criteria for a recommended standard....

OCCUPATIONAL EXPOSURE TO FIBROUS GLASS

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PREFACE

The Occupational Safety and Health Act of 1970 emphasizes the need for standards to protect the health of workers exposed to an ever-increasing number of potential hazards at their workplace. The National Institute for Occupational Safety and Health (NIOSH) has projected a formal system of research, with priorities determined on the basis of specified indices, to provide relevant data from which valid criteria and effective standards can be derived. Recommended standards for occupational exposure, which are the result of this work, are based on the health effects of exposure. The Secretary of Labor will weigh these recommendations along with other considerations such as feasibility and means of implementation in developing regulatory standards.

It is intended to present successive reports as research and epidemiologic studies are completed and sampling and analytical methods are developed. Criteria and standards will be reviewed periodically to ensure continuing protection of the worker.

I am pleased to acknowledge the contributions to this report on fibrous glass by members of the NIOSH staff and the valuable constructive comments by the Review Consultants on fibrous glass, the ad hoc committees of the Society for Occupational and Environmental Health, American Industrial Hygiene Association, American Academy of Industrial Hygiene, and the American Academy of Occupational Medicine and by Robert B. O'Connor, M.D., NIOSH consultant in occupational medicine. The NIOSH recommendations for standards are not necessarily a consensus of all the consultants and

professional societies that reviewed this criteria document on fibrous glass. The Review Consultants are listed on pages vi-ix.

John F. Finklea, M.D.
Director, National Institute
for Occupational Safety and Health

The Division of Criteria Documentation and Standards Development, National Institute for Occupational Safety and Health, had primary responsibility for development of the criteria and the recommended standard for fibrous glass. The division review staff for this document consisted of Douglas L. Smith, Ph.D. (chairman); J. Henry Wills, Ph.D; and Paul E. Caplan with Anna M. Baetjer, Sc.D. (consultant); Loren L. Hatch, D.O., Ph.D. (Division of Technical Services); and David L. Bayliss (Division of Surveillance, Hazard Evaluations and Field Studies).

Tabershaw-Cooper Associates, Inc., developed the basic information under contract No. HSM-99-72-130 for consideration by NIOSH staff and consultants. Frank W. Mackison was criteria manager and had NIOSH program responsibility for development of the first phase of the document. Paul A. Schulte served as criteria manager for the final phase.

REVIEW COMMITTEE
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH, 1973*

John M. Dement
Division of Field Studies
and Clinical Investigations

William M. Johnson, M.D.
Division of Field Studies
and Clinical Investigations

N. Leroy Lapp, M.D.
Appalachian Laboratory
for Occupational Safety and Health

James B. Lucas, M.D.
Division of Technical Services

Jeremiah R. Lynch
Director
Division of Training

Frank L. Mitchell, D.O.
Office of Research and Standards Development

William D. Wagner
Division of Laboratories
and Criteria Development

Ex Officio:
Charles H. Powell, Sc.D.
Assistant Institute Director
for Research and Standards Development

*Affiliation at time of review

NIOSH REVIEW CONSULTANTS ON FIBROUS GLASS, 1973*

Hans L. Falk, Ph.D.
Associate Director for Program
National Institute of Environmental Health Sciences
Research Triangle Park, North Carolina 27709

Paul Gross, M.D.
Distinguished Research Professor of Pathology
Medical University of South Carolina
Charleston, South Carolina 29401

Robert L. Harris, Jr., Ph.D.
Department of Environmental Science and Engineering
University of North Carolina
Chapel Hill, North Carolina 27514

Jon L. Konzen, M.D.
Medical Director
Owens-Corning Fiberglas Corporation
Toledo, Ohio 43659

David A. Padden
Senior Industrial Hygiene Consultant
United Auto Workers
Detroit, Michigan 48214

George W. Wright, M.D.
Professor of Medicine
School of Medicine
Case-Western Reserve University
Cleveland, Ohio 44106

*Affiliation at time of review

UNIVERSITY REVIEW CONSULTANTS ON FIBROUS GLASS, 1976

Robert Frank, Ph.D.
Department of Environmental Health
University of Washington
Seattle, Washington 98195

Morton Lippmann, Ph.D.
Institute of Environmental Medicine
New York University
New York, New York 10016

R. Harrison Rigdon, M.D.
Department of Pathology
College of Medicine
University of Texas
Galveston, Texas 77550

Hans Weill, M.D.
Pulmonary Diseases Section
School of Medicine
Tulane University
New Orleans, Louisiana 70112

NIOSH REVIEW CONSULTANTS ON FIBROUS GLASS, 1976

Anita Bahn, M.D., Sc.D.
Department of Research Medicine
University of Pennsylvania
Philadelphia, Pennsylvania 19174

Robert L. Harris, Jr., Ph.D.
Department of Environmental Science
and Engineering
University of North Carolina
Chapel Hill, North Carolina 27514

Leon Horowitz
American Mutual Liability Insurance Company
Wakefield, Massachusetts 01880

Lorin Kerr, M.D.
Director, Department of Occupational Health
United Mine Workers
Washington, D. C. 20005

Paul Kotin, M.D.
Johns-Manville Corporation
Greenwood Plaza
Denver, Colorado 80217

Marvin Kuschner, M.D.
State University of New York
Stony Brook, New York 11790

Roy Steinfurth
International Association of Heat
and Frost Insulators
Washington, D.C. 20036

CRITERIA DOCUMENT: RECOMMENDATIONS FOR AN OCCUPATIONAL EXPOSURE STANDARD FOR FIBROUS GLASS

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I. RECOMMENDATIONS FOR A FIBROUS GLASS STANDARD

The National Institute for Occupational Safety and Health recommends that employee exposure to fibrous glass be controlled in the workplace by adherence to the following sections. The standard is designed to protect the health and safety of workers for up to a 10-hour workday, 40-hour workweek over a normal working lifetime. Therefore, compliance with all sections of the standard should prevent adverse effects of fibrous glass on the health and safety of employees.

In developing these recommendations, the Institute proposes that two categories of fibrous glass be identified for control purposes. The delineation between categories is by fiber diameter, with 3.5 micrometers (μm) being the dividing line. The primary health effects associated with the larger diameter fibers involve skin, eye, and upper respiratory tract irritation, a relatively low incidence of fibrotic (lung) changes, and preliminary indications of a slight excess mortality risk due to nonmalignant respiratory diseases. In this regard, NIOSH considers the hazard potential of fibrous glass to be greater than that of nuisance dust, but less than that of coal dust or quartz. With small-diameter fibers, much less information on health effects is available. Experimental studies in animals have demonstrated carcinogenicity; however, with the test methods employed (implantation), it is not considered that these results, can be extrapolated directly to conditions of human exposure. On the basis of currently available information, NIOSH does not consider fibrous glass to be a substance that produces cancers as a result of occupational exposure. However, these smaller fibers can penetrate more deeply into the

lungs than larger fibers and until more definitive information is available, the possibility of potentially hazardous effects warrant special consideration. The recommended environmental levels are based on evidence in those instances where exposure to asbestos and fibrous glass can be compared and, considering the limitations and deficiencies of such data, fibrous glass seems to be considerably less hazardous than asbestos. In addition, although this criteria document addresses occupational exposure to fibrous glass, NIOSH considers that until more information is available, the recommended standard can also be applied to other man-made mineral fibers.

Fibrous glass is the name for a manufactured fiber in which the fiber-forming substance is glass. Glasses are a class of materials made from mixtures of silicon dioxide with oxides of various metals and other elements, that solidify from the molten state without crystallization. Table XV-1 lists several representative compositions of glasses. Synonyms for fibrous glass include fiberglass and glass fibers. A fiber is considered to be a particle with a length-to-diameter ratio of 3 to 1 or greater. An "action level" is defined as half the recommended time-weighted average (TWA) environmental limit. "Occupational exposure" is defined as exposure to airborne fibrous glass above the action level. In addition, because workers may be exposed to fibrous glass by dermal or eye contact occupational exposure includes contact with the skin and eyes to fibrous glass where it is manufactured, used, handled or stored. When environmental concentrations are at or below the action level, adherence to sections 1, 2(b), 4(c), and 8(b) is not required.

Section 1 - Environmental (Workplace Air)

(a) Concentration

Occupational exposure to fibrous glass shall be controlled so that no worker is exposed at an airborne concentration greater than 3,000,000 fibers per cubic meter of air (3 fibers per cubic centimeter of air) having a diameter equal to or less than 3.5 micrometers (μm) and a length equal to or greater than 10 micrometers determined as a time-weighted average (TWA) concentration for up to a 10-hour work shift in a 40-hour workweek; airborne concentrations determined as total fibrous glass shall be limited to a TWA concentration of 5 milligrams per cubic meter of air.

(b) Sampling and Analysis

Sampling in the work environment shall be performed by the method provided in Appendices I and III or by other methods with at least equivalent efficiency. Samples shall be analyzed by the methods provided in Appendices II and IV or by methods demonstrated to be at least equivalent in accuracy, precision, and sensitivity.

Section 2 - Medical

Medical surveillance shall be made available to employees as outlined below:

(a) Preplacement examinations shall include at least:

(1) Comprehensive medical and work histories with special emphasis directed towards evidence of acute or chronic skin conditions and pulmonary disease and prior exposures in dusty occupations such as those involving exposure to silica, coal dust, and asbestos.

(2) Physical examination giving particular attention to the skin and respiratory system. Examinations should include simple tests for dermographism, and such tests of pulmonary function as FEV 1 and FVC when considered to be appropriate by the responsible physician. Eye examinations should also be considered when appropriate.

(3) For those workers exposed above the action level to fibers less than 3.5 μm in diameter, more specific tests shall be considered such as chest roentgenograms, pulmonary function tests such as FEV 1 and FVC, and others related to the detection of chronic lung disease including primary tuberculosis.

(4) An evaluation of the worker's ability to use positive and negative pressure respirators and to function under partial oxygen deprivation.

(b) Periodic examinations shall be made available at least on an annual basis or at some other more frequent intervals to be determined by the responsible physician. These examinations shall include at least:

(1) Interim medical and work histories.

(2) Physical examination as outlined in (a)(2) and (a)(3) above.

(c) During examinations, applicants or employees having medical conditions which would be directly or indirectly aggravated by exposure to fibrous glass shall be counseled on the increased risk of impairment of their health from working with this substance.

(d) Initial medical examinations shall be made available to all workers within 6 months after the promulgation of a standard based on these recommendations.

(e) Pertinent medical records shall be maintained for all employees exposed to fibrous glass in the workplace. Such records shall be retained for at least 30 years after termination of employment. These records shall be made available to the designated medical representatives of the Secretary of Health, Education, and Welfare; of the Secretary of Labor; of the employer; and of the employee or former employee.

Section 3 - Labeling and Posting

(a) The following caution sign shall be affixed or posted in a readily visible location at or near entrances to areas or on processing or other equipment where there is occupational exposure to fibrous glass:

FIBROUS GLASS

CAUTION

AVOID BREATHING DUST

Thoroughly wash exposed skin surfaces and flush the eyes after handling.

All warning signs shall be printed both in English and in the predominant language of non-English-reading workers. Illiterate workers and workers reading languages other than those used on posted signs shall receive information regarding hazardous areas and shall be informed of instructions printed on signs.

Section 4 - Personal Protective Equipment and Clothing

Engineering controls shall be used if needed to maintain fibrous glass concentrations at or below the limits recommended in Section 1. When necessary, engineering controls shall be supplemented by the use of personal protective equipment. Requirements for personal protective equipment shall be as approved under provisions of 29 CFR 1910, Subpart I.

(a) Skin Protection

Protective clothing shall be worn to prevent fibrous glass contact with skin especially hands, arms, neck, and underarms.

(b) Eye Protection

Safety goggles or face shields and goggles shall be worn during tear-out or blowing operations or when applying fibrous glass materials overhead. They should be used in all areas where there is a likelihood that airborne glass fibers may contact the eyes.

(c) Respiratory Protection

(1) The only situations in which compliance with the recommended environmental limit may be achieved by the use of respirators are:

(A) During the time necessary to install or test required engineering controls; or

(B) In situations such as during the performance of nonroutine construction, demolition, maintenance, or repair activities when air concentrations of fibrous glass may exceed the recommended environmental limit. Respiratory protection is necessary in those operations where high volumes of dust are generated and where adherence to environmental exposure limits cannot be achieved by engineering controls.

(2) When use of respirators is permitted, they shall be selected and used in accordance with the following requirements.

(A) The employer shall establish and enforce a respiratory protective program meeting the requirements of 29 CFR 1910.134.

(B) When wearing of respirators is required, the employer shall provide respirators in accordance with Table I-1 and shall ensure that the employee uses the respirator in a proper manner. The respiratory protective devices in conformance with Table I-1 shall comply with the standards approved by NIOSH or the Mining Enforcement and Safety Administration (MESA) as specified under the provisions of 30 CFR 11.

(C) For the purpose of determining the type of respirator to be used, the employer shall measure the concentrations of fibrous glass in the workplace initially and thereafter whenever control, process, operation, worksite, or climate changes occur that are likely to increase the concentration of airborne fibrous glass. This requirement does not apply when only self-contained or combination supplied-air and self-contained positive pressure respirators are used.

(D) The employer shall ensure that employees are properly instructed at least annually through training and drills on the use of respirators assigned to them and on how to test for leakage, proper fit, and proper operation.

(E) Respirators specified in Table I-1 for use in atmospheres of higher concentrations of airborne fibrous glass may be used in atmospheres of lower concentrations.

(F) The employer shall establish and conduct a program of cleaning, sanitizing, inspecting, maintaining, repairing, and

storing respirators to ensure that employees are provided with clean respirators that are in good operating condition.

(G) The employer shall periodically monitor the use of respirators to ensure that the proper type of respirator is worn, to evaluate the effectiveness of the respiratory protection program, and to eliminate any deficiencies in use and care of respirators.

(H) Respirators shall be easily accessible and employees shall be informed of their location.

TABLE I-1

RESPIRATOR SELECTION GUIDE
FOR FIBROUS GLASS

Fibrous Glass Concentration	Respirator Type Approved Under Provisions of 30 CFR 11
Less than or equal to 15,000,000 fibers/cu m	(1) A dust and mist respirator.
Less than or equal to 30,000,000 fibers/cu m	(1) A dust and mist respirator except single-use or quarter-mask respirator; or (2) A high efficiency particulate filter respirator; or (3) A supplied-air respirator; or (4) A self-contained breathing apparatus.
Less than or equal to 150,000,000 fibers/cu m	(1) A high-efficiency particulate filter respirator with full facepiece; or (2) A supplied-air respirator with a full facepiece, helmet, or hood; or (3) A self-contained breathing apparatus with a full facepiece.
Less than or equal to 3,000,000,000 fibers/cu m	(1) A powered air-purifying respirator with a high efficiency particulate filter and full facepiece; or (2) A type C supplied-air respirator operated in pressure-demand or other positive pressure or continuous flow mode.
Greater than 3,000,000,000 fibers/cu m.	(1) A combination respirator which includes a type C supplied-air respirator operated in pressure-demand or continuous flow mode; or

TABLE I-1 (CONTINUED)

RESPIRATOR SELECTION GUIDE
FOR FIBROUS GLASS

Fibrous Glass Concentration	Respirator Type Approved Under Provisions of 30 CFR 11
Greater than 3,000,000,000 fibers/cu m.	(2) Self-contained breathing apparatus with full facepiece, pressure-demand or other positive pressure mode.

Section 5 - Informing Employees of Hazards from Fibrous Glass

(a) Workers initially assigned or reassigned to jobs involving occupational exposure to fibrous glass shall be informed of the hazards, symptoms of overexposure (including information on the characteristics of onset and stages of illness), appropriate procedures to be taken in the event of an emergency, precautions to ensure safe use, and to minimize exposure. Workers shall be advised of the availability of relevant information, including that prescribed in (c) below. This information shall be accessible to each worker occupationally exposed to fibrous glass.

(b) A continuing education program, conducted at least annually by a person or persons qualified by experience or special training, shall be instituted to ensure that all workers have current knowledge of job hazards, proper maintenance procedures and cleanup methods, and that they know how to use respirators correctly. The education program shall include a description of the general nature of the medical surveillance procedures

and why it is advantageous to the worker to undergo medical examinations.

(c) The required information shall be recorded on a "Material Safety Data Sheet" as specified in Appendix V or on any other form approved for the purpose by the Occupational Safety and Health Administration, US Department of Labor.

Section 6 - Work Practices and Control Procedures

(a) Exhaust Systems

Where a local exhaust ventilation and collection system is used, it shall be designed and maintained to prevent the accumulation of fibrous glass.

(1) Where materials containing fibrous glass are mechanically worked by power equipment, exhaust ventilation shall be used to limit airborne fibrous glass.

(2) Air from exhaust ventilation systems shall not be recirculated into the workroom.

(b) General Work Practices and Environmental Controls

A variety of situations exist that involve potential exposure to fibrous glass. To specifically detail work practices and controls for each situation would be impractical. In operations where there is occupational exposure to fibrous glass, employers shall develop comprehensive work practices relevant to the specific situations encountered. These practices should follow the recommended guidelines identified in this section, in Chapter VI, and in Appendix VI. Generally, occupational exposure to fibrous glass can occur in either stationary operations or in operations that regularly occur at different (nonstationary) locations. The general

principles to follow in these operations have been identified and are given below.

(1) Stationary Operations

Operations that involve regular handling of fibrous glass at a fixed location, such as manufacturing, shall be controlled by using appropriate enclosures and well-designed local exhaust systems.

Procedures shall be established that minimize the accumulation of waste dust or scrap materials. Specific procedures for containment of dust and handling of contained materials shall be instituted so that the possibility of secondary air contamination is minimized. Cleanup procedures based on wetting the material and use of vacuum-cleaning for pickup shall be employed.

(2) Nonstationary Operations

Operations that involve short-term or transient work involving fibrous glass at different locations present unique circumstances for exposure. Employers shall evaluate the various aspects of exposure that could result from work involving fibrous glass at multiple locations, and identify appropriate work practices or controls suitable to the operation. Where possible, use of portable exhaust ventilation is recommended. Respirators may be necessary when engineering controls or work procedures cannot maintain airborne fibrous glass levels below the recommended environmental limit. Appropriate cleanup procedures, aimed at minimizing the airborne concentration of fibrous glass, shall be used. These procedures include wet-sweeping and vacuum-cleaning. Care shall be taken in nonstationary operations to minimize the effects of meteorologic conditions, such as wind, in increasing airborne concentrations of fibrous

glass. Enclosures or temporary curtains shall be considered to control the amount and velocity of air moving through the workplace.

Section 7 - Sanitation Practices

(a) Plant sanitation shall meet the requirements of 29 CFR 1910.141.

(b) Appropriate locker rooms shall be available for changing into required protective clothing in accordance with 29 CFR 1910.141(e).

(c) Protective clothing shall be washed, dried, and inspected before reissue or reuse.

(d) The employer shall inform workers exposed to fibrous glass of the importance of laundering work clothes separately from other clothing. In operations where clothes are laundered under contract, contractors shall be informed of the hazards of laundering clothes contaminated with fibrous glass.

(e) Handwashing provisions satisfactory for removing glass fibers from the skin shall be provided and good personal hygiene shall be enforced. Hands, arms, and face shall be thoroughly washed prior to eating and at the end of the shift. Washing facilities shall be in in conformance with 29 CFR 1910.141(d).

(f) No food shall be stored, prepared, dispensed (even from vending machines), or eaten in fibrous glass work areas. The employer shall furnish an uncontaminated area for these purposes in conformance with 29 CFR 1910.141(g).

(g) General Housekeeping

(1) Fibrous glass waste and scrap shall be collected and

disposed of in a manner which will minimize its dispersal into the atmosphere.

