic effects of droplet introduction into the extremely turbulent field surrounding the rotor, rapidly draws each droplet into a fiber which is vitrified by the cooling effect of the surrounding air flow before the strains can be relaxed. Variations in rotor design, orientation, and operating conditions are used by various manufacturers to control the nature of the product as well as the economics of the process.

The other two fiberization methods depend on glass flow through a "bushing" to produce a primary filament of glass that is further narrowed into the final fiber size. Continuous fiber is made by combining the output of the large number of individual flows through the many holes in a bushing and connecting them to a rapidly rotating takeup reel. The speed of the reel is adjusted to pull the fiber hard enough to cause each individual fiber to neck down to the desired diameter just as it leaves the bushing. With the same diameter holes in the bushing, larger diameter fiber may be made by less rapid rotation of the take-up reel, while smaller diameter fiber may be made by more rapid takeup, down to the diameter where the statistical occurrence of inpurities or inhomogeneities in the molten glass cause fiber breakage to occur at uneconomical frequencies.

The final basic process, blowing, fiberizes and attenuates glass by impinging a jet of high-velocity air, steam or flame, usually from a perpendicular direction, upon the gravity-drawn primary filament from a bushing. The gas stream blows the primary filament into fiber of a diameter controlled by temperature, flow rate, impingement angle and composition of the glass. A variation of this basic scheme uses a molten stream centrifugally distributed by a rotor surrounded by a ring of high-velocity jets that cause the fiberization.

Special note should be taken of the flame attenuation processes that are capable of producing fiber of the narrowest obtainable (submicrometer) diameters by using a high-velocity gas/air flame to fiberize the primary filament.

Coating the fibers with lubricants, binders, sizings, etc., is always performed immediately after the fiber is drawn to its final diameter and before it is accumulated into cake, batt, mat or other combined form. The coating process is accomplished for continuous fiber by spraying or by passing the group of fibers through liquid coating on a roller, belt, or similar device. Discontinuous fiber is almost exclusively sprayed with the coating agent in solution, emulsion, or (occasionally) dry powder form. The discussion of individual branches of the basic fiber manufacturing industry will refer generally to these processes.

V.a Mineral Wools

Mineral wools are differentiated from other glass wools principally by the simplicity of their raw materials which may consist of either of native rock mixtures or any readily-fusible slag available from smelting or similar processes or combination of natural and man-made material. The materials are melted together according to a somewhat flexible formulation in cupola furnaces and then fiberized by centrifugal or air- or steam-blown centrifugal processes. A binder resin (typically phenolic) and/or a lubricant and dust-suppression oil are sprayed into the airborne fiber which is subsequently deposited on a moving, screen belt by the action of high-volume air throughput. For batt products the screen conveyor carries the mineral wool blanket through an oven to cure the binder resin and then either to a direct rolling operation or a series of choppers, slitters, facing appliers and/or other equipment designed to produce the specific product desired. "Loose" wool for blown-into-place insulation, furnance cements, insulating coatings and the like, are also deposited initially on a moving screen but without the resinous binder. The material is then screened or air floated to remove "shot" or "slugs," the lumps of mineral which fail to fiberize during the attenuation process; additional organic or inorganic binders or hydraulic cements are added and the product is packaged (usually in bags) for shipment. The mineral wools generally tend to have relatively large mean-fiber diameters (typically 5 to 10 μm) with very little fiber produced in respirable size ranges.

The mineral-wool plants visited in our survey tended (compared to the rest of the vitreous fiber industry) to be older, relatively poorly maintained, and have fewer provisions for dust collection and suppression, although the larger fiber size tended to minimize the actual amount of airborne fiber present in the environment. Even the dustiest-appearing two plants in our survey, which were sampled by the NIOSH representative accompanying the survey team, showed airborne fiber counts entirely below 3 and mostly below 2 fibers/cm^3.

The size range represented does, however, readily irritate normal skin and itching and other minor skin complaints seem to be the ubiquitous lot of beginning workers, and a major factor in early (first few weeks) resignations. Our survey confirms findings by other investigators [33] indicating that continued exposure produced a "hardening" or increased tolerance to dermal exposure and a cessation of problems except for outbreaks when hot, sticky weather caused increased perspiration and skin softening.