(2) Emphasis shall be placed on covering waste containers, proper storage of materials, and collection of fibrous glass dust.

(3) Cleanup of fibrous glass dust shall be performed using vacuum cleaners or wet cleaning methods. Dry sweeping shall not be performed.

Section 8 - Environmental Monitoring and Recordkeeping

(a) Determination of Workplace Air Levels

Each employer, who has a place of employment in which there is occupational exposure to fibrous glass, shall determine by an industrial hygiene survey whether exposure may occur to airborne concentrations of fibrous glass above the action level, ie, above half the TWA environmental limit. Surveys shall be repeated at least once every 3 years and within 30 days of any process change likely to result in an increase of airborne fibrous glass concentrations. Records of these surveys, including the basis for concluding that air levels are at or below the action level, shall be maintained. If it has been decided that the environmental concentration of fibrous glass may exceed the action level, then the following requirements shall apply.

(b) Personal Monitoring

(1) A program of personal monitoring shall be instituted to identify and measure, or permit calculation of, the exposures of all employees occupationally exposed to fibrous glass above the action level. Point source and area monitoring may be used to supplement personal monitoring.

(2) In all personal monitoring, samples representative of exposure in the breathing zone of the employee shall be collected. Procedures for sampling, calibration of equipment, and analysis of fibrous glass in samples shall be as provided in Section 1(b). This sampling and analysis shall be conducted every 3 months on at least 25% of the workers so that each worker's exposure is measured at least every year; the frequency of sampling and the fraction of employees sampled may be different if so directed by a professional industrial hygienist.

(3) For each TWA determination, a sufficient number of samples shall be taken to characterize the employee's exposure during each workshift. Variations in work and production schedules shall be considered in deciding when samples are to be collected. The number of representative TWA determinations for an operation or process shall be based on the variations in locations and job functions of employees relative to that operation or process.

(4) If an employee is found to be exposed in excess of the recommended TWA environmental limit, additional monitoring shall be promptly initiated. If excessive exposure is confirmed, control procedures shall be instituted as soon as possible; these may precede and obviate confirmatory monitoring if the employer desires. The employee shall be notified of the exposure and of the control measures being implemented. The exposure of that employee shall be measured at least once every 30 days. Such monitoring shall continue until two consecutive determinations, at least 1 week apart, confirm that the employee's exposure no longer exceeds the recommended environmental limit. Normal monitoring may then be resumed.

(c) Recordkeeping

Records of environmental monitoring shall be maintained for each employee for at least 30 years after the individual's employment has ended. These records shall include: the dates of environmental measurements, job function and location of the employee within the worksite at time of sampling, sampling and analytical methods used, and evidence of their accuracy, number, duration, and results of samples taken, TWA determinations based on these samples, type of personal protective equipment in use, if any, name of the employee being monitored, dates of employment with the company, and information regarding changes in job assignment. Employees and former employees shall be able to obtain information on their own environmental exposures. Environmental records shall be made available to designated representatives of the Secretary of Labor and of the Secretary of Health, Education, and Welfare.

Pertinent medical records shall be retained for 30 years after the last occupational exposure to fibrous glass. Records of environmental exposures applicable to an employee should be included in that employee's medical records. These medical records shall be made available to the designated medical representatives of the Secretary of Labor; of the Secretary of Health, Education, and Welfare; of the employer; and of the employee or former employee.

II. INTRODUCTION

This report presents the criteria and the recommended standard based thereon which were prepared to meet the need for preventing impairment of health from occupational exposure to fibrous glass. The criteria document fulfills the responsibility of the Secretary of Health, Education, and Welfare, under Section 20(a)(3) of the Occupational Safety and Health Act of 1970 to "...develop criteria dealing with toxic materials and harmful physical agents and substances which will describe...exposure levels at which no employee will suffer impaired health or functional capacities or diminished life expectancy as a result of his work experience."

The National Institute for Occupational Safety and Health (NIOSH), after a review of data and consultation with others, has formalized a system for the development of criteria upon which standards can be established to protect the health of workers from exposure to hazardous chemical and physical agents. It should be pointed out that any recommended criteria for a standard should guide management and labor to develop better engineering controls and more healthful work practices. Mere compliance with the recommended standard should not be the final goal.

These criteria for a standard for occupational exposure to fibrous glass are part of a continuing series of criteria developed by NIOSH. The proposed standard applies only to the processing, manufacture, and use of fibrous glass products as applicable under the Occupational Safety and Health Act of 1970. The proposed standard was not designed for the population-at-large, and any extrapolation beyond occupational exposure is not warranted. It is intended to (1) protect workers against development

of deleterious effects, (2) be measurable by techniques that are valid and available to industry and governmental agencies, and (3) be attainable with existing technology. The recommended standard has been designed to protect workers against the development of acute and chronic effects of exposure to fibrous glass. The acute effects include skin, eye, and respiratory tract irritation. The standard is also based on preventing chronic effects such as bronchiolar impairment, fibrosis, and carcinogenesis.

Fibrous glass first came into commercial use slightly more than 40 years ago. In one generation this material has become one of the most useful manufactured products, with tens of thousands of applications. The term fibrous glass describes a set of materials that can have different dimensions and consequently different biologic effects. Even though observed adverse effects of fibrous glass on humans have been confined primarily to skin irritation due to mechanical action, concern over possible long-term injury arising from inhaled fibers was evident from the earliest use of fibrous glass. Despite limited evidence of chronic effects from inhalation of fibrous glass, this concern continues to prevail, particularly with respect to possible long-term adverse effects in humans from exposure to fibers less than 3.5 μm in diameter over long periods of time. However, an evaluation of the available information has resulted in the NIOSH conclusion that occupational exposure to fibrous glass has not resulted in the development of cancer. No cases of human cancer that can be directly linked to exposure to fibrous glass exposure have been found. Many gaps are present in the literature on effects of fibrous glass on humans and animals. Few relevant animal experiments have been performed.

The counting method for determining the concentration of airborne fibrous glass is subject to limitations in precision and accuracy. The accuracy of the fiber counting method has not been determined and probably cannot be achieved since it provides essentially an appraised average as the final result. There are at present no other analytical techniques with which it can be adequately compared. An estimate of the accuracy of the counting procedure may be approximated empirically by comparing the results of replicate samples obtained by several proficient analytical laboratories.

III. BIOLOGIC EFFECTS OF EXPOSURE

Extent of Exposure

The manufacture of fibrous glass began in the 1930's and since then has increased to the extent that it is used in over 30,000 individual product applications [1-3]. "Fibrous glass" refers to groups of individual glass fibers combined in any of a variety of forms in the process of manufacture [4]. A glass fiber is defined as a glass particle with a length-to-diameter ratio of at least 3:1.

Fibrous glass operations are usually classified by the industry as textile or wool operations [1]. Textile fibers are generally formed as continuous filaments and are usually greater than 3.0 μm in diameter. In contrast, fibers produced by wool-forming methods may be as small as 0.05 μm in diameter and less than 1 μm in length [5]. Most glass fibers have diameters ranging from 1 to 15 μm. The percentage of fibrous glass with diameters less than 3.5 μm has not been reported. Fibers less than 1 μm in diameter are estimated to comprise less than 1% of the glass fiber market produced. These smaller diameter fibers are manufactured for high performance thermal and acoustical insulation for aircraft and space vehicles and for high efficiency filtration media [2].

Fibrous glass is manufactured by a few basic processes, although there are many subtle variants from operation to operation. The various manufacturing processes utilize different 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 to form fibers [6]. The glass in fibrous glass solidifies from the molten state without crystallization [7].

Most fibrous glass is now produced from borosilicate and low alkali silicate glasses that contain varying amounts of silica, soda, lime, alumina, and titania. Some types of fibers contain as much as 96% silica as silicon dioxide. In fibrous glass, silicon dioxide molecules are arranged in a nonperiodic, random molecular arrangement defined as amorphous [7]. This arrangement is different from the fixed pattern found in crystalline or free silica [8]. The silicon dioxide molecule has a tetrahedral configuration consisting of a central silicon ion surrounded by four oxygen ions. The three-dimensional network of silica terahedra is the basis for the various and unusual properties of glass. By the addition of modifying ingredients such as metallic oxides, which may either become part of the silica network or disrupt it, the properties of the amorphous glass can be varied and adjusted to various levels of performance [7]. Beryllium oxide has been added to glass in some cases to enhance its tensile strength. The compositions of some typical glass fibers are presented in Table XV-1.

Properties of fibrous glass such as chemical resistance, high tensile strength, and its ability to insulate against heat and sound are the bases for its use in thermal, electrical and acoustical insulation, filtration media, weather-proofing, plastic reinforcement, and in structural and textile materials. A few physical properties of some commercial fibrous glasses are presented in Table XV-2.

The majority of fabricated fibrous glass products contain binders, lubricants, and coatings such as those listed in Table XV-3. These surface treatments may present varying degrees of occupational health problems [1]. Surface treating of fibrous glass is performed to bind fibers together, to

protect them, and to increase resistance to impact and friction [2,4,7].

The variety of uses of fibrous glass presents many opportunities for occupational exposure; NIOSH estimates that 200,000 persons in the US may be exposed occupationally to fibrous glass.

In addition to occupational exposure, workers may be further exposed to small amounts of fibrous glass in ambient air and at home. There is a small but measurable amount of fibrous glass in ambient air, presumably contributed by the many fibrous glass products used in our society [9]. Small concentrations, ranging from less than 1,000 to 10,000 fibers/cu m of air, have been found in urban air and concentrations of 30-130 fibers/cu m have been found even in remote rural areas. These concentrations are as much as 10,000 times lower than concentrations of fibrous glass in occupational environments [9]. Fibrous glass used in the lining of ventilating ducts is a potential source of glass fibers in the air in buildings [10], but quantitative studies have shown that concentrations of such fibers in air are extremely low, around 1,000 fibers/cu m of air [11,12].

Historical Reports

The initial reports of biologic effects of fibrous glass appeared in the early 1940's [13-15]. Siebert [15] reported that between 1939 and 1941 a small but unspecified number of workers in a fibrous glass manufacturing plant experienced transitory mild skin irritation, usually at the beginning of employment or upon returning from vacation. Gardner [14,13] in 1940 and 1941 reported on a study in which rats were exposed by inhalation to glass wool. After 19 months of exposure at "as high a concentration as could be

maintained," no glass fibers were found in the animals' lungs. Slight amounts of chronic inflammation due to glass wool dust accumulation were observed and considered insignificant by the investigator [14]. The rats inhaled glass fibers specified as "short" lengths and under 3 μm in diameter. Gardner [14] suggested that inhalation of fibrous glass was impeded because the fibers tended to form felt-like masses on any surface with which they came in contact.

Effects on Humans

(a) Skin, Eyes, and Mucous Membranes

Extensive data on the effects of occupational exposure to fibrous glass is not available, but an indication of the frequency of reported health effects comes from a study performed in California [16]. Over a 30-month period during 1960-1962, 653 out of 691 cases attributed to fibrous glass involved effects on the skin and eyes. The nature of these effects was not reported. These cases were extracted from summaries of 30,000 cases of occupational disease regularly collected by a state agency.

One of the earliest studies of fibrous glass was performed by Sulzberger et al [17] in 1942. These investigators [17] reported a study of the reactions of 10 human volunteers who were rubbed with glass wool for 10 minutes daily for 7 to 19 days. This produced erythema, localized swelling, and pinhead papules, accompanied by some pain. The effects decreased with rubbing with glass wool on successive days, but there was scaling and thickening of the skin. Repeated rubbing, after a 2-week period without treatment, indicated no definite evidence of sensitization, confirming the findings noted in guinea pigs and rabbits (see Animal

Toxicity) [17]. Microscopic examination of skin sections showed a superficial inflammation.

Other observers have described itching of the skin, dermatitis, and changes in the mucous membranes of the eyes and upper respiratory tract occurring in people working with fibrous glass [18-26]. Although eye irritation has been reported as a result of fibrous glass exposure, such reports are rare [25]. Schwartz and Botvinick [21] noted 25 cases of industrial dermatitis during a 6-month period in a plant that employed 2,000 workers in the manufacture of glass wool for insulation and thread. These investigators [21] found that the binder material used on glass fibers also had effects on the skin. Seven workers with dermatitis were patch tested with binder and three showed positive reactions. The binder was a mixture of starch, polyvinyl alcohol, and a substituted pyrazine. The investigators [21] concluded that the results of the patch tests and the history of onset of dermatitis after several weeks of exposure indicated that the binder was a sensitizing agent rather than a primary irritant.

Erwin [24] stated that at one time practically all 120 workers handling fibrous glass in an aircraft manufacturing plant had mild skin irritations which subsided after better work practices were instituted. Nine employees who developed persistent eczematoid dermatitis while working with fibrous glass were described; they had to be transferred to jobs where there were no fibrous glass or binder exposures. The effects noted could not be reliably attributed by the author [24] to either the binders or the fibrous glass.

One of the earliest reported attempts to define the relationship between fiber dimensions and cutaneous response was that of Heisel and Mitchell in 1957 [27]. They studied skin reactions obtained by patch testing and rubbing fibrous glass on the skin of 92 fibrous glass production workers and of 50 white female volunteers not occupationally exposed to glass fibers. Glass fiber of four different diameters, less than 0.7, 8.8-10.1, 17.7-18.1, and 38.1 μm, was tested. The patch test reactions consisted of small, isolated, erythematous papules, some of which were capped with tiny pustules. Coarse fibers (17.7-18.1 μm and 38.1 μm) produced more skin reactions than did fine ones (0.7 μm and 8.8-10.1 μm), and fibers cut to 3-5 mm lengths were more irritant than fibers 2 cm in length. The coated fibers with starch produced no change in the skin effects. The investigators [27] were unable to develop any evidence of sensitization, but tests carried out 3 weeks apart showed that two individuals with dermographism had urticarial responses to glass irritation.

In 1968 Heisel and Hunt [28], continuing work on fiber dimensions and skin reactions, tested fibers of 2.5-4.5 μm, 3.6-5.8 μm, and 5.3-6.3 μm diameter. The tests included daily skin rubbings with fibrous glass for 45 seconds on 5 consecutive days and patch tests that remained in place for 48, 96, or 168 hours. Their conclusion was that fibers with diameters 5.3 μm or greater would cause transient mechanical irritation, whereas those with diameters less than 4.5 μm would not [27,28].

More serious epidermal responses to glass were reported by McKenna et al [29] in a survey of 126 operators engaged in the manufacture of continuous filament glass fibers in an environment described as hot and

humid. In this operation, the employees' hands were wet a great deal of the time. The authors noted 8 cases of paronychia (inflammation around the fingernails) with abnormal nail formation, 14 cases of folliculitis of the feet, lower legs, forearms, or hands, and 63 instances of maceration of the fourth interdigital space of the foot. No information was provided on the intensity of exposure to fibrous glass, fiber sizes, or the prevalence of similar findings in other populations not exposed to glass but to hot, humid environments. The combination of irritation from glass and favorable opportunities for infection appeared to produce an unusual prevalence of dermal effects in this group.

Possick et al [30] evaluated fibrous glass manufacturing operations and found skin irritation similar to that reported by McKenna et al [29] among the workers although none were found to have disabling dermatitis. In their 1970 review of fibrous glass dermatitis, the investigators [30] stated that skin irritation occurred mainly in new workers who developed burning, itching, or prickling of the skin, associated with papules and papulovesicles. The manifestations were worse in warm and humid weather and usually stopped within a week or so after exposure began, but some workers would quit working with fibrous glass because of the experience. Skin penetration by a fiber was reported to be directly proportional to fiber diameter and inversely proportional to fiber length. The investigators [30] recommended that prospective employees (5% approximately) with dermographism be identified and not allowed to work closely with fibrous glass. They stated that some individuals with atopic dermatitis may not tolerate contact with fibrous glass because of their low itch threshold [30].

The occurrence of itching and dermatitis resulting from the wearing of garments which had been washed at the same time or in the same washing machine as fibrous glass fabrics has been the subject of several reports [31-34]. Such occurrences have led to a rule by the Federal Trade Commission [35], which became effective January 2, 1968, requiring that fibrous glass curtains and draperies and their component fabrics be labeled to advise purchasers that skin irritation may result from either handling such products or from body contact with clothing and other articles which have been washed along with such products.

The potential for eye injury from fibrous glass was illustrated by a case history reported by Longley and Jones [36]. A woman who worked 1 day a week for 8 to 9 months with electrical cables insulated with fibrous glass had recurring itching of the skin, especially of the scalp and eyelids, and then developed acute conjunctivitis and keratitis with a sterile corneal abcess. The absence of ocular effects in other employees doing similar work was attributed to their wearing glasses while the patient did not. This report of Longley and Jones [36] is notable because it is one of the few reports which provide information on airborne dust concentration, reported to be 1.5 mg/cu m. The methods of sampling and analysis were not given. One cannot be certain that glass fibers were not introduced directly into the eye by clothing or hands, or that a clump of airborne fibrous glass was not involved [36].

(b) Respiratory Tract

Isolated case reports appeared between 1944 and 1961 describing severe acute pulmonary reactions associated with fibrous glass inhalation [37-41]. Tara [37] described asthma in a woman who manufactured fire-

resistant clothing. After working with asbestos for 1 year and fibrous glass for 3 years, she developed severe asthmatic attacks, which were diagnosed by physical examination, and eosinophils in the sputum. The asthma disappeared after she stopped working with fibrous glass. Kahlau [38] reported fatal pneumonia in an upholsterer after exposure to dust from a synthetic material containing glass wool. It was interpreted as an acute dust reaction complicated by bacterial infection. Bezjak [39] noted a somewhat similar case in which a man inhaled glass wool (presumably as a plug) during the repair of an incubator, and developed a severe cough followed 3 weeks later by pneumonia in the lower lobe of the right lung. The plug of glass wool was coughed up and there was complete recovery after chemotherapy for the pneumonia. A fourth case was reported in 1961 by Murphy [40] who described pulmonary disease in an electrical worker who had been dismantling fibrous glass-insulated appliances, such as hot water heaters. After several months of repeated exposures, the worker noticed a dry cough, loss of weight, eye smarting, shortness of breath, and hemoptysis. Bronchoscopy led to a tentative diagnosis of bronchiectasis of the right lung. The right lower lobe was removed. Upon examination of the lobe, multiple focal abscesses, involving the terminal bronchioles and the peribronchial parenchyma, were found. The particulate matter found was reported as being identical to that of the insulating material, the glass fibers varying in size from 1 μm to 14 μm in diameter and up to 60 μm in length. Pulmonary fibrosis was reported as slight. The patient recovered and continued to work with fibrous glass employing respiratory protective measures and was considered to be well 3.5 years after the operation.

Trumper and Honigsberg [41] reported acute pharyngeal irritation in a sheet metal worker after he had cut an overhead hatchway through 2 inches of fibrous glass. Glass fibers were found imbedded in the mucosa of his throat, which were located by painting the area with a fluorescent dye. After the fibers were removed, his distress was relieved.

In 1948, Cirla [23] described the findings in 25 workers exposed to fibrous glass in a plant manufacturing electrical conductors. The workers complained of irritation of the upper respiratory tract but no clinical evidence of lung disease was found.

During 30 months in 1960-1962, 691 instances of occupational disease attributed to fibrous glass exposure were reported in California, which annually receives over 30,000 case reports of occupational disease [16]. Of the 691 cases, 38 were primarily respiratory tract irritation. There were 28 additional reports of respiratory tract irritation in a 13-month period in 1967 and 1968 [16]. Occupational designations showed that most complaints were made by individuals who were working directly with fibrous glass or fibrous glass plastics, especially in cutting, sanding, or machining, but some worked only in areas outside the locations where the dust was generated. Roentgenographic evaluations were performed in 13 of the 28 reports, but none showed clear-cut roentgenographic changes attributable to the glass. Three of the more severe cases involved maintenance employees who had removed fibrous glass insulation from steam pipes. The effects were listed as sore throat, nasal congestion, laryngeal pain, and cough as well as itching. Physicians' reports in the 66 cases indicated bronchitis in 66%, pharyngitis in 25%, rhinitis in 20%, asthma in 6%, laryngitis in 4%, sinusitis in 3%, and nosebleed in 1 case. There were

no reports of permanent disability in any individual but the extent of follow-up was not reported [16].

Epidemiologic Studies

Diseases of the respiratory system are the subjects of most epidemiologic studies involving fibrous glass. These studies were usually cross-sectional prevalence studies, many of which were comprised of workers from the same plant. A knowledge of the smoking histories of exposed workers or controls is important in the evaluation of epidemiologic studies. Unless otherwise stated, no information on smoking histories has been provided in the following reports.

In 1960, Mungo [42] studied all 13 workers in a plant manufacturing electrical parts who had handled plastic laminates with fibrous glass reinforcement for 2 to 4 years. All 13 workers were found to have irritation of the skin and of the mucous membranes of the upper respiratory tract. Twelve had normal chest roentgenographs; one (aged 20 years) had accentuation of the bronchovascular markings. One total dust count of 64,000,000 particles/cu m (64 particles/cc) of air as taken with a "midget impinger apparatus" was reported, but the percent of particles that were fibers and the size of the fibers were not mentioned.

Bjure et al [43] in 1964 performed cardiopulmonary evaluations of six insulators who had worked for 8 to 29 years with glass wool and rock wool and compared the results with those of eight men who had worked from 7 to 30 years largely with asbestos-insulating materials. The average length of exposure was 14 years for the group exposed to glass wool and 18 years for the group exposed to asbestos; average ages were 39 and 44.5 years,

respectively. There was no quantification of exposure data. The asbestos-exposed group showed significant ($P < 0.01$) reductions in vital capacity, forced expiratory volume, and diffusion capacity as compared with the fibrous glass-exposed group. Pleural thickening was found in all eight of the group exposed to asbestos and in none of those exposed to fibrous glass. In spite of prolonged exposure to glass wool and rock wool, no impairment was found in the cardiopulmonary functions studied. However, neither group was compared with unexposed controls.

Wright [44] in 1968 reported a roentgenographic survey conducted in 1963 of employees in the plant that had been studied by Siebert [15] in 1939-1941 and which, by 1968, had been engaged in the manufacture of glass wool for approximately 30 years. He studied employees who had worked for 10 years or more in the plant. The distribution of length of service was not given, but it was stated that some had been employed for as many as 25 years. Wright [44] stated that all workers in the factory area currently on the payroll, except those who had spent more than a year in sections where free crystalline silica was present, were included. Male clerical and management staff were also studied. In all, Wright [44] reviewed roentgenographs of 1,389 employees, classified as clerical workers, factory workers, or unclassified, and divided into four exposure catagories, from light to heavy. Concentrations of airborne dust and glass were determined in samples collected by electrostatic precipitators, membrane filters, and midget impingers [44,45]. Total dust concentrations varied from 0.93 mg/cu m to 13.3 mg/cu m throughout the plant, with an average of 2.24 mg/cu m. Complete chemical analysis of the dust was not made. Particle concentrations, based on area averages, ranged from 3.2 to 11.3 million

particles/cu m [0.09 to 0.32 million particles/cubic foot of air (mppcf)], with an average of 0.22 mppcf. It was reported that fibers made up less than 1% of the total particles counted [44,45]. The median diameter of the fibers was 6 μm, with 85% ranging from 2 to 10 μm and 9% less than 3 μm in diameter. The averaged data from samples throughout the plant indicated that 16% of the fibers were less than 40 μm in length and 6% were less than 20 μm.

Wright [44] stated that there had been extensive installation of exhaust and ventilation equipment and that the population described had been exposed to higher concentrations in the past than at the time of the study. No distinctive roentgenographic patterns were observed nor were there increased bronchovascular markings or nodulations occurring in unusual numbers or primarily in the heavily exposed groups. No pleural calcifications were found, but six instances of pleural thickening were seen in lightly exposed individuals. Intrapulmonary and hilum calcifications were observed in about 50% of each group studied. The investigator [44] assumed that such a high percentage of calcifications represented the healed phase of primary tuberculosis or endemic histoplasmosis. Small calcified nodules in the lungs are not an unusual finding for either of these diseases. Wright [44] reported that the design of the experiment and the duration of exposure did not permit any conclusions regarding neoplastic potential.

Pulmonary function studies in a group of workers were reported in 1968 by Utidjian [46] and in 1970 by Utidjian and deTreville [47]. The studies were conducted in the same plant that Wright [44] had studied. Forced expiratory volume in 1 second (FEV 1) and in 3 seconds (FEV 3) and

maximum mid-expiratory flow (MMF) determinations were made on 232 men and categorized into age groups, ie, under 30 years, 30-49 years, and 50 years or over. Each age group was further subdivided into categories (I-III) based on jobs and estimated dust concentrations. Category I represented the least exposure, II represented medium exposure and III represented the highest exposure. No environmental concentrations of fibrous glass were reported. Symptoms of cough, bronchitis, dyspnea, wheezing, and chest illnesses were not more frequent in those with higher exposures, but prevalence of most symptoms did increase with age. Deviations from predicted vital capacity values also did not correlate with exposures. In the report by Utidjian and deTreville [47], the authors noted no apparent effect from fibrous glass dust when they compared employees with the greatest and the least exposure.

A more detailed evaluation of 30 individuals in the highest exposure group who were over 50 years of age, 15 from the least exposure group, and 15 from the highest exposure group was reported by deTreville and coworkers [48]. The study included general histories, respiratory disease questionnaires, physical examinations, fluoroscopy of the chest, electrocardiograms, hematologic tests, pulmonary ventilatory tests, and tests for diffusing capacity (CO steady state method). There were no more ventilation or diffusion abnormalities found in the heavily exposed group than in the lightly exposed one. The results from both groups were compared with predicted values derived from the Veterans Administration Army Cooperative Study of Pulmonary Function [49] and no difference was found. The study of pulmonary function [49] involved healthy people selected from hospital personnel and patients.

In another study related to the work force of the previously described fibrous glass production plant [44-48], Gross et al [50] in 1971 described post-mortem findings in 20 fibrous glass workers who had been exposed for 16 to 32 years and compared the findings with those from 26 urban (Pittsburgh) dwellers with no known occupational exposures to fibrous glass. The inclusion of exposed or unexposed individuals in the study was the choice of the investigators and not the result of random sampling. Both groups studied were generally the same with regard to histopathologic findings. Enlargement of air space within the lungs by alveolar destruction was found in 13 of 20 fibrous glass workers and in 19 of the 26 comparison group. Significant thickening of the walls of small and medium size vessels with luminal narrowing was found in 5 fibrous glass workers and 10 comparisons. Fibers of similar size and number were found in the lungs of fibrous glass workers and in the comparison group but the identity of these fibers was not known. Cholak et al [45] had previously reported that 9% of the airborne fibers in the factory where the workers were employed had been less than 3 μm in diameter (weighted average). A comparison of the dimensions and amount of the dust in the lungs in the two groups showed no significant differences [50]. Average fiber diameter in glass workers was 2.3 μm and the average length was 27 ± 6 μm. There was an average of 96,000 fibers/g of dry lung in the exposed workers.

Nasr et al [51] in 1971 reviewed roentgenographs of workers in the same plant previously discussed [45-47]. Nasr's analysis was based on 2,028 male fiber glass production workers. Of these, 1,832 were production workers and 196 were office workers; 1,571 (62.67%) had been employed 10 or more years, 1,022 (50%) 15 or more years, 665 (33%) 20 or more years, and

391 (12%) for 25 or more years. Roentgenographic abnormalities of the chest were found in 329 workers (16.22% of the total), the most prevalent changes being increased lung markings, abnormal aorta, abnormal heart configuration, and emphysema. No difference in prevalence of all these chest abnormalities was detected between production and office workers. Nodular opacities were found in 9 of the 2,028 workers, and questionable nodularity was suspected in 17 others. Whether these abnormalities were in the office workers or production workers was not stated. While the data enable a comparison of the prevalence of total abnormalities in production workers with that in office workers, sufficiently detailed information is not provided on specific abnormalities, such as pleural thickening, increased lung markings, fibrosis, or suspected pneumoconiosis, as related to type or duration of exposure [51].

In 1973 Hill et al [52] reported on the comparison of pulmonary function in 70 fibrous glass production workers in England employed for an average of 19.85 years with that of an unexposed, matched control group. Study of roentgenographs, pulmonary function tests, and physical examinations revealed no differences between the two groups. In a follow-up examination 5 years later [53], Hill re-examined 53 of the original study members. The health status of the other 17 workers was not investigated. Roentgenograms revealing pleural thickening in some of the 53 cases led to a review of the original control group. Pleural thickening was equivalent in both groups. Environmental investigations involving sampling with membrane filters and microscopic examination indicated that total dust in the operators' breathing zones ranged from 0.4 to 12.7 mg/cu m. Of this, counts of respirable size dust (less than 5.5μm in diameter)

ranged from 1,000,000 to 4,800,000 fibers/cu m (1.0 to 4.8 fibers/cc). The "general atmosphere" at the time of the investigation contained an average number of 900,000 fibers/cu m (0.9 fibers/cc). Respirable size dust counts at the dust source 2 feet from an operator's breathing zone ranged from 3,400,000 to 10,700,000 fibers/cu m (3.4 to 10.7 fibers/cc). The high proportion of heavier fibers accounts for the rapid fall-off in fiber count between the dust source and the operator's breathing zone, approximately 2 feet above the source. Fibers collected at the site of emission for sizing purposes indicated that approximately 75% were less than 4 μm and 35% were less than 2 μm in diameter. Fifty percent of the fibers were longer than 50 μm.

In 1975, Enterline and Henderson [54] reported a study of retired workers from six plants engaged in the manufacture of fibrous glass insulation. A total of 617 workers retired between 1945 and 1972; of this group only 416 males who had reached age 65 were studied. The health status of the 201 workers excluded from the study was not known and could have been significant in the data analysis. These included 144 workers who had not attained age 65 (41 who died before age 65 and 103 who had not attained age 65 by December 31, 1972). The remaining 57 workers were women and were not included due to what was considered to be the small number involved and because the authors believed the women would have to be studied separately, since their expected mortality differs from that of men [54].

The mortality experience of the 416 men was compared with the expected mortality based on the cause, age, and time-specific mortality rates of the population of all white men living in the US. A modified life

table method of analysis was used, involving computation of years of life lived by the cohort in five age groups: 65 to 69 years, 70 to 74 years, 75 to 79 years, 80 to 84 years, and 85 years and over during 5 time periods: 1945 to 1952, 1953 to 1957, 1958 to 1962, 1963 to 1967, and 1968 to 1972. Expected deaths were calculated by applying the age-cause-specific white male death rates for the entire US from every fifth year from 1950 to 1970. The standard mortality ratios (SMR's) were computed by calculating the ratios of observed to expected for selected causes of death including cancers, heart, and respiratory diseases [54].

SMR's were reported for all 416 retirees and for 276 of that group who had normal retirements. The SMR's for all retirees generally showed no excess of observed deaths by any disease cause. The SMR's for the 276 normal retirees showed a slight excess of observed deaths for the categories "all other heart disease" and "nonmalignant diseases of the respiratory system." When 35 workers who had reached age 65 but had retired earlier due to disability were studied, the SMR for all causes of death was 118.6. This represents 18.6% more deaths in the study group than in the general population. In these workers retiring from disability, chronic bronchitis was observed in 3 workers and expected in 0.5 workers. This difference may be important but the small numbers do not allow substantial conclusions to be made. None of the excesses of death were statistically significant [54].

Bayliss et al [55] in 1976 reported a retrospective cohort analysis of mortality patterns among a cohort of fibrous glass production workers in the oldest facility in the US. The study cohort consisted of 1,448 white males with 5 or more years of employment. All members of the cohort were

initially employed between 1940 and 1949. Follow up of all members of the study cohort was accomplished from the time of termination of employment to June 1, 1972, with all persons accounted for. Comparison was made between the observed number of deaths in the study cohort and the number expected on the basis of age, calendar time, and cause-specific mortality rates for the white male population of the United States.

The analysis indicated an excessive risk for one cause-of-death category, that of "nonmalignant respiratory diseases," where 19 deaths were observed and only 10.04 were expected. This category excluded influenza and pneumonia. Bronchiectasis was observed at autopsy in 6 of the 19 cases. (D Bayliss, written report, 1977). The excess of observed nonmalignant respiratory disease deaths was statistically significant ($P<0.05$). Although the role of prior employment in industries other than fibrous glass production cannot be totally evaluated in the etiology of this excessive nonmalignant respiratory disease risk, note should be made that the authors [55] stated "several employees had incidental periods of employment in dusty trades." When the mortality comparisons were made on the basis of interval.since the start of employment, the ratio of observed to expected deaths was significantly greater ($P<0.05$) for those who died after 5 or more years the since start of employment and highly significant ($P<0.01$) for those who died after 10 or more years. The results of this study are presented in Tables XV-4 and XV-5. The exposures in the plant were estimated from an industrial hygiene survey conducted by the same investigators in 1975 [5,55]. An average fiber count of 80,000 fibers/cu m of air (0.08 fibers/cc) was observed, and the average total dust concentration was 0.3 mg/cu m. The collected glass fibers had a median

diameter of 1.8 μm and a length of 28 μm. A more detailed discussion of the environmental data is presented in Chapter IV. Due to limited dust measurements, the lifetime exposure for persons in the cohort study was not determined; however, the investigators [55] stated that historic low exposure levels in the plant had not changed significantly. The length and diameter of airborne glass fibers may have been larger in the past, as indicated by the previous industrial hygiene survey of the same plant by Cholak et al [45] in 1963.

Bayliss et al [55] performed a second study when it was learned that some members of the original cohort might have been exposed to smaller diameter glass fibers than those being produced in the 1970's at the facility under study. During 1941 to 1949 a pilot operation in the facility used a flame attenuation process that produced bulk fibers ranging from 1 μm to 3 μm in diameter. The pilot operation was conducted concurrently with the regular production of fibrous glass insulation.

A case-control study was performed to evaluate the potential health hazard of the smaller glass fibers to the exposed workers [55]. Each death due to malignant or nonmalignant respiratory disease among workers at the plant, or in which respiratory disease was mentioned as a contributory cause, was matched with that of a control selected sequentially from an alphabetized list of the remaining study group members. The 49 cases and 49 controls were matched according to birth date, race, and sex. All subjects had been initially employed in fibrous glass production between 1940 and 1949. Of the 49 cases with respiratory disease, 9 were presumed to have worked with and had been potentially exposed to the smaller diameter fibrous glass on the basis of their work with the flame

exposed to the smaller diameter fibrous glass on the basis of their work with the flame attenuation process. However, not all nine could be paired with controls who had similar exposure. In contrast, of the 40 respiratory disease cases without potential exposure to small-diameter fibrous glass, only 2 matched controls had potential exposures to small-diameter fibrous glass. The results of the study are shown in Table XV-6.

Analysis of the differences between cases and controls by the McNemar Chi-square method for matched pairs showed that exposure to small-diameter fibrous glass was associated with malignant respiratory disease ($0.05 < P < 0.10$) at a level which was stated by the authors [55] to be of borderline significance.

Animal Toxicity

(a) Dermal Effects

In 1942, Sulzberger et al [17] studied the effect of fibrous glass on the skin of animals. In one study, 16 rabbits were rubbed with fibrous glass or other material, for 2 minutes each, on 6 depilated areas 4.5 cm in diameter. Rubbings occurred 5 days a week for 1 month. Two types of fibrous glass, two types of unspecified competing material and two cotton controls were applied to the depilated skin of each rabbit. Twenty-six guinea pigs were rubbed at 8 similiar sites with two fibrous glass textile materials. Skin reactions in both species resulted from the mechanical action of the fibers on the skin. The rabbits' skin had a faint redness, scaling, and superficial yellow crusting. Reactions in guinea pigs were similar but more intense than those of the rabbits with more erythema and crusting.

Similar results in guinea pigs have been reported by Pellerat and Coudert [22]. These investigators also measured the amount of histamine in the blood of guinea pigs and found that it was increased as a result of rubbing the skin with fibrous glass.

(b) Inhalation

In 1955 Schepers and Delahant [56] conducted a study of 100 guinea pigs continuously exposed to glass wool for 20 months and to what was called glass cotton for 20 subsequent months. The glass wool had a nominal diameter of 6 μm. Exposures occurred in a dust chamber measuring 8 x 8 x 8 feet. The dust concentrations of glass wool as determined by electrostatic precipitator measurements ranged from 5.0 to 5.2 mg/cu m (0.143 to 0.146 mg/cu ft). Impinger readings ranged from 49.4 to 77.7 million particles/cu m (1.4 to 2.2 mppcf) as measured by light field count. After 20 months of exposure to these conditions, the glass wool was replaced by glass cotton with a maximum diameter of 3 μm and at a concentration of 0.03 to 0.07 mg/cu ft (1.1 to 2.5 mg/cu m). A series of 50 white rats were likewise exposed to the glass wool in the same chamber for 20 months and subsequently to glass cotton until the end of the 24th month. No controls were provided. Seventeen of 100 guinea pigs and 20 of 50 rats died during the experiments. Deaths were attributed to pneumonia. Microscopic examination of guinea pigs killed during the 18th day of exposure revealed glass wool dust in their bronchi. After 4 months of exposure, there was considerable epithelial hyperplasia and cellular desquamation in the smaller bronchioles and cellular infiltration of alveolar walls, with hyperplasia of parenchymal pulmonary lymph nodes. Atelectatic areas were visible. Dust reaction foci were detectable by macroscopic examination at

the 40th week of exposure and the investigators related these to the atelectatic areas seen at 4 months. Lung abscesses were found in 10% of the rats but there was little evidence for dust pigmentation or tissue reaction. Fibrosis was not evident in either rats or guinea pigs.

In 1960 Gross et al [57] reported a number of experiments with nonfibrous glass dust that was ball-milled from glass flakes. Ninty-five percent of the dust particles were less than 1 μm in diameter. Three groups of 40 rats each and 3 groups of 15 guinea pigs each were exposed either to glass dust (18 mg/cu m), quartz dust (24 mg/cu m), or Kaolin dust (27 mg/cu m) dust for 6 hours/day, 5 days/week for 1 year. The animals were allowed to live for 1 year following the 12-month exposure. Macroscopic examination at autopsy revealed no significant changes from controls in either species. Microscopic examination of guinea pig tissues revealed widely scattered and relatively small foci of clustered alveoli which contained massed dust cells. The lymph nodes also contained dust cells in the form of small, loosely scattered foci. Interstitial pulmonary fibrosis, associated with prominent basophilia of elastic tissue, and calcifications were found in four guinea pigs. In the rats the indication of dust exposure consisted of widely scattered small foci of clustered alveolar macrophages.

The most significant study of the effects of fibrous glass by inhalation was performed by Gross et al [58] who exposed rats and hamsters to fibrous glass at 100 mg/cu m, for 6 hours/day, 5 days/week for 24 months and reported the results in 1970. The average glass fiber diameter was 0.5 μm and the average length was 10 μm. Of the airborne dust, 70-76% was found to be fibrous by means of collection on a membrane filter and

evaluation with phase contrast microscopy. The rats and hamsters were divided into 3 groups of 30 animals of each species. Another group of 20 animals of each species served as controls. One group of animals was exposed to fibrous glass coated with phenol-formaldehyde resin, a second group was exposed to fibrous glass coated with a starch binder, and the third group was exposed to uncoated fibrous glass. Five rats and five hamsters from each group were killed after 6 months and a similar number were killed after 12 months of exposure. The exact number of animals that were killed at 24 months after exposure was not specified [58].