The Work Practices Survey followed several of the mineral-wool products further down the line, including both industrial and home insulation applications of these products.

Other than hearing protection in fiberization areas of basic fiber manufacturers, there was little or no consistancy in the provision and use of personal protective equipment. Many producers provide dust respirators, safety glasses, gloves and barrier creams if desired by the employees, and some offer coveralls and aprons. However, few require constant use of any of the devices, and none of those visited by our survey enforced requirements other than the use of safety glasses and, in some cases, safety shoes.

V.b Glass Wools

The upstream end of a glass-wool plant, rather than having any resemblance to a mineral-wool plant, is essentially identical to that part of a plant making bottles, windows, or any other glass product. Finely powdered mineral ingredients are dry mixed into "batch" which is progressively fed to a large, continuously-operated furnace or melter. The material fuses into molten glass as it flows through the closely temperature-controlled furnace and into the "forehearth" or output end where the stream is divided into substreams, each of which feeds either a fiberization process or a marble former. In the latter case the glass is used to produce half-inch to inch-diameter spheres which may subsequently be fed through a marble melter and a small conduit (akin to a miniature forehearth) and then to a fiberization process.

Glass wool is formed from the molten glass by a centrifugal process or by blowing with high-velocity air, steam, or flame. The vast majority of glass wool is produced with mean-fiber diameters ranging from 3 to 12 µm. (Although the glass-wool fiber-size spectrum is continuous, we will separately discuss the predominantly < 3 through submicron range fiber in Section V.d).

The wool is formed airborne, sprayed with sizing, binders, or lubricants, and gathered onto a moving, wire-mesh belt by a large throughput of air. It should be noted in passing that the air for this step, in both mineral- and glass-wool plants, varies from tens to hundreds of thousands of ft^3/min and invariably dominates the airflow in the plant as a whole, giving both direction and velocity to most of the casual air circulation, thus contributing to some extent to the low, airborne-fiber counts in breathing air.

The blanket thus formed may then be either oven-baked to cure or partially cure its resin coating or it may be merely air-dried to await curing in a subsequent forming operation. If intended for insulating batts of various types, it is usually cured at this stage and then passed through machines which apply facing, if required, and/or split, trim, and cut to final product shape. The product is then greatly compressed to reduce bulk for shipping and is packaged. Compression and packaging may be done in either order with rectangular flat insulating batts usually being stacked, compressed, and then packaged while roll goods may either be fully compressed and then wrapped or partially compressed, bagged in plastic, and then completely compressed by evacuating the plastic bag. (It was an observation of the survey personnel that the operations which compress the batts mechanically by rapidly squeezing out 80-90% of the interstitial air, may be disproportionate contributors of airborne fiber.)

Partially cured or uncured resin-coated-glass fiber blanket is cut in conveniently sized pieces or rolls at this stage and either transported to other plant areas for subsequent fabrication or wrapped and shipped to secondary manufacturers for their use.

Secondary operations may be performed in the same plant (typically), another plant of the same company, or the plant of a customer. The operations usually involve the confinement of the un- or semi-cured glass wool in a form or mold which is heated to finish the resin cure. A great number of products are manufactured by this general scheme, such as wall and ceiling paneling by rolling and curing, pipe insulation by placing in molds and oven baking, and vehicle hoodliners, headliners, and decorative ceiling tile by compression in heated matched-metal-molds. Each of these products then typically receives final shaping by trim sawing, slitting, die cutting or other procedure and is packaged for shipment.

Another secondary operation conducted in most wool plants (wherever the quantity of suitable scrap justifies it) is the production of insulating blowing wool. In this operation the wool batts (usually but not necessarily off-grade, surplus or scrap) and trimmings from other products which are suitable (no paper or foil facing, not high in resin) are torn or shredded by a mechanical chopper and bagged for sale. In some plants, the survey noted that considerable visible dust is associated with the production of blowing wool.