No differences in tissue reactions between the three groups were detected; however, there were differences between the exposed anz the control animals. In the exposed rats, pneumonia and endemic chronic bronchitis and its sequelae were found at a higher, but unspecified, rate than in unexposed rats. Pneumonia, however, is a normal finding in aged laboratory rats. Exposed rats showed an accumulation of dust-filled macrophages within alveoli. A few foci of septal collagenous fibrosis were seen in some rats, but there was no other evidence of fibrosis. A large amount of dust in some of the satellite lymph nodes was found in rats after 2 years of exposure. In the hamsters, macrophage-containing alveoli clustered around respiratory bronchioles. Alveolar ducts contained dust-filled macrophages. Ferruginous bodies were observed. In contrast to the satellite lymph nodes of rats, those of hamsters were not enlarged even at 24 months [58].

Botham and Holt [59], in 1971, investigated the production of ferruginous bodies after inhalation of glass fibers and described their evolution in some detail. Eighteen male guinea pigs were exposed once for

24 hours to glass fibers that were mostly 20 μm in length or shorter and less than 3 μm diameter, mostly less than 1 μm. Fibers measuring 40 μm in length were noted rarely. The exposure concentration was described only as "high." The animals were killed and examined at various intervals after exposure. In the lungs most of the fibers that were visible with the light microscope were less than 20 μm in length; fibers longer than 40 μm were rarely observed. Fibers retained in the lungs deposited initially in the bronchioles. Some fibers moved inward to the alveoli, where they were taken up by macrophages, some of which then combined to form giant cells. The presence of fibers was associated with the escape of erythrocytes from alveolar capillaries. Erythrocytes had been cleared from the respiratory regions and some were seen in bronchiolar debris and others apparently had been ingested by macrophages. Ferroproteins were produced in the cytoplasm of these macrophages. Where glass fibers and ferroproteins occurred in the same cell, the ferroproteins deposited on the longest fiber while other fibers in the cell invariably remained uncoated. The coating then underwent a change until it attained a beaded form. Eventually these structures broke between the beads allowing for clearance by the macrophages.

In the same study, Botham and Holt [59] compared the fate of glass fibers inhaled by guinea pigs with that of inhaled anthophyllite absestos fibers. They found that the sequences of fiber coating and fragmentation were similar but occurred in a shorter time with tne glass fiber. Ferruginous bodies developed as early as 2 to 5 days after exposure to fibrous glass and to asbestos and some could still be found even at 18 months after exposure.

Botham and Holt [60] repeated the experiment using nonfibrous glass dust that was chemically similar to the glass fibers of their earlier experiments. The dust particles were irregular in shape, most having maximum dimensions less than 10 μm, but longer particles (up to 100 μm in length) were found occasionally. Ten guinea pigs were exposed at "high" but unspecified concentrations, killed at various intervals up to 28 days, and examined. The effects of the inhalation of glass dust differed from those observed after inhalation of glass fibers in that fewer erythrocytes escaped from capillaries, very few giant cells were produced, and erythrocytes and intercellular glass particles were cleared more readily because junctions between respiratory and terminal bronchioles were not blocked by giant cells. Intracellular granules containing positive iron staining (Perls-positive) material did not appreciably increase in number or intensity of staining during the month, and particles were not coated with Perls-positive material during the time required to form pseudo-asbestos bodies from glass fibers.

(c) Intratracheal

In 1955, Schepers and Delahant [56] described the results of three intratracheal experiments with glass wool in guinea pigs. In these experiments, fibers of three different dimensional batches were used. Batch A had average diameters of 6 μm, with a range from 3 μm to 8 μm. Batch B was approximately 3 μm in diameter and batch C measured 3 μm or less in diameter with a large proportion around 1 μm. All fibers were 20 to 50 μm in length. The glass fibers in suspensions in saline were introduced intratracheally in three doses of 0.5 ml each with 1-week intervals between doses. Batches A and B were 5% suspensions and batch C

3 μm to 8 μm. Batch B was approximately 3 μm in diameter and batch C measured 3 μm or less in diameter with a large proportion around 1 μm. All fibers were 20 to 50 μm in length. The glass fibers in suspensions in saline were introduced intratracheally in three doses of 0.5 ml each with 1-week intervals between doses. Batches A and B were 5% suspensions and batch C was a 0.5% suspension by weight in isotonic saline. The investigators found that atelectasis was more prevalent in the animals that received the fibrous glass with the smaller diameters than in those that received the largest diameter material. No fibrosis was observed.

Wenzel et al [61] studied the effects of two different sizes of glass fibers administered intratracheally to rats. The finer fibers, 3 μm in diameter and 5-15 μm in length, were administered to 25 female rats and the coarser fibers, 30 μm in diameter and 30-100 μm in length, were administered to 24 female rats. Each group of rats was given one administration of 50 mg, the animals being killed and examined 90, 180, 270, or 360 days later. No control animals were reported. Examination of animals from both groups, killed 3 months after administration, showed widespread uniform distribution of fibers in all lung sections. Intratracheal administration of the finer glass fibers produced desquamation of alveolar epithelium after 3 months and hyperplasia of the mucous membrane. Glass fibers were imbedded in the interstitium (interlobar, interlobular, intracinar, intraductular, and intraalveolar septal connective tissue). Six months after exposure, extensive formation of fibroblasts, fibrocytes, and "glass fiber nodules" were seen. Extensive emphysema and chronic bronchitis were seen at 6 months and were increasingly prevalent at 9 and 12 months after administration. At 12

months atelectases were evident and the bronchioles were hyperplastic [61].

The administration of the coarse fibers resulted in different and less severe tissue reactions than that of fine fibers in the first 9 months. During this time fibers were imbedded in the interstitium and surrounded by connective tissue. At 6 months, the number of fibers present in lung sections was reduced when compared with that in sections at 3 months. The lesions present after 9 months included chronic bronchitis, stenoses of the bronchial lumen with hyperplasia of the peribronchial lymphatic tissue, and atrophic emphysema and atelectasis in the adjacent lung tissue [61].

Gross et al [62] studied a variety of fibrous materials including uncoated glass fibers, ceramic aluminum silicate, silicon carbide whiskers, cosmetic talc, attapulgite, and chrysotile. When the fibers were introduced intratracheally, ferruginous bodies were produced in hamsters in response to all the fibers except attapulgite. Though not indicative of pathogenic potential, the finding is of interest in interpreting epidemiologic studies on ferruginous body content of human lungs. Gross et al [62] observed that while ferruginous bodies have been determined experimentally in animals, there do not seem to be any reported findings of ferruginous bodies in the sputa of workers who inhaled fibrous glass, as so commonly occurs with asbestos exposures [62].

In another report Gross et al [63] compared the lesions in rats produced by intratracheal injections of fibrous quartz, asbestos, talc, and synthetic chrysotile, silicon carbide whiskers, fibrous ceramic aluminum silicate, five varieties of fibrous glass, and brucite. The fibrous glass averaged about 1 μm in diameter and either had various coatings, no

coatings, or was etched. A dose of 10.5 mg was given. All types of fibers produced proliferative inflammations in the smaller bronchi and bronchioles that were attributed to mechanical trauma from the method of introduction.

The main pulmonary response produced by fibrous glass, brucite, silicon carbide whiskers, and aluminum silicate was the mobilization of dust-filled macrophages which occupied the alveoli evaginating from respiratory bronchioles. The walls of these alveoli were thickened by a combination of surface cell enlargement and proliferation of the septal argyrophilic stroma. The investigators [63] stated that these lesions were reversible and did not affect the anatomic integrity of air spaces or produce proliferation of collagen [63].

In 1974, Kuschner and Wright [64] studied the effects of intratracheal instillation of glass fibers of different dimensions in guinea pigs. Groups of 30 guinea pigs were given intratracheal administrations of one of six possible categories of glass fibers that were differentiated according to dimension. The dimensions of the fibers are shown in Table III-1.

TABLE III-1

TYPES OF GLASS FIBERS USED IN INTRATRACHEAL ADMINISTRATION TO GUINEA PIGS

Fiber Description	Fiber Dimensions	
	Diameter, μm	Length, μm
Very thin and short	<0.3	<5
Very thin and long	<0.3	>10
Thin and short	<1	7%>10
Thin and long	<1	7%<10
Thick and short	2	88%<10
Thick and long	2	75%>10

Adapted from Kuschner and Wright [64]

The fibers were administered in a series of two to six injections [64]. The total amounts injected into each animal ranged from 3 to 25 mg. The animals were killed at 6 months, 1 year, and 2 years after the last administration.

The first two categories studied consisted of thin fibers, most with diameters less than 1 μm. Short thin fibers, of which only 7% were longer than 10 μm, and long thin fibers, of which only 7% were shorter than 10 μm, caused different tissue reactions. No fibrosis was found after exposure to

short fibers but alveoli filled with macrophages and fibers within macrophages in the lymph nodes were observed. Exposure to long fibers resulted in interstitial reaction at areas around respiratory bronchi and proximal alveoli 6 months after exposure. At 1 year after exposure, peribronchiolar interstitial fibrosis was observed [64].

Thinner fibers, most with diameters less than 0.3 μm and lengths less than 5 μm or greater than 10 μm, produced reactions similar to those induced by the previous set of long and short thin fibers. The very thin, long fibers caused a fibrotic reaction whereas the very thin, short fibers did not [64].

Thick fibers, with diameters averaging 2 μm, with 88% shorter than 10 μm or 75% longer than 10 μm, were compared. The short, thick fibers resulted in some interstitial fibrosis after 2 years. This may have been due to the presence of the 12% of fibers in that group longer than 10 μm. The long, thick fibers caused focal areas of interstitial fibrosis at 6 months after exposure [64].

The investigators [64] also studied various sizes of asbestos fibers by the method described and found a markedly greater degree of fibrosis with the longer fibers. They theorized that the marked quantitative difference between fibrous glass and asbestos was a consequence of the lesser durability of a long glass fiber as compared with the durability of asbestos. In the experiments in which long glass fibers were introduced, a "surprisingly" large number of short fibers appeared in the lymph nodes.

The mechanism which Kuschner and Wright [64] believed best explains the commonality of response to a variety of asbestos fibers and to glass is one that has been determined for granulocytes [65] and has been extended to

macrophages [66,67]. Cells attempting to engulf long fibers are involved in incomplete or "frustrated" phagocytosis. The process, known as exocytosis, results in leakage of tissue-damaging enzymes from the cell without being specifically toxic to the phagocyte. The resultant tissue damage is presumed to be the ultimate inciter of fibrosis.

(d) Intraperitoneal

A study of the effects of two sizes of fibrous glass, injected intraperitoneally, was performed by Pott et al [68]. In one type of fibrous glass, identified as MN104, 50% of the fibers measured less than 0.2 μm in diameter and had lengths less than 11 μm. In the other type of fiber, identified as MN112, 50% of the fibers were less than 1 μm in diameter and shorter than 28 μm. Wistar rats received various injected doses up to 25 mg of the fibrous glass. Also, some animals received Union Internationale Contra Cancer (UICC) crocidolite or granular corundum for comparison. The MN104 glass was administered to three different groups of 80 rats each in doses of 2, 10, and 25 mg given twice. Tumor rates of 27.4, 53.2, and 71.4%, respectively, corresponded to the three dose levels. Animals that received 20 mg of MN112 glass had a tumor incidence of 37.8%. This was comparable to the 38.5% occurrence found in the group of rats that received 2 mg of crocidolite. The other comparison group received two 25-mg doses of granular corundum and had a tumor rate of 8.0% Mesotheliomas in the abdomen or thorax were the most frequently encountered tumors, followed by spindle cell sarcomas. More than 70% of all tumors were classified as mesotheliomas (F Pott, written report, February 1976).

In an earlier phase of the study, Pott and Friedrichs [69] compared intraperitoneally administered doses of chrysotile, fibrous glass,

hematite, and nemalite as well as relatively nonfibrous materials such as actinolite and talc. At the end of 530 days, 16 to 25 tumors were found in groups of 40 rats injected with 25 mg of the materials on a weekly basis for 4 weeks. Only five tumors were found in rats given milled chrysotile and no tumors occurred in any group of the rats receiving any of the nonfibrous materials. Abdominal tumors were mainly found in animals with a considerable amount of abdominal fibrosis. The investigators [69] concluded that fiber dimension rather than chemical action was responsible for the tumors. These reports [68,69] support the contention that the dimensions of fibrous materials rather than their chemical composition may be more important in dust pathogenicity.

Davis [70] injected a dose of 10 mg of glass fibers, 0.05 μm in diameter and as long as 100 μm, into the peritoneal cavity of 25 Balb/C mice. An unspecified strain of rats also received the same size glass fibers but at a dose level of 25 mg. All animals were left for their full life span or until there were signs of tumor development. Davis found 3 tumors (12%) in mice and 3 tumors (16%) in rats. In some of the advanced tumors, the cells adopted a spindle cell pattern very similar to a fibrosarcoma. Electron microscope studies suggested that most tumors arose from undifferentiated mesenchymal cells in the submesothelial tissues. Davis [70] concluded that the tumors produced by glass fibers appeared to be structurally identical to those produced in the peritoneal cavities of rats and mice by injection of crocidolite asbestos.

(e) Intrapleural

Wagner et al [71] studied the effects in Wistar rats of intrapleural innoculations of glass fibers having different diameters. The fibers used

were of two sizes designated as fine and coarse. In the fine sample, 99% of the fibers had diameters less than 0.5 μm. The median length was 1.7 μm, and only 2% of the fibers were more than 20 μm in length. In the coarse sample, only 17% had diameters less than 1 μm, and the median fiber diameter was 1.8 μm, median length was 22 μm, and 10% of the fibers were longer than 50 μm. Ninety-six rats, 48 of each sex, were randomly allocated to one of three treatment groups consisting of coarse or fine fibrous glass or saline given as the control. The dose/rat of 20 mg in 0.4 ml of normal saline was given once to each animal. Mesotheliomas were diagnosed in 4 of 32 animals ($P<0.01$) that received the fine diameter fibrous glass, whereas none occurred in the group receiving either the coarse fibers or the controls. The altered morphology in the mesothelial cells of the rats that were exposed to fibrous glass was assessed on a 7-point scale ranging from no change to mesothelioma. In addition to the four identified mesotheliomas, there were seven rats with "marked" cellular hyperplasia. Only one rat injected with fine fibrous glass showed no signs of hyperplasia compared with 12 of those injected with coarse glass fibers. These data are summarized in Table XV-7. Table XV-8 is a list of the percentage of rats that developed mesotheliomas after exposure to various fibrous materials in earlier experiments.

Davis [69] studied the effects of injecting various fibrous materials, including fibrous glass, into the pleural and peritoneal cavities of Balb/C mice. Two different diameters, 0.05 μm and 3.5 μm, and two different lengths, mostly "several hundred" μm and less than 20 μm, of borosilicate glass were studied. Samples of fibrous glass belonging to these four dimensional categories were administered to groups of 25 mice in

single doses of 10 mg/mouse. Animals were killed between 2 and 18 months after injection. All the glass samples produced granulomas within the pleural cavity but these differed markedly in their sizes and structures. Short fiber samples of both large (3.5 μm) and small (0.05 μm) diameter glass produced very small, compact granulomas which never formed adhesions between the lungs, heart, and chest wall. The longer fibers produced many large granulomas, which often filled a greater part of the pleural cavity and formed firm adhesions between the lungs, diaphragm, heart, and chest wall. Small amounts of collagen were present within the granular tissue 2 weeks after injection and continued to increase, developing a level of fibrosis as severe as that produced by similar doses of chrysotile or crocidolite asbestos [69].

Stanton et al [72] described a technique in which a thin pledget of fibrous glass, coated with heat cured phenol-formaldehyde resin, was used to hold asbestos fibers suspended in gelatin against the pleural and pericardial surfaces of rats. The fibrous glass pledgets themselves produced no neoplasms. The pledgets impregnated with the asbestos mineral crocidolite, however, produced what were described as "mesothelial sarcomas" in 22 of 30 rats (74%).

Stanton and Wrench [73] reported an extension of their earlier work in which they included several experiments with fibrous glass. Specific pathogen free (SPF) female Osborne-Mendel rats, 30 in each exposure group, were used. The asbestos minerals (amosite, chrysotile, and crocidolite) in 40-mg doses led to mesothelial tumors in 58% to 75% of rats surviving the operation for at least 1 year. Reduced doses of crocidolite were associated with correlative reductions of tumor incidence. Intact fibrous

glass pledgets resulted in no tumors in 58 animals. Partially pulverized material containing fibers in the 1 to 20-μm length range was associated with a low incidence, about 4%, whether coarse pledget material, fibrous Pyrex glass under 10 μm in diameter, or old glass wool 1 to 15 μm in diameter, was used. When partially pulverized AAA fibrous glass, less than 3 μm in diameter, was tested, the tumor incidence was 12% for uncoated and 18% for coated material. Whereas two types of fibrous glass with fibers of larger size (up to 25 μm in diameter) produced only 4 mesotheliomas among 91 rats (4.4%). The authors concluded that carcinogenicity of fibrous glass was related more to the dimensions of the materials than to their physicochemical properties. They calculated that the tumor incidence correlated reasonably well with the theoretical number of microfibers (defined as fibers in the mean diameter range of 1.25 by 3.75 μm) present in the lesions, irrespective of whether the material was asbestos or fibrous glass [73].

Continuing this line of investigation, Stanton and his colleagues [74] analyzed data from the foregoing and conducted additional experiments with particular reference to the lengths and diameters of fibers. When tested for oncogenic activity on the pleura of rats, asbestos, fibrous glass, and aluminum oxide were most active when composed predominantly of fibers between 0.5 and 5 μm in diameter and shorter than 80 μm in length. The authors [74] regarded these results as reflecting physical structure rather than physiocochemical properties in producing the neoplastic response. However, their previous paper [73] had showed that powdered crocidolite and chrysotile, with quite similar distributions of sizes of particles, produced mesotheliomas in 75 and 58%, respectively, of the

pleura of rats to which they were applied.

In 1973, Maroudas et al [75] reported the results from a series of in vitro studies undertaken to determine whether there were any known properties of living cells that would cause them to react to the dimensions of foreign bodies, such as glass fibers. Fibroblasts, except under special conditions, require the support of a solid substrate for growth, a property which has been termed "anchorage dependence." Growth in suspension reportedly does not occur unless the cells can attach to solid particles above a critical dimension. On the basis of the results from a series of cell suspensions, the investigators [75] noted that particles shorter than 20 μm did not induce growth in vitro nor, on the basis of the animal studies of Stanton and Wrench [73], induce mesothelioma in vivo. The investigators [75] postulated that fibers induce two basic types of cellular reaction according to length, an anchorage-dependent growth at 40 to 320 μm and phagocytosis of fibers shorter than 20 μm.

Stanton et al [76] studied 17 different dimensional configurations of fibrous glass to determine their comparative ability to induce pleural sarcomas in rats. Sixteen groups, each containing 30 Osborne-Mendel SPF female rats, were exposed to various configurations of fibrous glass. A control group consisted of 130 rats and only received the pledget vehicle which was made of coarse fibrous glass. The exposures were achieved by pleural implantation of coarse 45-mg fibrous glass pledgets that contained 40-mg of test glass fibers chosen on the basis of diameter and length and, in some cases, wholeness. Estimation of particle size distribution for each sample was made by optical and electron microscopy, the fibers being categorized into 34 dimensional ranges. Calculations were made for the

number of particles of a given size in the standard 40-mg dose and the percent weight occupied by particles of a given size. The rats were exposed at 12 to 20 weeks of age. Survivors were allowed to live until the 25th month, when they were killed and examined microscopically.

During the 17 experiments, 89 pleural sarcomas were observed; none were seen in the controls. The investigators [76] estimated the probability of tumor induction for each group using standard actuarial life table methods to adjust for deaths of animals without tumors before the end of the experiment. The estimates of tumor probabilities for each dimension category are shown in Table XV-9. The rank order of tumor probabilities coincides with tumor incidence except for one case. The higher tumor probabilities were associated with concentrations of relatively long (> 8 μm) and thin (< 2.5 μm) fibers.

Using regression techniques, two nonoverlapping size categories, used individually, showed highly significant relationships with tumor probability. The first of these categories included fibers longer than 8 μm and with diameters less than or equal to 0.25 μm. The other category was comprised of fibers longer than 64 μm and with diameters between 0.25 μm and 1.5 μm.

The estimated probabilities of pleural sarcoma ranged from 85.3% to zero. However, analysis of the standard deviations of the probabilities of pleural sarcomas indicates that only three categories of response were distinguishable--high, intermediate, and low risk [76].

Stanton et al [76] noted than an apparent correlation exists between the amount of collagen in the lesion and the probability of pleural sarcoma. Collagen deposition, induced by fine, long fibers, appears to be

similar to the tissue capsule or envelope that develops around various types of implanted foreign bodies [76,77].

Brand et al [77] reviewed the factors and mechanisms involved in sarcoma development upon implantation in tissue of various types of foreign bodies presumed to be chemically inert. Fibrous glass can be considered a foreign body in organisms. There is much evidence that the physical presence of an implanted material alone is responsible for tumorigenesis [72-76]. Foreign body tumorigenesis is reported to be a multistage developmental process. Some of the salient features of the process are: monoclonal origin from mesenchymal stem cells of the micro-vasculature, origination of neoplastic destination and specific tumor determinants in cells distant from the implant during the earliest stage of the tumorigenic process, the regular finding of varied aneuploidies, the importance of fibrosis and macrophage inactivity during the preneoplastic maturation process, and direct contact with the foreign body surface as the terminal requirement for preneoplastic cells to attain neoplastic autonomy. Whether all these stages occur with fibrous glass is not known.

The literature reviewed by Brand [77] indicates that the size and shape of foreign bodies has a strong influence on tumorigenic potential. This finding has been supported by many studies involving fibrous glass [64,70-76]. Rodents are also quite susceptible to foreign body implants and show a sarcomatous response [77]. Most of the animal studies with fibrous glass involved rodents.

(f) Fiber Aerodynamics and Deposition

Timbrell [78,79] described the findings of a variety of experiments conducted to determine the aerodynamic characteristics of fibrous particles

and their penetration and retention in animal lungs. These experiments were performed by exposing rats to asbestos and subsequently to fibrous glass, by simulation using hollow casts of porcine lungs, and by use of various size-selective elutriators and gravitational spectrometers.

In 1965 Timbrell [78] concluded that the behavior of fibers in air is determined primarily by the diameter of the fibers; the length of fibers has only a limited effect. The behavior of fibers in air, indicated by falling speed, compared to the behavior of a reference spherical particle of unit density is described by the term, "aerodynamic diameter." The aerodynamic diameter determines what happens to particles brought within the breathing zone. Those particles with falling speeds greater than the velocity of air entering the nostrils are not taken into the respiratory system. Those particles with a falling speed equal to the velocity of air entering the nostrils can either be collected at various points in the respiratory passages or penetrate to the alveoli. Timbrell [78] found that the ratio of the aerodynamic diameter to the absolute diameter in very long fibers has been found to be, on the average, three [78]. The largest compact particles found in human and rat lungs had aerodynamic diameters of 10 μm; for these particles the absolute diameter was about 3.5 μm. Fibers larger than about 3.5 μm would usually deposit in the nasopharynx or tracheobronchial regions of the respiratory system. Fibers less than about 3.5 μm in diameter would likely escape deposition in the upper regions and penetrate deeply into the lung, especially into the alveoli. The maximum alveolar penetration occurs with fibers 2 μm in diameter and decreases to a minimum of about 20% with fibers 0.4 μm in diameter [79].

Harris [80] and Harris and Fraser [81] in 1976 developed a mathematical model for estimating lung deposition of straight fibers such as fibrous glass. The model indicated that slightly over 30% of fibers, 25 μm in length and depending on their diameters, might be deposited in alveoli. Further, the amount of deposition would decrease to 1-3% as fibers increased in length up to 200 μm.

Lippmann et al in 1974 [82] presented some experimental deposition data obtained by using a hollow bronchial cast of the human airway, and comparing this data with predicted depositions for the same airways. The predicted depositions were based on experimental data on the deposition of spherical particles. The investigators [82] found that equations for deposition of fibers would not accurately predict what would occur in a cast of the human respiratory system at flowrates greater than 30 liters/minute because of underestimation of the deposition in larger bronchi.

Brain et al [83] in 1976 reported on a study that compared the deposition of particulate matter in the lung as a result of aerosol inhalation or intratracheal instillation. This study did not involve fibrous glass but it is illustrative of differential particle deposition resulting from two different routes of exposure. Radioactively labeled nonfibrous particles were administered to hamsters and rats. It was found that the distribution of intratracheally instilled particles differed considerably from that produced following inhalation of comparable particles. Quantitative techniques indicated that the distribution of these particles was more even with inhalation than with intratracheal instillation, so that there was less concentration in particular sites

within the lung after the inhalation method than after the intratracheal method. Whether these same patterns of deposition occur with fibrous particles has not been determined [83].

Correlation of Exposure and Effect

The literature on fibrous glass indicates that fibers of differing size exert different biologic effects [27,28,56,58,61,64,76,78]. The dimensions of glass fibers rather than the chemical composition have been assumed to be the etiologic factors in biologic activity. This assumption has been based on the results of the comparative studies of different sized fibrous materials, expecially fibrous glass, along with comparisons of differential biologic effects of fibrous and nonfibrous glass [64,66,68,70-72,76]. Fibrous aerosols having the same concentration as measured by fiber count but markedly differing in diameter, length, or other configuration of the fibers may affect different regions of the respiratory system. After simulating fiber behavior with a mathematical model Harris [80] reported a decreasing probability of fiber deposition in airways distal to the terminal bronchioles with increasing aerodynamic diameter, with increasing length, and with increasing interception as the cross-section of the airway decreased. This may be interpreted generally to mean that larger fibers would be less likely to deposit in alveoli than smaller fibers. Exposure conditions in occupational or experimental situations often include aerosols or workroom atmospheres that contain particles of differing lengths and diameters [5,58,78,79].

Most epidemiologic studies of workers exposed to glass fibers 2-10 μm in diameter demonstrated no excess of roentgenographic abnormalities,

pulmonary dysfunction, or malignancy [44,46-48,50,79]. These were all cross-sectional prevalence studies conducted among current employees. Such studies gave no indication of the health of those who had ceased employment prior to the study or the individual lengths of exposure. Most of these epidemiologic studies investigated the workforce of the oldest fibrous glass production plant in the US [44]. Cholak et al [45] characterized the exposure conditions in this plant in 1963. Samples were taken using midget impingers and dust counts made using a microscope technique. Total dust concentrations ranged from 0.93 to 13.3 mg/cu m. The number of particulates ranged from 3.2 to 11.3 million particles/cu m (0.09 mppcf to 0.32 mppcf). Of these particles, only 1% or 0.002 mppcf (70,000 fibers/cu m) were found to be fibrous and 85% of these were between 2 and 10 μm in diameter (median, 6 μm). Average plant values indicated that 16% of the fibers were less than 40 μm in length and 6% were less than 20 μm.

Bayliss et al [55] performed a retrospective cohort study on former employees of the same plant. This study involved a cohort of 1,448 men, 376 of whom had died between January 1, 1940 and June 1, 1972. Using life table methods of analysis, 404 deaths were expected to occur. Only one cause-of-death category indicated a possible excess of disease; this was "nonmalignant respiratory disease exclusive of influenza and pneumonia." Environmental investigations indicated a mean airborne fibrous glass concentration of 80,000 fibers/cu m (0.08 fibers/cc) with 85% of the fibers counted being equal to or less than 3.5 μm in diameter. When Cholak et al [45] studied the conditions of the plant in 1963 the median diameter of fibers was 6 μm with average fiber counts of 70,000 fibers/cu m. Hence, the retrospective cohort study of Bayliss et al [55] indicated that fibers

3 to 6 μm in diameter or larger were correlated with an increased risk of deaths due to nonmalignant respiratory diseases exclusive of influenza and pneumonia. Of 19 deaths due to nonmalignant respiratory disease 6 were found at autopsy to be due to bronchiectasis.

Enterline and Henderson [54] studied the mortality and morbidity experience of 416 retired fibrous glass insulation production workers who were at least 65 years old. No statistically significant excess of observed versus expected deaths for any cause was found. The size concentration of glass fibers that these workers were exposed to was not reported. However, most fibrous glass insulation is greater than 4 μm in diameter although smaller diameter fibers are known to exist in the air of insulation production plants [5]. When the experience of 276 workers with normal retirements (as opposed to disability and early retirements) was studied, slight excesses of observed vs expected deaths for the categories "all other heart disease" and nonmalignant "diseases of the respiratory system" were detected. There was also a slight excess of deaths from all causes in a group of 35 workers who had reached age 65 after retiring earlier due to disability. Among the total of 127 workers who retired early because of disability, chronic bronchitis was observed six times more than was to be expected but the number of workers involved was very small. The design of this study excluded workers with significant effects due to fibrous glass exposure if they died before they reached age 65; on the other hand, the mean followup period from the first exposure was about 30 years.

Hill et al [52] found no difference in pulmonary function between 70 fibrous glass production workers (mean exposure, 19.8 years) and an

unexposed matched control group. Examination of roentgenographs, pulmonary function tests and physical examinations also revealed no differences between the two groups. In a followup study 5 years later, Hill et al [52] re-examined 53 of the original 70 study members and an unreported number of the control group and found equivalent amounts of pleural thickening. The fates of the unexamined 17 other workers were not reported. Environmental investigations in the production plant revealed that total dust in the operators' breathing zones ranged from 0.4 to 12.7 mg/cu m. Mean fiber counts in the breathing zones of operators sampled were 1,400,000 to 5,500,000 fibers/cu m (ranged from 1.4 to 5.5 fibers/cc). Of the fibers, 75% were less than 4 μm in diameter and 34% were less than 2 μm [52].

The epidemiologic and case studies except for that of Bayliss et al [55] indicate a dearth of pathologic reactions in populations exposed to fibrous glass with diameters of 2 to 10 μm. Many of the studies were limited in their ability to detect significant abnormalities in the health of exposed workers. These limitations included the designs of studies that excluded workers previously, but not currently, employed. Thus far human exposures to smaller diameter fibrous glass have not been of a sufficient extent or duration for adequate study, so that the animal studies with small fibers are of special importance.

Animals have been exposed to fibrous glass by various routes such as inhalation, intratracheal, intraperitoneal, and intrapleural administrations. No neoplastic response and only slight fibrosis was observed as a result of inhalation exposures [58] whereas fibrosis has been found after intratracheal, intrapleural, and intraperitoneal administrations [61,64,71], and neoplasms have been observed after the last

two modes of administration. All factors in these studies were not sufficiently similar to allow exact comparisons.

Intratracheal instillation of fibers by Kuschner and Wright [64] resulted in a fibrogenic response in guinea pigs. This study demonstrated a relationship of fiber diameter and length to the degree of cellular change observed in the guinea pigs. Fibers longer than 10 μm consistently produced fibrotic responses whereas shorter fibers did not. The fibers that produced the fibrotic response were generally less than 1 μm in diameter although some fibrosis was observed in the animals that received long fibers with diameters averaging 2 μm [64].

The inhalation experiments [56,58,60] involving fibrous glass have not been as extensive as experiments using other modes of administration. In the most relevant inhalation experiment performed, only slight fibrogenic and no neoplastic responses were reported [58].

The studies by Botham and Holt [59] indicate progressive changes occurring in guinea pigs after a single exposure to "high" concentrations of fibers mostly less than 1 μm in diameter and 20 μm or less in length. Fibers that were retained in the lung were deposited initially in the bronchioles. Some fibers moved inwards to the alveoli where they were engulfed by macrophages. The longest fibers became coated with a ferroprotein Perls-positive substance which attained a beaded form on the fibers. Eventually these structures broke between the beads and most of the fragments were cleared.

The effects of long term inhalation exposure to fibrous glass were presented by Schepers and Delahant [56] and by Gross et al [58]. Schepers and Delahant [56] exposed guinea pigs to fibers 6 μm in diameter at

concentrations of approximately 5 mg/cu m for 20 months and then to fibers with diameters of 3 μm at concentrations of 2 to 2.5 mg/cu m for another 20 months. No controls were used and the significance of pathologic findings is in doubt. No fibrosis was observed but there were manifestations of focal atelectasis. Similar results were found by the investigators [56] after intratracheal administrations of fibers with diameters of 3 μm or less.

The inhalation study by Gross [58] using 100 mg/cu m of dust, of which 70 to 76% was fibrous with average diameters of 0.5 μm and lengths from 5 to 20 μm, revealed no fibrosis except for a few foci of septal collagenous fibrosis in some rats or no atelectasis during 24 months of exposure. By the end of exposure only 20 animals of an initial group of 110 animals of each species, rats and hamsters, were available for evaluation. Since this is a small sample, possible pathologic effects may not have been detected. Microscopic tissue changes that were observed consisted of collections of macrophages with engulfed fibers localized in alveoli. Glass fibers deposited in the lungs of rats and hamsters were 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 those of animals killed during or shortly after the exposure, suggesting pulmonary clearance of the material [58].

Studies [56,58,61,64] concerning the fibrogenic potential of fibrous glass indicate that length and diameter are important factors. Whether fibrosis is a necessary precursor to neoplasia is speculative [64,77].

The irritant and abrasive effects of fibrous glass on the skin, the upper respiratory tract, and the eye have been reported by a number of

investigators [16-19,27-30,35,36,40].

Erwin [24] observed dermatitis and skin irritation in a group of workers handling fibrous glass fabric and a mixture of copolymer resins in the manufacture of reinforced plastic products. The skin irritation was aggravated because of the necessity of handling the material with bare hands and the frequent washings necessary to remove the plastic fluid from the skin. The small fibers of glass (dimension not stated) seemed to be mechanical irritants and in some cases caused sensitization. The sensitization reaction may have been due to the plastic rather than to the glass fibers particularly if the plastic contained formaldehyde [24]. Heisel and Hunt [28] reported that fabric made from glass fibers with diameters less than 4.6 μm could be applied directly to the skin without concern for irritation. These findings are supported by those of Possick et al [30] who found that fibers of large diameters were more likely to cause skin irritation. The potential for irritation by glass fibers between 5 and 10 μm in diameter was considered to be from moderate to high. These observations indicate that concern must be given to all sizes of glass fibers and not to a specific size alone if the total occupational health problem associated with fibrous glass exposure is to be adequately controlled.

A summary of the effects from various exposures to fibrous glass is presented in Table XV-10.

Carcinogenicity, Mutagenicity, Teratogenicity, and Effects on Reproduction

Sincock and Seabright [84] exposed two groups of cultured Chinese hamster cells to glass fibers, glass powder, UICC crocidolite asbestos, and

SFA chrysotile asbestos for 48 hours or 5 days. The dusts were added at a concentration of 0.01 mg/ml. Cells exposed to asbestos showed karyotypic alterations to a greater degree than cells exposed to glass fibers or dust. Exposure for 5 days to the glass fibers produced slightly more, but not statistically significant, alterations than were found in unexposed controls. These findings were not considered by the authors [84] as indicative of a mutagenic potential of fibrous glass.

Stanton et al [72-74,76], Davis [70], Wagner et al [71], and Pott and associates [68,69] have been able to repeatedly produce tumors in animals after either intrapleural or intraperitoneal administration of fibers predominately less than 1 μm in diameter. Stanton et al [76] stated that the probability of tumor formation in rats with fibers less than 0.25 μm in diameter and longer than 8 μm was 85%. The dose in this study was 40 mg per animal.

Davis [70] produced tumors in Balb/C mice and in an unspecified strain of rats after a single injection of long (up to several hundred μm), and thin (average diameter, 0.05 μm) glass fibers. Mice received an intraperitoneal dose of 10 mg and this resulted in a 12% (3/25) tumor response. Rats received an intraperitoneal dose of 25 mg and this resulted in a 16% (3/18) tumor response. Some of the advanced tumors were classified by the investigator [70] as fibrosarcomas.

In similar experiments involving injection of glass fibers into the pleural cavities of mice, Davis [70] found that long fibers (up to several hundred μm) of either 0.05 or 3.5 μm in diameter produced granulomas markedly different in size and structure from short (<20 μm) fibers. The short fibers produced granulomas which never formed adhesions between

lungs, heart, and chest wall. The long fibers produced many large granulomas, which often filled a greater part of the pleural cavity and formed firm adhesions between lungs, heart, and diaphragm. Wagner et al [71] also reported a 12% tumor incidence in rats after intrapleural administration of a 20-mg dose of glass fibers having a median diameter of 0.12 μm. Pott and Friedrichs [68] found a proportional relationship between dose and tumor incidence after intraperitoneal administration. Doses of 2 mg, 10 mg, and 25 mg, each given twice, produced tumors with rates of 27.4, 53.2, and 71.4%, respectively, in rats.

The carcinogenic responses in animals after intrapleural or intraperitoneal administration of fibrous glass are consistent with the responses found after implantation of other foreign body materials such as polyethylene, asbestos, nylon, cellophane, and Teflon. A review of the literature on this subject entitled "Foreign Body Tumorigenesis" has been recently authored by Brand et al [77]. Responses to implanted materials have been described by the relatively synonymous terms "physical carcinogenesis," "solid-state carginogenesis," and "foreign body tumorigenesis." It has been demonstrated that the tumorigenic response depends on physical rather than chemical factors. The most important of these factors is the size and shape of foreign materials which determine the appearance and incidence of foreign body tumors. Most of the tumors found after foreign body implantation have been sarcomatous. The appearance of these tumors is also dependent on the strain and species of the host animal. Rodents are particularly responsive to foreign bodies. The data on the relative responsiveness of humans is equivocal. Another prerequisite of the tumorigenic response is that it is preceded by the

normal reaction of biologic tissues to foreign bodies. Not all foreign body reactions result in tumor formations but all tumorigenic responses begin with foreign body reactions, followed by the appearance of fibrosis and diminished inflammatory reaction. The forces that cause the normal foreign body reaction to develop into a tumorigenic response have not been determined. While these experiments contribute to the elucidation of mechanisms of tumor formation, they do not indicate that fibrous glass will be carcinogenic after inhalation or after exposure in the occupational environment.

The routes of exposure used in many of the intrapleural and intraperitoneal experiments have been considered to be inappropriate to indicate the effects of fibrous glass after inhalation. It is not valid to extrapolate from the results from these intracavitary exposures in animals to humans in the workplace.

Bayliss et al [55] performed one of the few epidemiologic studies designed to detect a risk mortality due to cancer. As a result of a retrospective cohort analysis of mortality patterns in fibrous glass production workers, 49 cases of respiratory disease, malignant and nonmalignant, were found.