Housekeeping in surveyed glass wool plants was rated as fair to quite good, ranking, in this respect, between the mineral-wool plants and the very clean, glass-textile operations. Waste disposal was similar to the rest of the industry with non-reworkable scrap typically being trucked to a municipal or company owned dump or landfill.

Personal protective gear requirements are varied. Hearing protection usually is required around fiberization operations, respiratory protection is occasionally required in very dusty areas, and various plants have requirements for safety glasses and/or shoes throughout the plant.

Most plants have respirators or dust masks, gloves and hand creams available upon employee request. Some will provide aprons or coveralls for unusually dirty jobs.

Medical facilities have about the same relationship to plant size generally prevailing in industry; large plants have complete clinical facilities and staff physicians while smaller plants have foremen or supervisors with first aid training and have some sort of contractual arrangement with a local hospital or medical group. Frequently, smaller plants will employ a full-time nurse. Pre-employment and continuing physical examination procedures have shown an even wider variation ranging from none to very complete pre- and post-employment physical examinations with full-plate x-rays and vital capacity measurements. It is interesting to note that employers who gave no physicals cited one of two reasons: either high turnover, which made the procedure both costly and of limited longitudinal value, or union opposition to company-performed examinations. Union officials contacted during the survey confirmed this stand, indicating that companies might deny or terminate employment for certain physical conditions which did not bear upon immediate competence for the intended position but might subsequently involve disability benefits.

The survey followed glass-wool use from basic manufacturing through secondary fabricators to ultimate installers and users of insulation and other glass-wool products.

In essentially all cases during the industrial portion of the survey, the glass wool handling involved only a small portion of an industry and the peripheral housekeeping, medical services, protective gear, etc., reflected the prevailing practices in that industry. Insulation installers, on the other hand, tend to work principally with glass wool products but the individual operations are so small that each man tended to operate individually and provide himself equipment (dust masks, gloves, etc.) which he personally desired for his comfort and/or any health hazard he perceived.

V.c Glass Textile Fiber

All glass continuous fiber is produced by pulling fiber from a multiple orifice bushing by a spinning takeup reel. Between the bushing and the reel the fiber receives a size or lubricant coating by spray or roller. The gathered, sized combination of all of the fibers from a single bushing is called strand. The filled reels (called cakes) are then air dried and/or oven cured prior to further processing.

Subsequent processing can take a number of different directions. Much of the fiber is turned into roving, consisting of a bundle of strands gathered together from cakes or creels. The roving is wound together in a configuration appropriate for its subsequent use. Some is sold directly to companies doing spray-up fabrication of glass-reinforced plastics that use spray guns which chop and spray roving along with the resin. Other roving is chopped in the fiber producer's plant and sold to the plastics industry as chopped fiber of various lengths and designations. Most chopped fiber is produced by chopping the original strand without the intermediate step of making roving. Other roving is woven into a coarse glass cloth designated "woven roving," and sold for use in hand lay-up of reinforced plastic products. Roving is also used directly by manufacturers of filament-wound reinforced plastic tanks, rocket motor cases, and similar products. A small quantity of roving is heavily resin impregnated, cured, and formed into helical reinforcement for flexible ducting in heating and cooling system construction.

Another use of strand is to make chopped or continuous strand mats. Chopped strand mat is a non-woven fabric of randomly arranged fibers 20-50 mm in length. Strength is provided by chemical binders. Most chopped strand mat is used in lay-up of reinforced plastics.

Continuous strand mat uses unchopped fiber. Much of the strength is derived from interlocking of the spiraling strands with little binder. A unique use is as die pads for metal stamping and molding to improve appearance and surface strength.

Much strand is twisted and/or plied into yarn and woven into fabrics for special purpose apparel such as thermal-resistant clothing or for decorative use as in draperies. Other major uses of fibrous glass cloth are for reinforcement for high-strength plastics such as aircraft structures, radar antennas, and printed circuit boards. Strand is also used for manufacture of the "glass belts" used in vehicle tires.

The fiber produced by the continuous bushing-pull technique is, by its nature, of a relatively tight diameter range, lacking the broad distribution of the wools which contain both very fine and very coarse fiber along with the nominal size. Typical textile fibers (other than those with diameters under 3.5 µm, treated in the next section) fall in size ranges from about 4 µm to 15 µm, closely distributed around the nominal value for each.