Bayliss et al [55] then extended their retrospective cohort mortality study to include a case-control study of a group of workers exposed to fibrous glass of a smaller and potentially more dangerous diameter during the operation of a pilot process. This group was exposed to fibers ranging from 1 μm to 3 μm in diameter during 1941-1949. Cases and controls were matched according to birth date, race, sex, and date of employment. The results of the matching indicated that there were four deaths from

malignant respiratory disease in workers who had been in the pilot process compared with no such deaths in the controls. This finding had a probability level between 0.10 and 0.05 which was considered by the authors to be of "borderline" significance [55]. However, this level is not generally considered statistically significant.

Sampling and Analytical Methods

The concentration of fibrous glass in air has been determined on the basis of the weight of the dust per volume of air or the number of fibers present per volume of air. Samples for gravimetric analysis may be taken of either total airborne dust or respirable dust by use of tared filters, cyclones, or elutriators, although these are not equivalent devices in their size selective properties.

Two "semispecific" analytical methods have been used for studies of fibrous glass exposures as indicated by total airborne dust samples. One method was used by Johnson et al [85] in 1967. This method involves a chemical analysis of the air sample for "total silica" using the Talvitie method [86]; on the basis of the known silica content of the glass being sampled, the amount of glass dust may be calculated. This method has numerous problems associated with it. First, the silica content differs for the various types of borosilicate glass used to make fibrous glass, ranging from about 34 to 73%. Second, interference will result when free silica or other silicate materials are present.

The second analytical method involves an ashing procedure (JL Konzen, written communication, November 1972). According to this method, the sample is collected on a membrane filter and ashed in a platinum crucible at approximately 530 C until a constant weight is reached. The remaining ash is considered to be the glass portion of the sample. The major problem associated with this method is the possibility of other materials being present which do not volatilize at 530 C. In addition, the reliability of

the ash weight can be very low when only small initial dust weights are present. The current Threshold Limit Value (TLV) is based on gravimetric determinations. The gravimetric approach is easy to use, efficient, and widely known. However, the advisability of determining concentrations of fibrous glass on the basis of weight alone may be questioned since the number of fibers and their dimensions may determine toxicologic significance. A gravimetric determination is a useful indication of exposure to fibrous glass of large diameter (> 3.5 μm) but not for fibers of smaller diameters.

Gravimetric determinations of fibrous glass have been shown to be independent of the number of fibers, especially when fiber diameters are within the respirable range. For fibers of the same length, fiber weight is a function of the square of the diameter. Therefore a fiber 1 μm in diameter weighs 100 times as much as a 0.1-μm diameter fiber of the same length. If the work place environment is evaluated solely on a total weight basis, the presence of very few large-diameter fibers can increase the weight appreciably. When fibers constitute only a small part of the total airborne particulates, this disagreement between gravimetric and fiber count determinations will be especially marked.

Dement [5] noted a total fibrous glass airborne dust concentration of 0.4 mg/cu m in one bulk fiber operation with a corresponding average fiber count of 1,000,000 fibers/cu m (1.0 fiber/cc) while in another bulk operation the measurements were 0.7 mg/cu m and 9,700,000 fibers/cu m (9.7 fibers/cc). Thus, the relationship between fiber concentration and mass concentration may vary considerably with fiber dimensions. In the plants that Konzen [90] studied less than 2% of the total airborne particulate

materials were fibrous. In Cholak et al's study [45], fibers made up less than 1% of the airborne particulate but this consituted 47% of the average dust weight per unit volume in the atmosphere. Where nonfibrous dusts are present the use of cyclone or elutriator pre-samplers is generally acceptable. Total dust samples of fibrous glass can easily be taken with fibrous glass; however, considerable problems arise when cyclones or elutriators are used for respirable sampling of fibrous materials. The inability of these instruments to separate fibrous dusts was demonstrated by Bien and Corn [88]. Ortiz and Ettinger [89] reported that the studies of Bien and Corn [88] did not indicate any attempt at calibration of the 10-mm cyclone for the size-selective sampling of fibrous aerosols. These investigators [89] found that a fixed cyclone sampling flow rate of 1.7 liters/minute would provide an adequate approximation of the "respirable" mass fraction (as defined from results using an Andersen Impactor) for the fibrous aerosol.

There are indications from the work of Stanton et al [76], Pott et al [68], and Botham and Holt [59] that the number of fibers may be significant in determining biologic effects. Since the number of fibers rather than their weight is considered to be a more accurate estimate of exposure to small diameter ($< 3.5\ \mu m$) fibrous glass, a method acceptable for counting fibers has been evaluated and recommended for use.

A method for collecting, mounting, sizing, and counting asbestos fibers has been developed [90] for use with the occupational health standard 29 CFR 1910.1001. This method involves sample collection with a membrane filter and counting with phase contrast microscopy at 400-450X. The method [90] should be more effective for fibrous glass than for

asbestos since most glass fibers found in the workplace air are larger than asbestos fibers and fewer in number. For these reasons glass fibers should be easier to perceive in an optical field. Dement [5] found that, in the operation he studied, the number of fibers less than 5 μm in length was not more than 5%. Fibers longer than 5 μm are easily resolved by optical microscopy (resolution limit is approximately 0.3 μm). Using the phase-contrast fiber counting method, Dement [5] found that fiber levels as low as 10,000 fibers/cu m (0.01 fibers/cc), based on a 4-hour sample at 2 liters/minute air flow, could be determined.

There are limitations to the phase-contrast fiber count method [90]. It is not specific for glass fibers and can lead to over counting in operations involving mixed fiber exposures. However, the frequency of exposures to mixed fibers is probably small. Glass fibers are also more distinct than most particles that would be viewed in the optical field. These fibers are relatively easy to differentiate.

The accuracy of the counting method [90] has not been determined, and probably cannot be since it provides essentially an appraised average using a microscopic technique. There are, at present, no other techniques with which it can be properly compared.

The precision of the fiber counting method [90] has not been determined for fibrous glass but it has been for asbestos. Various factors affect the precision of the method for measuring asbestos in air, and, to some extent, all of these would occur in counting fibrous glass. These factors include statistical variation, individual counter bias, variation between microscopes, fineness of fibers, and variation in distribution across the face of the filters. In laboratory measurements of the

precision of the counting procedure, the pooled coefficient of variation from the factors cited above has been found to range from 0.15 to 0.30. When this method for asbestos was evaluated by NIOSH laboratories, the pooled coefficient of variation was 0.22. Other limitations of the fiber count method include the time required for sample analysis, and the fact that only a few replicate analyses can be made on a sample filter.

Two sampling and analytical methods have been recommended because fibrous glass of different dimensions has different degrees of hazard. One method is not sufficient for estimating the exposure from airborne fibrous glass of different diameters. A fiber count method has been recommended for small-diameter fibers and a gravimetric method has been recommended for all glass fibers but which will essentially estimate large fiber exposure. When both analytical methods are used, estimates of exposure should be accurate to within known limitations regardless of fiber size present in workplace air.

Environmental Concentrations

It is important to recognize that in virtually all occupational situations where fibrous glass is present, the exposure is not to fibers of uniform diameter, but to a range which usually includes a substantial percentage of fibers having diameters considered to be of respirable size.

Balzer [91] reported on the distribution of glass fibers by diameter for air taken from occupational environments, fibrous glass-lined ventilation systems, and ambient air. These data are summarized graphically in Figure XV-1. All data is from California. The diameter of glass fibers measured in ambient air and ventilation systems had mean

diameters of 4.3 and 3.7 μm, respectively, whereas samples taken during the installation of fibrous glass insulation materials had a fiber diameter of 6.5 μm and a range of 0.3 to 2.5 μm. About 15% of the fibers from the occupational environment are less than 3 μm in diameter. The mean concentrations of fibers for each of the three sampling sources are 2,570 fibers/cu m in ambient air, 870 fibers/cu m in ventilation systems, and 405,900 fibers/cu m during the installation of insulation materials.

Fowler et al [92] determined that insulation workers, during the actual application of fibrous glass insulation products, were exposed to airborne concentrations of glass fibers ranging from 500,000 to 8,000,000 fibers/cu m (0.5 to 8 fibers/cc), with a median of 1,300,000 fibers/cu m (1.3 fibers/cc) and a mean of 1,800,000 fibers/cu m (1.8 fibers/cc). Sampling was accomplished using membrane filters and fibers were sized and counted using optical microscopy. Computed gravimetric concentrations of airborne glass fibers were estimated to be less than 1.0 mg/cu m in most situations. Actual measurements of gravimetric concentrations were not presented. The investigators [93] commented that the air at construction sites is quite dusty and attempts to relate results from total gravimetric samples to the concentration of fibrous glass may be misleading. Mean fiber diameters in parent insulating materials ranged from 4.0 to 10.2 μm, but the mean diameters in breathing zone air samples during use of these materials ranged from 2.3 to 8.4 μm.

In 1963, Cholak et al [45] reported the concentrations of particulates in the workroom air of the oldest fibrous glass production plant in the US. The average concentrations of total solid particles in the air ranged from 0.93 to 13.3 mg/cu m with an average concentration of

2.24 mg/cu m. Samples were collected with Greenburg-Smith impingers. The average number of particles of all types in the air was 7,700,000 particles/cu m (0.22 mppcf) with a range of 3,200,000 to 11,200,000 particles/cu m (0.09 to 0.32 mppcf). Fibers constituted less than 1% of these airborne particulates, and fiber counts averaged 70,000 fibers/cu m (0.002 mppcf). The fibrous particulates constituted 47% of the average weight of dust per unit volume, which represented an average fibrous glass concentration of 1.63 mg/cu m. The average median diameter of the fibers was found to be 6.4 μm (9% were less than 3 μm but only 0.2% were less than 2 μm). Eighty-five percent of the fibers were between 2 and 10 μm in diameter and almost 90% were less than 100 μm in length; fibers shorter than 5 μm were rarely found.

The data collected by Cholak et al [45] indicated that the weight of particles in the air had very little relationship to the number of particles present, a few large particles being responsible for a major portion of the weight.

Hill et al [52] in 1973 reported the size and concentrations of fibrous glass in a production plant in England. Fibers were collected on membrane filters using Casella personal samplers. A mean dust concentration of 0.4 mg/cu m was measured gravimetrically. All fibers with an aspect ratio greater than 3:1 and between 5 and 100 μm in length were counted by microscopic examination of 200 random fields selected from each exposed filter. Samples were taken within the operators' breathing zones, which were considered to be 2 feet from the dust source. Dust concentrations and fiber dimensions are presented in Table XV-11. Mean fiber counts in operators' breathing zones, at the operations sampled,

ranged from 1,300,000 to 5,500,000 fibers/cu m (1.3 to 5.5 fibers/cc). Two feet below breathing zones, at bench level, the concentrations had mean values of 3,400,000 and 10,400,000 fibers/cu m (3.4 and 10.4 fibers/cc). The authors [52] cited the high proportion of heavy fibers as the reason for the decrease in both fiber count and gravimetric estimation of dust between the source and the breathing zones of the operators.

In 1974, Dement [5] reported on investigations of airborne particulates in 10 fibrous glass production facilities. The study consisted of four facilities producing fibers used in standard home insulation (designated as large-diameter fibers) and six facilities producing or using fibers measuring less than 1 μm in diameter (designated as small-diameter fibers). Two samplers were placed on each worker or at a specific plant location. One sampler, equipped with a membrane filter, collected dust for fiber counting and sizing and the other sampler, containing a PVC filter, collected a total airborne dust sample for gravimetric analysis. All sampling periods lasted 4 to 6 hours.

In facilities where large-diameter fibers were present, mean fiber counts ranged from 60,000 to 130,000 fibers/cu m (0.06 to 0.13 fiber/cc). The highest single concentration was 830,000 fibers/cu m (0.83 fiber/cc). Mean total dust concentrations ranged from 0.34 to 2.73 mg/cu m. The highest single concentration was 14.5 mg/cu m. The median diameter of the fibers found in the various plants ranged from 1.1 to 4.3 μm. In most operations sampled, over 50% of fibers were less than 3.5 μm in diameter. The median length ranged from 19 to 70 μm.

In facilities where small-diameter fibers were present, fibers ranged from less than 0.1 to 2.0 μm with the majority being less than 1.0 μm and

40 to 85% less than 0.5 μm. Mean airborne fiber counts for these facilities ranged from 1,000,000 to 21,900,000 fibers/cu m (1.0 to 21.9 fibers/cc); the single highest concentration was 44,100,000 fibers/cu m (44.1 fibers/cc). In bulk handling operations, four of six facilities had a mean concentration in excess of 5,000,000 fibers/cu m (5.0 fibers/cc). All operations studied had mean gravimetric concentrations less than 1.0 mg/cu m with the single highest observed concentration being 2.0 mg/cu m [5].

Johnson et al [85] estimated the concentrations of total and respirable glass measured both gravimetrically and by fiber count in five fibrous glass plants, four of which manufactured insulation materials and one of which made textiles. Most samples were collected on membrane filters. Respirable samples were obtained by fitting the filter holder with a 10-mm nylon cyclone. Estimations of glass were computed from analyses of total silica [86]. A composite of the samples from the four insulation plants indicated the mean total glass dust concentration in forming operations to be 0.32 mg/cu m, with individual samples ranging from less than 0.01 mg/cu m to 1.74 mg/cu m. The composite mean respirable glass dust concentration was 0.06 mg/cu m for the forming operations and the maximum individual respirable value was 0.47 mg/cu m. In the textile mill, the dust concentrations were lower than in the forming operations, the highest concentration being encountered in waste recovery operations, where the mean total glass dust concentration was 0.16 mg/cu m and the mean respirable concentration was 0.12 mg/cu m with peaks of 0.48 and 0.73 mg/cu m for total and respirable glass dust, respectively.

Total glass fiber concentrations averaged 370,000 fibers/cu m (0.37 fiber/cc) in forming operations (range, 40,000 to 1,950,000 fibers/cu m) [85]. One count in the textile plant was 16,370,000 fibers/cu m (16.37 fibers/cc), with others ranging from 60,000 to 1,260,000 fibers/cu m (0.06 to 1.26 fibers/cc). Mean respirable fiber concentrations in forming operations were 250,000 fibers/cu m (0.25 fiber/cc) (range, 20,000 to 2,950,000 fibers/cu m). Results of these data on respirable samples may be questioned, however, because Bien and Corn [88] demonstrated that fibers and spherical particles behave quite differently in cyclone collectors.

Corn et al [93] studied three plants using fibrous glass in 1972. These plants performed a variety of textile and insulation manufacturing operations involving applications of fibrous glass. A total of 115 general air and personal air samples were collected on 37 mm-diameter membrane filters at a sampling rate of 2 liters/minute for 2 hours and subsequently analyzed. Total suspended particulate matter concentrations ranged from 0.7 to 6.0 mg/cu m at one plant (the oldest fibrous glass production plant), from less than 0.1 to 5.2 mg/cu m at the second plant, and from 0.2 to 6.8 mg/cu m at the third. The study by Cholak et al [45] of the old fibrous glass production plant showed that concentrations of total particulates ranging from 0.31 to 23.9 mg/cu m, with an overall average of 2.24 mg/cu m. Likewise, the study by Dement [5] included this same plant and the author found no operations with total dust concentrations averaging above 0.7 mg/cu m. The highest concentration for a single sample was 0.9 mg/cu m.

If approximate worker exposures to fibers of small diameter (less than 3 μm) are calculated from the data of Cholak et al [45] and Corn et al

[93], the numbers and the masses of such fibers are extremely low. The highest concentration of airborne glass fiber under 3 μm in diameter measured by Cholak et al [45] was 40,000 fibers/cu m (0.04 fibers/cc); values for fibers less than 2 μm in diameter were less than 2,000 fibers/cu m (0.002 fibers/cc) (sample No.2 contained 280,000 total particulates, 5,000 of which were fibers; 21.3% of the fibers were less than 3 μm in diameter while only 1.3% were less than 2 μm). The data of Corn et al [93] can similarly be recalculated to show that airborne concentration of fibers under 3.5 μm in diameter and longer than 5 μm in length were well below (100,000 fibers/cu m) 0.1 fiber/cc.

Environmental levels for various operations involving fibrous glass are summarized in Tables XV-12 to XV-14.

Engineering Controls

Studies of various facilities using or producing fibrous glass with diameters greater than 3.5 μm have indicated that airborne fiber concentrations generally are less than (1,000,000 fibers/cu m) 1.0 fiber/cc in fiber-counts and less than 2 mg/cu m by gravimetric measurement [5,86,87]. At times, in operations involving fibrous glass with diameters less than 3.5 μm airborne fiber concentrations have been found to be much higher, with mean counts ranging from 1,000,000 to 21,900,000 fibers/cu m. The smaller diameter fibers are the ones that are usually found in the greatest concentrations. These are the fibers that should be most strictly controlled.

Well-designed and properly maintained local exhaust systems with appropriate capture velocities have minimized fibrous glass contamination

of workers' breathing zones in production facilities. Many fibrous glass manufacturing operations are conducted at fixed locations where established principles of engineering control (eg, ventilation, enclosure, or isolation) of operations may be applicable. Other operations, such as the use of fibrous glass on construction sites, may not lend themselves so readily to such control mechanisms. In the great majority of applications of fibrous glass, whether for thermal, acoustical or electrical insulation, for filtration, paper products, or textiles; or for thousands of reinforced plastics products--certain operations are performed which have the potential for dispersing fibrous glass into the air. These operations include cutting, sawing, grinding, sanding, and polishing. As with any other material subjected to such particulate dispersing operations, the basic engineering objective should be to prevent the particles from entering the general workplace air. The most generally applicable control measure is local exhaust ventilation, including high velocity, low volume tool attachments. Such ventilation should follow the principles presented in Industrial Ventilation, a Manual of Recommended Practices, published by the American Conference of Governmental Industrial Hygienists [94], or in Fundamentals Governing The Design and Operation of Local Exhaust Systems, Z9.2 (1971), published by the American National Standards Institute [95]. Useful information is also available in the NIOSH publication Recommended Industrial Ventilation Guidelines [96].

Other control measures, including enclosure, isolation, or change of process may be useful in many situations and should be given consideration. Certain procedures of fibrous glass production or use have been found to result in elevated concentrations of airborne fibers. Dement [5] reported

that some of the highest occupational exposures occurred at the end of a processing line where fibrous glass insulation was packaged, or where fibrous glass was sawed and scrap was shoveled into waste bins. Secondary exposure hazards were found to exist where waste bins or dust collection receptacles served as a source for air contamination due to the lack of adequate exhaust ventilation, bin covers, or failure to remove dust containers from the immediate work area. Scrap reclamation processes are excessively dusty and frequently require enclosure and well designed local exhaust and dust collection systems.

Pneumatic bag fillers also produce considerable amounts of dust in areas quite close to worker breathing zones. Properly designed annular local exhaust systems surrounding the filling beak may appreciably reduce dust levels. Ram ejectors, in which a measured weight of glass wool is compressed within an enclosure and then forced into a bag, and screw-type filling machines are appreciably less dusty.

The use of compressed air to clean off various cutting surfaces or machinery often results in increasing airborne dust. Appropriate capture hoods should be used when compressed air is used.

High concentrations of glass fibers are likely to be found in various demolition and "tearing out" activities. Since these activities involve working at multiple locations, portable exhaust ventilation, prewetting, and in some cases respirators, are frequently required. Respirators are not considered to be substitutes for proper engineering controls but there may be circumstances where respirators should be used. The use of respirators is discussed in Chapter VI.

In many applications, particularly those involving the production of reinforced plastics, there may be exposures to a variety of chemicals, some of which may present more potentially disabling occupational health hazards than posed by fibrous glass. Therefore, the control measures employed must be designed to control all potentially hazardous exposures, including those associated with fibrous glass. Engineering controls and work practices for specific types of operations involving fibrous glass are contained in a report [6] and discussed in Appendix VI.

V. DEVELOPMENT OF THE STANDARD

Basis for Previous Standards

Mineral wool and fibrous glass appeared as synonymous terms in the tentative TLV list of the American Conference of Governmental Industrial Hygienists (ACGIH) in 1963 [97], with a suggested but undocumented time-weighted average (TWA) of 2 mg/cu m. In 1965 [98], this was revised to apply to fibrous glass alone with a tentative TLV of 5 mg/cu m as a TWA. This value was never transferred to the list of adopted values, but, in 1969, fibrous glass continued in the list of candidate substances [99] as an "inert" or nuisance particulate for which a TLV of 50 mppcf or 15 mg/cu m, whichever is less, of total dust less than 1% SiO2 was suggested, with the provision that this applied to fibrous glass of less than 5-7 μm in diameter. No TLV for coarse fibrous glass had been set at that time.

In 1970, fibrous glass was listed as a nuisance dust in both the adopted and the proposed lists of the ACGIH, the TLV for such dusts being lowered to 30 mppcf or 10 mg/cu m, whichever was less, of total dust less than 1% SiO2 [100]. In 1971, glass was transferred to the list of adopted TLV's, as "Glass, fibrous or dust" [101], again as an "inert" or nuisance particulate. The provision remained, limiting this TLV to glass fibers of less than 5 - 7 μm in diameter.

The documentation for the ACGIH value published in 1971 [102] emphasized that the evidence, though still incomplete, supported the lack of fibrogenic activity and other adverse effects on health by fibrous glass dust and justified its consideration as an "inert" material.

The Commonwealth of Massachusetts has set 30 mppcf as the maximum

allowable concentration (MAC) of glass based on an 8-hour daily exposure. There was no stipulation of particle dimensions [103].

No workroom air standard specifically for fibrous glass has been established under the Occupational Safety and Health Act of 1970. However, an inert or nuisance dust standard of 15 mppcf or 5 mg/cu m respirable fraction and 50 mppcf or 15 mg/cu m total dust, both as 8-hour TWA concentrations, was promulgated in 1972 by the Occupational Safety and Health Administration, US Department of Labor (37 CFR 1910.23) and is currently applicable to fibrous glass. This standard is based, in part, on the 1968 ACGIH recommendations for fibrous glass [104]. The present TLV recommended by the ACGIH in 1976 is 30 mppcf or 10 mg/cu m for glass fibers less than 7 μm in diameter [105].

Permissible levels of toxic substances in the working environment for the USSR, Bulgaria, and Yugoslavia have been published by the Joint ILO/WHO Committee on Occupational Health [103]. The MAC of respirable dusts in Bulgaria is 2 mg/cu m for glass and mineral fibers. The Yugoslavian MAC of harmful substances in the atmosphere is 3 mg/cu m for glass and mineral fibers and 2 mg/cu m for glass wool dust. In the USSR, the MAC for glass and mineral fibers is 3 mg/cu m. The USSR considers that setting of such concentrations should be based entirely on the presence or absence of biologic effects without regard to whether these levels can be reached in practice [106].

Basis for the Recommended Standard

(a) Environmental (Workplace Air)

The data available for evaluation of the biologic effects of fibrous glass and determination of the potential health hazards are severely limited in their usefulness in recommending an environmental limit. Human exposures to fibrous glass have indicated few reported health changes except those related to skin and respiratory tract irritation. However, this does not necessarily mean that more severe health effects resulting from exposure to fibrous glass are absent, rather only that they may not have been observed and thus not reported. The absence of these reports may be due to the relatively short duration that small diameter (less than 3.5 μm) fibrous glass has been in commercial production along with the short duration of exposure of adequate study groups.

Fibrous glass was first manufactured in the 1930's, became more extensively used in the 1940's and 1950's, and the smaller diameter material, less than 3.5 μm, has come into use on a large scale only since the 1960's [1,2]. If there is a potential for a health hazard from small-diameter fibrous glass, sufficient exposure in terms of numbers of people exposed and duration of exposure has not occurred and not enough time has elapsed for potential chronic effects to be recognized. The reason to believe that chronic effects from fibrous glass exposure are possible is derived from the demonstrated biologic activity of this material in animal models [64,66,68-76], and from the similarities in biologic activity and physical form between fibrous glass and asbestos [64,66,71,73]. In animals, fibrous glass has been reported to have fibrogenic and carcinogenic effects qualitatively similar to those of asbestos but to a

lesser degree [64,71,73]. The carcinogenic responses to glass fibers is consistent with the responses of animals to foreign bodies and is believed to be the result of physical rather than chemical factors [64,74,76,77]. Chronic effects, similar to those observed with exposure to asbestos, have not been found in people occupationally exposed to fibrous glass. However, these exposures have generally been to fibers larger than the asbestos fibers and for shorter periods of time. Concern exists, therefore, that occupational exposure to fibrous glass having fiber dimensions similar to those of asbestos fibers might lead to chronic effects [73]. Factors that would mitigate the possible occurrence of chronic effects include a rapid lung clearance time for fibrous glass [59,60], and the general presence of fewer numbers of small diameter fibers in fibrous glass workplaces than usually exist in asbestos operations. Unlike asbestos, fibrous glass does not fracture linearly to produce small diameter fibrils. In vivo, fibrous glass has been found to be less durable than asbestos, being more easily fragmented, phagocytized, and rapidly cleared from the lungs [59,60].

Fibrous glass has been reported to accumulate to some degree in the lungs of exposed humans and animals [50,58-60]. Gross [50] found an average of 100,000 fibers/g of dry lung tissue after selected post-mortem examinations of fibrous glass production workers [58]. These fibers were not identified as to composition.

Botham and Holt [59,60] found glass fibers measuring mostly less than 1 μm in diameter in guinea pigs which were killed following a single exposure. Fibers up to 0.5 mm in length were also present in the aerosol. Extracellular glass fibers were occasionally found in the cartilaginous and terminal bronchioles of animals killed up to 21 days after the exposure;

however, the occurrence was much more frequent in animals killed 1 or 2 days after exposure. Free glass fibers were completely cleared from these sites after 1 month in a manner similar to that observed for anthophyllite asbestos but the rate of clearance was much faster. Some glass fibers were found to be engulfed by macrophages which became detached from the interalveolar septa and moved outward into the larger air ducts. Some of the glass fibers became coated and fragmented by a ferroprotein Perls-positive material and subsequently became fragmented between beads of coating and were engulfed by macrophages. At 18 months after exposure, most long glass fibers had cleared from the lung and only fibers shorter than 2 μm had remained.

Fibrosis has been reported after administration of fibrous glass to animals [58,64,71]. Gross et al [58] found several foci of septal collagenous fibrosis in a few rats exposed for up to 24 months at 100 mg/cu m of fibrous glass, 0.5 μm in diameter. Glass dust was found in satellite lymph nodes and there was an accumulation of dust-filled macrophages in the alveoli. Kuschner and Wright [64] observed interstitial fibrosis around the respiratory bronchioles and proximal alveoli of guinea pigs 2 years after intratracheal administration of long thin fibers, 50% of which were longer than 10 μm and all less than 0.6 μm in diameter. Similar pathologic responses were observed with long thick fibers, 75% of which were longer than 10 μm and 94% having diameters less than 3 μm and 22.1% less than 1 μm. Short thick fibers also produced some fibrosis but the authors [64] theorized that this was due to the 12% of fibers present which were longer than 10 μm. No fibrosis was found after administration of fibers shorter than 5 μm in length [64].

No fibrosis, as indicated by pulmonary function tests, a roentgenographic survey, or post-mortem examinations was found in workers occupationally employed up to 30 years to fibrous glass having a median diameter of 6 μm [44,46-48,50-52]. Fiber concentrations in the operations where most of these studies were performed ranged from 30,000 to 460,000 fibers/cu m (0.03 to 0.46 fiber/cc) with an average of 70,000 fibers/cu m (0.07 fiber/cc) [44,45].

Many of the studies that have been performed to determine the biologic effects of fibrous glass have severe limitations. The majority of epidemiologic studies [42-48,51,52,54] are cross-sectional prevalence studies which have examined currently employed workers at a specific time. These investigations have been incapable of determining both the incidence of respiratory disease, and, especially, the fate of workers having long periods of occupational exposure who, for one reason or another, were not included in a given study. These employees could represent significant cases of diminished health.

The study of Bayliss et al [55] was not a cross-sectional study, rather, it was a retrospective cohort study that indicated a statistically significant excess of mortality due to nonmalignant respiratory disease excluding influenza and pneumonia in workers exposed for up to 20 years to airborne glass fibers having a median diameter of 6 μm. This investigation included not only current workers, but also those no longer employed. The authors [55] recognized the possibility of worker exposure from sources unrelated to fibrous glass and attempted to counter the potential problem through experimental design. Whether prior exposure of some of the subjects in dusty and silica-producing trades would affect the conclusions

is uncertain at this time. In a study of retired fibrous glass workers, Enterline and Henderson [54] found a small but not statistically significant excess in deaths due to nonmalignant respiratory disease. This study was limited to retired fibrous glass workers, including disability and early retirements, who had reached age 65. The mortality experiences of workers under age 65 were excluded, a factor which might have affected the reported findings. In the epidemiologic studies, the smoking histories of the participants was not a controlled variable.

In an extension of their retrospective cohort study, Bayliss et al [55] further investigated 49 cases of respiratory disease identified from the cohort and matched them with 49 controls not having respiratory disease. These groups were then compared on the basis of their exposure to fibers 1 to 3 μm in diameter in a pilot plant operation. It was reported [55] that exposure in the pilot plant resulted in a small, but not statistically significant, excess of deaths ($0.05 < P < 0.1$) for the matched pairs, which the authors considered to be of borderline significance. Subsequent to the original report, it was stated (JL Konzen, written communication, January 1976) that the designation "pilot plant" was an administrative term which included specialized operations at multiple locations in the plant rather than at any single place where similar exposures to fibrous glass occurred. Although data are very limited, the studies of Bayliss et al [55] and Enterline and Henderson [54] represent the few human studies available which might be suggestive of chronic health effects resulting from fibrous glass exposure.

On the basis of the information available for evaluation, fibrous glass is not at this time considered to present a carcinogenic hazard in

the workplace. The carcinomatous responses of laboratory animals following pleural implantation or intraperitoneal instillation of fibrous glass involves artificial routes of exposure that are inappropriate as indicators of the potential effects of inhalation. It is likely that the cancers produced by fibrous glass represent a nonspecific response to foreign bodies. This response is dependent on physical characteristics of the foreign body, characteristics of the host, and the duration that the material is present in the host. Tumors were found after fibrous glass implantation in rodents which have a well-documented susceptibility to tumorigenic foreign materials of the proper dimensions. Fibrous glass has not been shown to translocate to the pleural or peritoneal cavities; however, this has not been extensively studied.

Much of the concern about fibrous glass results from certain similarities with asbestos. Both are fibrous materials of varying lengths and diameters. The diameters of glass fibers are generally larger than those of asbestos fibers. Asbestos fibers and fibrils are most often less than 1 μm in diameter. The asbestos fibers tend to fracture longitudinally to form fibrils less than 0.5 μm in diameter. Fibrous glass was found to clear more rapidly than anthophyllite asbestos in a comparative study of single inhalation exposures [59]. Similarities in fibrogenic response between fibrous glass and asbestos have been observed from intratracheal studies in rats but the response was quantitatively less with fibrous glass [64]. Both fibrous glass and asbestos acted quite similarly in the various studies where tumors were produced but generally fibrous glass produced a lesser incidence of tumors.

Few health effects in humans have been found after fibrous glass exposures. These exposures have been, for the most part, to large-diameter fibrous glass. The health effects that have been observed include skin, eye, and upper respiratory tract irritation, a relatively low frequency of fibrotic changes, and a very slight indication of an excess mortality risk due to nonmalignant respiratory diseases. There is not sufficient data available to determine a dose-response relationship and consequently a confident level of no-observed-effect. Data from animal studies contributes little to an understanding of a dose-response relationship except with regard to the response relative to various fiber dimensions. The available data are sufficient to demonstrate that fibrous glass does not act like an inert or nuisance dust because it can produce fibrosis in animals and respiratory tract irritation in humans. There are no indications that fibrous glass will act like asbestos in humans except possibly where there are high concentrations of submicron fibers. These conditions have rarely, if ever, occurred and they are not expected to occur significantly in the future. However, this eventuality has been anticipated in the recommended environmental limit and the recommended standard in general.

The biologic effects of fibrous glass have been compared on the bases of fiber diameter and the resulting differential deposition of the material in the respiratory tract. Large-diameter fibrous glass has been demonstrated to have different characteristics in biologic systems than small-diameter glass [64]. The studies of Timbrell [78,79] indicate that 3.5 μm approximates the diameter of the thickest long fibers observed in rats following inhalation exposure. Gross et al [50] found that 90% of the

fibers in lungs of deceased fibrous glass workers were less than 3.5 μm in diameter. Many environmental studies [5,87,93] have used the value of 3.5 μm to distinguish airborne fibrous glass capable of penetrating the respiratory system to the alveoli.

It is recommended that to protect against nonmalignant effects on the respiratory system, and the possibility of malignant respiratory effects, that occupational exposures to fibrous glass be controlled in a two-fold manner based on the size of the fibers and their concentration by number and weight. The two-fold recommendation considers differentiation of fibrous glass by diameter and length. The concern for the biologic activity of fibers of different diameters has been discussed. A differentiation of fibers on a length basis considers a number of factors. Animal studies indicate that long fibers, defined as longer than 10 μm, are more biologically active than short fibers [64,71,73,75,76]. Pragmatically, in defining fibers as particulates with a 3 to 1 aspect ratio, a fiber 3.5 μm in diameter would have a length of about 10 μm. A value of 10 μm has been selected to represent a lower limit for the purpose of counting glass fibers in the occupational environment.

The environmental limit to be recommended for fibrous glass cannot be based solely on numerical dose-response data since such data are not available. The recommendations for an environmental limit therefore includes professional judgment of the relative health effects of fibrous glass compared with asbestos and with inert or nuisance dust. Fibrous glass is not an inert dust yet it is not as hazardous as asbestos. The recommended standard is considered to reflect this degree of relative health hazard.

The observations of health effects associated with worker populations exposed to small-diameter fibrous glass have been rare and generally confined to skin and respiratory tract irritation. Small-diameter fibrous glass is a relatively new material and populations exposed for a long period of time do not yet exist. The current airborne concentrations of fibrous glass in operations using small-diameter fibrous glass may serve as an indicator of probably acceptable levels of fibrous glass exposure. Konzen [87] reported that in manufacturing operations where 80% of airborne fibrous material is less than 3.5 μm in diameter the average concentration of airborne fibrous glass was 400,000 fiber/cu m (0.4 fibers/cc) or less. Dement [5] reported a mean value of 6,700,000 fibers/cu m (6.7 fibers/cc) in six facilities where small-diameter fibrous glass is used or produced. Fowler et al [92] noted that the concentrations of fibrous glass at sites where fibrous glass insulation was being installed was 1,800,000 fibers/cu m (1.8 fibers/cc); about 50% of the fibers were less than 3.5 μm in diameter. Hill et al [52] reported that respirable fibers ranged from 1,300,000 to 5,500,000 fibers/cu m (1.3 to 5.5 fibers/cc). The calculated average from the data of Hill et al [52] was 3,900,000 fibers/cu m (3.9 fibers/cc). The average of the mean concentrations in these studies [5,52,87,92] involving exposures to small diameter fibers is approximately 3,000,000 fibers/cu m (3 fibers/cc). There is an absence of firmly established health effects from exposures of the workers at the concentrations given in these four studies [5,52,87,92]. The mean concentration from these studies represents a concentration that is greater than that recommended for asbestos and yet is less than the concentration recommended for inert or nuisance dust. Therefore, as a result of the

evaluation that the airborne concentration of fibrous glass should be less than that for an inert dust and, in the absence of firmly established health effects at current environmental concentrations, it is recommended that occupational exposure to fibrous glass be limited to a TWA concentration of 3,000,000 fibers/cu m (3 fibers/cc) for fibers equal to or less than 3.5 μm in diameter and longer than 10 μm. Such an environmental limit should provide protection for workers exposed to fibrous glass, especially in operations using small-diameter fibers. The recommendation will control the airborne concentration of small-diameter fibers, which have generally been found at concentrations that exceed the recommended environmental limit, and which are considered to have potential long-term adverse health effects in humans.

Large-diameter glass fibers irritate the skin, eyes and respiratory tract [18,27,28],36]. In addition, suggestions of increased mortality due to nonmalignant respiratory disease in humans have been reported [54,55]. Limiting fibrous glass exposures by reducing environmental levels of total fibrous glass dust is recommended to control the skin, eye, and respiratory effects resulting from occupational exposure to fibrous glass. In production facilities where most airborne fibers are larger than 3.5 μm in diameter, total dust levels have been found to be generally in the range of 1-5 mg/cu m for various production and installation operations [5,6,45,85,92-94]. There are no reports available from other operations where environmental data have been collected which indicate that upper respiratory tract irritation will occur. A TWA concentration of 5 mg/cu m for total fibrous glass is recommended to control skin, eye, and respiratory tract irritation resulting from exposures to large-diameter fibrous glass.

In summation, occupational exposure to fibrous glass should be controlled so that no worker is exposed at an airborne TWA concentration greater than 3,000,000 fibers/cu m of air having a diameter equal to or less than 3.5 μm and a length equal to or greater than 10 μm. Airborne concentrations determined as total fibrous glass shall not exceed a TWA concentration of 5 mg/cu m of air.

(b) Sampling and Analysis

Fibrous glass has been shown to have different biologic effects based on fiber size. To adequately determine the exposure from different size fibers two different approaches to sampling and analysis are recommended; one that will determine the number of fibers (less than or equal to 3.5 μm in diameter and greater than or equal to 10 μm in length) and one that will determine the weight of all fibers.

The lack of correspondence between the weight of a fibrous dust sample and the number of fibers applies especially to small-diameter fibers and has been discussed in Chapter IV. To evaluate exposure to small-diameter fibers, an environmental level, based on fiber counts, has been recommended. This method is based on sampling with membrane filters and analysis by optical microscopy. An environmental limit using a count of fibers has been recommended because the number of fibers, in addition to the mere presence of fibers, may be significant in causing adverse health effects [68,69,76]. An environmental limit using the weight of fibers per volume of air has been recommended to limit what are considered to be high concentrations of all sizes of fibrous glass and particularly of fibers larger than 3.5 μ in diameter.

(c) Medical Surveillance and Recordkeeping

Fibrous glass has been observed to have effects on the skin, eyes, and respiratory system [16,25,41,42]. Eye irritation or other more severe effects on eyes have been reported rarely. Most reported effects represent transitory skin irritation, much of which can be minimized if proper work practices are followed. Certain people who may be especially susceptible to skin effects from exposure to fibrous glass may develop persistent skin irritation. These people should be informed of the hazards before employment or before initiation of work with fibrous glass.

Fibrous glass may enter the respiratory tract. Although the literature indicates respiratory disease as a result of exposure to fibrous glass is rare, evidence suggests that it can occur [16,38,40,54,55]. Workers should be regularly examined with special attention given to tests of pulmonary function as are considered appropriate. For fibrous glass smaller than 3.5 μm in diameter, specific tests and examinations related to the detection of chronic lung disease are recommended. These include but are not limited to chest roentgenography and pulmonary function tests.

Fibers about 5 μm or greater in diameter have been found to cause skin irritation; however, this has not been reported with smaller fibers in experimental situations [27].

Medical records shall be retained for 30 years after the last occupational exposure to fibrous glass so that any health effects that appear after long periods of time may be correlated with the results of the employee's previous medical examinations and with the records of employee's exposure.