The glass-textile fiber manufacturing industry typically features modern, clean, well-lighted plants compared to the average plant in the glass-or mineral-wool industry. Although lacking the massive air flow intrinsic to the wool processes, the textile-glass plants have neither the airborne fiberization step nor the fine fiber, fraction-of-the size distribution which favors airborne fiber dust. Most plants visited by the survey provided air collection equipment at particularly dusty operations, such as slitting, edge trimming, and chopping. Dust, fuzz, and lint collection systems used with such operations are typically a suction box, terminated through a cyclone or cyclone and bag filter.

In the textile plants, similar in this respect to the wool plants, use of personal protective equipment is largely left to the discretion of the individual worker with the exception of safety glasses or shoes that are required by most employers. In most cases, gloves and dust masks, and in some cases other equipment, are available and are provided in response to employee request.

It should be noted in passing that each of the companies surveyed recognizes a major occupational health hazard in its batch-mixing operation where finely divided crystalline silica becomes airborne. All plants require respiratory protection in these areas. As the batch operation does not involve exposure to fibrous glass, however, no review of this process is included in these recommendations.

Housekeeping in the plants surveyed tended to be good, with scrap going either for reprocessing into chopped fiber or for insulating materials, with the balance going to dump or landfill.

Stated health problems have been limited to the same sort of beginning worker and summer-season, skin irritation shared by the balance of the industry.

Among the plants surveyed most had a relatively complete health program, with physical exams, both pre- and post-employment, being the usual practice and a complete chest x-ray normally part of the exam.

The products of the glass textile industry were followed by the survey down through the glass reinforced plastics industry. Again the outstanding glass-related problem was one of beginning and seasonal dermatitis with other health and safety practices being largely dominated by the requirements for dealing with resins, solvents, catalysts and accelerators.

As with other secondary industries the sophistication of the formal health and safety program tended to be determined by company size and main product industry.

V.d Fine Fiber Wools and Textiles

Fine fiber fiber glass is combined in this report by fiber size and, hence, likelihood of respiration. Two distinct production processes are involved. Fine fiber wool is produced by high velocity flame attenuation of primary fibers. The airborne fiber is gathered onto a moving screen by a large air flow. The fiber may be sized or lubricated during deposition by a spray nozzle array or may, when intended for further chemical processing or for high-temperature insulation, be left uncoated. The uncoated fiber tends to more easily become airborne during subsequent processing. The blanket of fine fiber wool is then either processed in the same manner as other wools (subsection 2) or wound off onto mandrels when it is to be redispersed or used as bulk fiber. Fine fiber wools may have fiber diameter distributions as small as 0.05 to 0.2 μm for highly specialized applications, but the vast preponderance lies in the 0.5 to 2.5 μm range.

Fine fiber wools find uses as high-efficiency, high-temperature insulation, filters (as bulk wool cartridges, sandwiched mat, or felted fiber paper) for gasses or liquids, as the starting material for fine fiber silica super-efficiency insulations.

Fine-glass textile fiber is produced by a bushing-pull, mandrel-wind process similar to the glass-textile-fiber production method described in subsection 3, parametrically adjusted to produce continuous fiber. The commercially drawn fibers range down to a nominal 3.5 µm diameter, although finer fiber has been drawn. After curing, the fiber is twisted or plied into yarns or thread and sold to the textile industry for weaving and subsequent use. Among the distinguishing characteristics of fine-fiber fabric (in addition to inertness and temperature resistance) is an unusually soft, supple "hand", making it suitable for special purpose garments such as space suits, in which use it acquired most of its public attention.

As discussed in the first major division of this report, there is no evidence to convict, and very little to indict, fibrous glass of presenting a severe or chronic health hazard. Yet, it is an undisputed fact that, except for the statistical tail of the diameter distribution in normal glass wools, little data has been gathered about human exposure to fine glass fiber and that none, thus far, has any epidemiological significance.

Thus, each of the fine-fiber manufacturers included in the survey (thought to include all such facilities in this country) has provision for extensive pre-employment and continuing physical examinations and each is well above the industry median in providing controlled air movement both in the fiber-forming area and locally where operations may create dust. Each plant also shows evidence of some attention to housekeeping, both by layout and labor.

And yet, only one of the plants requires respirators (an approved disposable) in the fiber-forming area, and another requires them in a handling operation. Otherwise the situation resembles the balance of the industry, characterized by availability of a wide variety of personal protective equipment but spotty use, except for mandatory glasses, shoes, or hearing protection in some plants.

Industries using fine fiber were also visited by survey teams but in each case the glass use was very subsidiary to the other processes and the industrial hygiene situation was dominated by the requirements of other plant functions.

V.e Survey Summary and Conclusion

The number of individual products which include glass fiber has been estimated in the vicinity of 35,000. It would obviously not be feasible for a single survey to visit all plants making these products. And yet in the forty visits we did make, we attempted to survey as representative a cross section of producer, secondary manufacturer, and user industries as was possible within the time and administrative constraints of our program. Indeed, the breadth and contrasts of the survey were a source of continual amazement to the personnel involved, ranging from industrial giants to garage industries and even a residential installation.

The basic fiber-production factories themselves spanned an "age of enlightenment" in working conditions and industrial hygiene in the dates of their construction. Thus a summary which tried to generalize about the fibrous glass industry would have as much value as stating that the Mississippi River is one foot deep on the average.

One fact that did emerge was the wide variations which exist, dependent upon company or plant size, plant age, and portion of the industrial sector represented. The effect of plant size was rather predictable. Below some arbitrary size it becomes infeasible for first aid, safety, industrial health, etc., to be separate functions, but rather, in the smallest operations, they become a few of the "many hats" worn by the owner(s) and/or manager. In larger companies the functions are distributed among middle management (e.g., the personnel manager may be responsible for safety and or industrial health). At some greater, perhaps ideal, size, the functions become distinct and specialized, and finally, in the largest industries, the functions become centralized with individual plant activities in these categories again distributed among middle management with liaison to the central organization.

The variation in conditions from plant to plant with age and sector of the industry (mineral wool, glass wool, glass textiles) is most striking. While most of the newer, glass-textile and glass- and mineral-wool plants are well-lit, comfortable, and pay obvious attention to cleanliness, a few of the older mineral-wool plants represent the absolute antithesis of this, being virtually buried in fiber everywhere except those places where constant foot traffic keeps pathways clear. In some cases, the air (although of relatively low respirable fiber count according to samples taken by NIOSH) produced an accumulation of fiber on the clothing of the survey personnel and considerable "fiber itch" after the few hours of exposure during surveying.

We were impressed throughout the program with the attitude of genuine concern and interest shown at all levels by the various individuals in industry with whom the survey had occasion to interface. Both management and the specific functionaries in health and safety proved, by-and-large, cooperative and open-minded being, in many cases, surprisingly conversant with the current status of research in this field. It is this attitude which leads us to feel that further investigation will be most useful in terms of prompt application of results to industry.

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16. Abstract (Limit: 200 words)

To gather information on work practices and engineering controls that can be effectively used to control occupational exposure to fibrous glass, Calspan Corporation conducted field surveys and a literature search, and consulted with unions, trade groups, and medical experts in the field. Forty field surveys were conducted, including glass textile, glass and mineral wool manufacturers; fine fiber producers and users; glass-reinforced plastic operations; and appliance, filter, and vehicle manufacturers; as well as commercial and residential insulation installers. The variation in conditions from plant to plant with age and sector of the industry (mineral wool, glass wool, glass textiles) is most striking. While most of the newer, glass-textile and glass-wool and mineral-wool plants are well-lit, comfortable, and pay obvious attention to cleanliness, a few of the older mineral-wool plants represent the absolute antithesis of this. In some cases, the air (although of relatively low respirable fiber count according to samples taken by NIOSH) produced an accumulation of fiber on the clothing of the survey personnel and considerable "fiber itch" after the few hours of exposure during surveying.

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