(d) Personal Protective Equipment and Clothing

The areas of the body most susceptible to hazard from fibrous glass are skin, eyes, and respiratory system. Prevention of contact with these areas by fibrous glass can be accomplished by the interposition of protective equipment and protective clothing.

Respiratory protection is necessary in those operations where high volumes of dust are generated and where adherence to environmental exposure limits cannot be achieved by engineering controls. While the primary concern is for fibers having diameters of 3.5 μm or less, larger diameter fibers are also potentially deleterious to the nasopharyngeal region. In this region large glass fibers may cause laceration and subsequent expectoration of bloody sputum or saliva [38,40]. Fibers capable of causing laceration in the nasopharynx can be prevented from entering the nose by disposable respirators.

Respirators are recommended where engineering controls cannot be applied in operations involving fibrous glass 1 μm or less in diameter, because of the extreme respirability of such fibers. These fibers have not been shown to regularly produce pathologic effects in the respiratory system after occupational exposure. However, these kinds of exposures have been few in number and only of recent occurrence, so that all consequences of exposures may not be manifested yet. To insure that very small fibers (those less than 1 μm in diameter) will not penetrate the lungs it is suggested that in situations where there is exposure to these fibers that respirators be used even if engineering controls are present.

(e) Informing Employees of Hazards

Employees shall be informed of hazards associated with exposure to fibrous glass so that they may know the reasons for recommended practices, limits, and controls.

(f) Work Practices

Strict adherence to detailed work practices are necessary where there is occupational exposure to fibrous glass to prevent skin, eye, and respiratory tract irritation. Irritation can be avoided mainly by preventing tissue contact through incorporation of good hygienic practices and the use of appropriate clothing and protective equipment.

The basis for work practices to be applied with fibrous glass is that exposure may be minimized by reducing the likelihood that fibrous glass will be made airborne or allowed to contact skin or eyes.

(g) Monitoring and Recordkeeping Requirements

Compliance with the recommended standard requires determination of employee exposures. Exposures to fibrous glass can be determined by taking samples in employees' breathing zones. The major concerns with fibrous glass are the long-term effects from exposures. Records of employees' exposures shall be kept for 30 years after the last occupational exposure so that any chronic health effects that appear may be correlated with exposure information.

VI. WORK PRACTICES

(a) General

Since there are many thousands of uses for fibrous glass, a discussion of work practices must be limited to a consideration of general principles; however, work practices for some specific types of operations involving fibrous glass are discussed in Appendix VI. In a majority of uses of fibrous glass, other possibly more hazardous materials are also involved. In such cases, the work practices are primarily aimed at controlling the greater hazard. Generally, the principles involved are similar for most hazardous substances and basically involve following fundamental industrial hygiene practices. Industries, alone or in cooperation with trades, that work with fibrous glass should be required to develop their own specific codes of work practices. The National Insulation Manufacturers Association has published its recommended health practices for handling and applying thermal insulation products containing mineral fibers [107]. Many of its recommendations are also applicable to other uses of fibrous glass products.

(b) Personal Hygiene

With fibrous glass and many of the plastics with which it is used, the observance of good personal hygiene is of primary importance if dermatologic problems are to be avoided or minimized. Conveniently located hand washing facilities should be provided and employees should be instructed as to the importance of their proper use [24,33]. In addition, exposed workers should shower at the end of the work shift before changing into street clothes.

Special consideration should be given to the laundering of work clothes exposed to fibrous glass. Contamination of other clothes that come in contact with work clothes in laundry machines has been observed [25,33]. In operations where clothes are laundered under contract, it is important to inform contractors of the hazards of laundering clothes contaminated with fibrous glass.

Glass fibers larger than about 5 μm in diameter have been found to cause skin irritation in experimental situations but this was not found with smaller diameter fibers [27].

Most skin problems arise from direct contact with fibrous glass through handling rather than from airborne fibers or dust. Decisions on whether to use gloves or other protective clothing will depend on the nature of the work as well as the nature of the materials involved [21]. Where the exposure is limited to fibrous glass, experience has generally demonstrated that the use of gloves is not always indicated. Some workers regularly exposed to fibrous glass seem to become toughened to the fibers and may not need to wear gloves. Those with only intermittent exposures may not become "hardened" to the fibers. For intermittent jobs such as tear-out of insulation materials, gloves and also general skin protective clothing should be worn.

(c) Housekeeping

Good housekeeping practices are essential for minimizing exposures to fibrous glass [21,107]. Vacuum cleaning, washdown procedures, and wet sweeping should be used where practical to control or reduce airborne concentrations of fibrous glass dust. Dry sweeping or the use of compressed air to remove dust should be prohibited. Scrap materials and

debris should not be allowed to accumulate. Waste materials should be placed in suitable, covered storage containers located as close as possible to the point of origin of the waste. Disposal should be by methods which will ensure that fibrous glass will not disperse into the atmosphere.

The feasibility of engineering control methods such as dilution or exhaust ventilation and enclosure will vary, depending on whether operations are being performed at fixed locations or in the field, including construction sites. As indicated earlier, most uses of fibrous glass are likely to also involve other potentially hazardous substances such as resins, solvents, and plasticizers. Information on many of the substances used in conjunction with fibrous glass may be found in the NIOSH publication Fiberglass Layup and Sprayup--Good Practices For Employees, published in April 1976 [108].

(d) Respiratory Protective Devices

Respiratory protective devices are not needed for fibrous glass exposures below the recommended environmental limit. For situations where airborne concentrations may exceed the limits recommended, respirators approved by NIOSH or the Mining Enforcement and Safety Administration (MESA) under provisions of 30 CFR 11, may be used but not as a substitute for feasible engineering controls. Whenever respirators are used, a respirator program conforming to the requirements of the occupational safety and health standards for respiratory protection, 29 CFR 1910.134, should be followed. Respirators may be needed on such potentially dusty work as tear-out and blowing operations in confined spaces [40]. When feasible, exhaust ventilation of the enclosure should be used to provide general room air changes and limit the need for wearing respirators. The

air must not be exhausted into other work areas. Respirators are not recommended to be used as primary control measures in lieu of appropriate environmental engineering controls during routine, ongoing operations.

(e) Eye Protection

Eye protection, consisting of safety goggles or face shields and goggles are recommended for use in work necessitating tear-out, blowing, or at any time when there is the likelihood of getting large quantities of airborne fibrous glass in the eyes, such as when applying insulation overhead [36,105].

VII. RESEARCH NEEDS

Little is known about the fate and health hazards of inhaled fibrous glass of small diameters. Since glass fibers measuring less than 3.5 μm in diameter are relatively new in commercial products, exposed groups have not been identified from epidemiologic data. A need exists for studies of the effects of small-diameter fibrous glass (less than 3.5 μm and especially less than 1 μm on specific cohorts over long periods of time. An epidemiologic study on the mortality experience of 12,000 workers, sponsored by the Thermal Insulation Manufacturers Association (TIMA), is now in progress on occupational exposures to manufactured (manmade) mineral fibers including fibrous glass. The study, consisting of 3 groups of workers, is scheduled to be completed in phases between June 1977 and May 1978. Although these groups have been exposed primarily to fibers greater than 1 to 3.5 μm in diameter, they also have been exposed to fibers less than 1 μm. Also, the exposures are claimed to have been for a sufficient period of time to hopefully answer questions concerning the demonstrated latent period observed for many occupational carcinogens. Further research involving retrospective and prospective epidemiologic studies of other populations exposed predominantly to fibers less than 1 μm in diameter is desirable.

Another current study, also sponsored by TIMA, may give better insights on environmental concentrations, fiber characterizations, and durations of exposure. This information should aid in correlation of industrial hygiene data with epidemiologic data to determine the presence of dose-response relationships.

Questions remain concerning the effects of fibrous glass larger than 3.5 μm in diameter. The observation that an inordinate number of cases (6) of bronchiectasis were present among the deaths reported by Bayliss et al [55] out of a total of 25 deaths due to nonmalignant respiratory disease among workers with fibrous glass, needs confirmation and demonstration of the pathogenic role of glass fibers, if possible. A case-control pairing would be an adequate design for the study of bronchiectasis which is rarely reported independently as an entity in US vital statistics. A case-control study should include consideration of exposure concentrations, fiber size, and duration of employment. Cases of bronchiectasis should be matched on a variety of dependent variables; this would involve using many controls for each case.

Environmental data exist for large manufacturing and production operations involving fibrous glass; however, little data are available, but research recently initiated may meet the need to detail exposures that may occur in small shops, tear-out of insulation on renovation or demolition jobs, or for other "on location" situations. Such exposures should be characterized so that appropriate work practices and control procedures may be recommended for the future. More information is needed on the exact extent of exposures to fibrous glass with diameters less than 3.5 μm.

There is a need for continued testing and development of analytic methods for fibrous glass so that precision and accuracy may be determined. The development of other more rapid and efficient methods of analysis would be useful.

A need exists for a variety of animal studies involving fibrous glass, especially long-term investigations of chronic effects of fibers of

varying dimensions. Studies are needed on the mechanism of fibrogenesis and carcinogenesis with fibrous material. Such studies should address entry and biologic availability of fibrous material in the occupational environment with due regard for host defense mechanisms, species differences in response, and considerations of dose-response and no-effect levels. Inhalation studies of glass fibers using guinea pigs would be especially useful to enable comparisons with existing findings from intratracheal instillations in these animals [61,64]. Information is also lacking on the fate of inhaled glass fibers. TIMA indicates that a two-phase activity is in process for preparation of sample materials for exposure experiments and identification of available inhalation facilities and scientific and technical expertise. Elucidation of possible clearance and translocation mechanisms is needed. These types of studies would serve as a basis for the evaluation of the recommended environmental limit.

The International Agency for Research on Cancer is currently investigating the health risks from occupational exposure during production of manufactured mineral fibers throughout Western Europe. In addition, the use of neutron-activated fibrous materials is being studied for anatomic and metabolic fate at the Atomic Energy Research Establishment (AERE) in the United Kingdom along with studies which are under consideration by the Pneumoconiosis Research Unit in Cardiff, Wales, on the bioassay of inhaled, defined fibrous particles.

A further question needing clarification is the physical fate of manufactured (manmade) mineral fibers, with emphasis on splitting, fragmentation, solubility, and the relation of these properties to tissue effects.

The above description of research needs evidences the insufficiency of data with regard to the potential health effects of long, thin fibers, especially those smaller than about 1 μm in diameter. Current research attempting to satisfy these research needs may fill a considerable part of the gap within a few years.

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IX. APPENDIX I

AIR SAMPLING METHOD - MEMBRANE FILTER

General Requirements

The following sampling and anlytical methods for fiber counting are adapted from the NIOSH membrane filter method for evaluating airborne asbestos fibers [90].

(a) Air samples representative of the breathing zones of workers must be collected to characterize the exposure from each job or specific operation in each work area.

(b) Samples collected shall be representative of the exposure of individual workers.

(c) Suggested records:

(1) The date and time of sample collection.

(2) Sampling duration.

(3) Total sample volume.

(4) Location of sampling.

(6) Other pertinent information.

Sampling

(a) Samples shall be collected so as to be representative of the breathing zones of workers without interfering with their freedom of movement.

(b) Samples shall be collected to permit determination of TWA exposures for every job involving exposure to fibrous glass in sufficient

numbers to determine the variability of exposures in the work situation.

(c) Equipment

The sampling train consists of a membrane filter and a vacuum pump.

(1) Membrane filter: Samples of fibrous glass are collected in the breathing zones of the workers using a personal sampler with cellulose ester membrane filter. The filter is a 0.8-μm pore size mixed cellulose ester membrane mounted in a open-face sampling cassette which can be attached to the worker near his or her breathing zone.

(2) Pump: A battery-operated pump, complete with clip for attachment to the worker's belt, capable of operation at 2.5 liters/minute or less.

(d) Calibration

The personal sampling pump should be recharged prior to calibration and then calibrated against a bubble meter, wet test meter, spirometer, or similar device at a flowrate of 1.0 to 2.5 liters/minute. The sampling train used in the calibration (pump, hose, filter) shall be equivalent to the one used in the field. The calibration should be performed to an accuracy of $\pm$ 5%.

(e) Sampling Procedure

(1) Sampling is performed using an open-face membrane filter cassette.

(2) The sampler shall be operated at a flowrate between 1.5 and 2 liters/minute.

(3) The temperature and pressure of the atmosphere being sampled are measured and recorded.

(4) One membrane filter is treated in the same manner as the sample filters with the exception that no air is drawn through it. This filter serves as a blank.

(5) Immediately after sampling, personal filter samples should be sealed in individual plastic filter holders for shipment. The filters shall not be loaded to the point where portions of the sample might be dislodged from the collecting filter during handling.

(f) Optimum Sampling Times

A requirement for a minimum count of 100 fibers or 20 fields has been determined to be the optimum choice to achieve low variability of the fiber count (as approximated by a Poisson distribution) and reduced counting times. In other words, the optimum fiber density on the filter should be 1 to 5 fibers/microscope counting field. To estimate optimum sampling times, the approximate field area of the counting scope and the pump flowrate must be known in advance.

The following equation is used to calculate the range of optimum sampling times which can then be plotted on log-log paper:

$$\text{Minutes} = \frac{(FB/FL)(ECA/MFA)}{(FR)(AC)}$$

where: FB/FL = 1 to 5 fibers/field

ECA = Effective collecting area of filter in square millimeters (855 square mm for 37-mm filter)

MFA = Microscope field area in mm (generally 0.003 to 0.006 square mm)

FR = Pump flowrate in cc/minute

AC = Air concentration of fibers in fibers/cc

(NOTE: If air concentrations are expressed in fibers/cu m they must be changed to fibers/cc for this equation.)

X. APPENDIX II

ANALYTICAL METHOD - FIBER COUNT

Principle of the Method

(a) Environmental dust samples are collected by drawing air through a membrane filter by means of a battery-powered personal sampling pump.

(b) The filter is transformed from an opaque solid membrane to a transparent, optically homogeneous gel.

(c) The fibers are sized and counted by phase-contrast microscopy at 400-450X magnification.

Range and Sensitivity

(a) This method has been successfully applied at concentrations of 10,000 to 20,000,000 fibers/cu m (0.01 to 20 fibers/cc) for fibers longer than 5 μm. Large deviations from the specified conditions of the method may result in filters with either too few or too many fibers. Too few fibers will yield air concentration estimates of low statistical precision.

(b) A sensitivity of 10,000 fibers/cu m (0.01 fiber/cc) has been reported [JM Dement, written communication, 1975] based on a 4-hour sample at 2 liters/minute air flow.

Interferences

All particulates, such as asbestos or mineral wool, with a length-to-width ratio of 3 to 1 or greater, and length greater than 10 μm should, in

the absence of other information, be considered as glass fibers and counted as such. Asbestos interference can be eliminated using phase contrast, polarized light microscopy.

Advantages of the Method

(a) The fiber count method allows for repeated counts, and storage for counting at a later time. The method consumes only part of the filter, thereby allowing for at least one replicate sample analysis at a later time.

(b) Fiber counts are assumed to be more toxicologically significant than fiber weight for fibers less than 3.5 μm in diameter.

(c) Fiber size determinations may be performed.

Disadvantages of the Method

(a) The fiber count method is slow and tedious.

(b) Variation in counts may be significant between different observers.

(c) The sensitivity of the method is dependent on the sampling time and flowrate. The sensitivity and useful range of this method has not been determined specifically for fibrous glass but is based on the method recommended for asbestos.

Apparatus

(a) Optical Equipment

(1) Microscope body with binocular head, 10X Huygenian

eyepieces, and Koehler illumination.

(2) Porton reticle.

(3) Mechanical stage, and stage micrometer with 0.01-mm subdivisions.

(4) Abbe or Zernike condenser fitted with phase ring with a numerical aperture equal to or greater than the numerical aperture of the objective.

(5) A phase-ring centering telescope or Bertrand lens and a green filter if recommended by the microscope manufacturer.

(6) Fiber mounting equipment

(A) Microscope slides, and cover slips, usually 0.17 mm thick.

(B) Scalpel, tweezers, lens tissues, and glass rod or spatula for mounting procedures.

(b) Wheaton Balsam Bottle.

Reagents

(a) Dimethyl phthalate.

(b) Diethyl oxalate.

Analysis of Samples

(a) Calibration and Standardization

(1) Porton Reticle and the Counting Field

The fiber count procedure consists of comparing fiber length with calibrated circles, and counting all fibers > 10 μm in length within a

given counting field. A Porton reticle is used for this purpose. The Porton reticle is a glass plate inscribed with a series of circles and rectangles. The square on the left, divided into six rectangles, is defined as the counting field.

(2) Placement in Eyepiece

Place the Porton reticle inside one Huygenian eyepiece, resting it on the field-limiting diaphragm. Keep the reticle clean, since dirt on the reticle will be in focus and will complicate the counting and sizing process.

(3) Stage Micrometer

The Porton reticle cannot be used for counting until it has been properly calibrated with a stage micrometer. Most stage micrometer scales are approximately 2 mm long, divided into units of 10 μm.

(4) Microscope Adjustment

When adjusting the microscope, follow the manufacturer's instructions while observing the following guidelines.

(A) The light source image must be in focus and centered on the condenser iris or annular diaphragm.

(B) The object for examination must be in focus.

(C) The illuminator field iris must be in focus, centered on the sample, and opened only to the point where the field of view is illuminated.

(D) The phase rings (annular diaphragm and phase-shifting elements) must be concentric.

(5) Porton Reticle Calibration Procedure

Each eyepiece-objective-reticle combination on the microscope must be calibrated. Should any of the three be changed (disassembly, replacement, zoom adjustment, etc) the combination must be recalibrated. Calibration may change if the interpupillary distance is changed. For proper calibration, the following procedure should be followed closely.

Using a 10X objective, place the stage micrometer on the mechanical stage and focus and center the image. Change to the 40-45X objective and adjust the first scale division to coincide with the left boundary of the Porton rectangle. Count the number of divisions between the left and right boundaries of the long horizontal dimension of the largest rectangle, estimating any portion of the final division. This measurement represents 200 L units and the measurement is then divided by 200 to find "L." The large rectangle is 100 L units long on the short vertical dimension. The calculated "L" is inserted into the formula $D = L(2N)1/2$ where "N" is the circle number (indicated on the reticle) and "D" is the circle diameter. Since the circle diameters vary logarithmically, every other circle doubles in diameter. For example, number three is twice the diameter of number one; number four is twice the counting field area consisting of the left six smaller rectangles can be calculated from the relation 10,000 L. The reticle calibration is now completed for this specific objective-eyepiece-recticle combination.

(b) Preparation of Mounting Solution

An important part of the sample evaluation is the mounting process which involves a special mounting medium of prescribed viscosity. The proper viscosity is important to expedite filter clearing and to minimize particle migration. Once the sample has been mounted, an elapsed time of

approximately 15 minutes is needed before the sample is ready for evaluation.

Combine the dimethyl phthalate and diethyl oxalate in a 1 to 1 ratio by volume and pour the solution into a Wheaton balsam bottle. Add 0.05 gram of new membrane filter/ml of solution to reach the necessary viscosity. The mixture must be stirred periodically until the filter material is dissolved and a homogeneous mixture is formed. The normal shelf life of the mounting solution is about 6 months. Approximately 300 samples can be prepared from 20 ml of mounting solution.

(c) Sample Mounting

Cleanliness is important. The working area must be kept clean to prevent sample contamination and erroneous counts. The following steps should be followed when mounting a sample.

(1) Clean the slides and cover slips with lens tissue. Lay the slide down on a clean surface with the frosted end up. It is good practice to rest one edge of the cover slip on the slide and the other edge on the working surface. By doing this, you keep from becoming contaminated.

(2) Wipe all the mounting tools clean with lens tissue and place them on a clean surface (such as lens tissue). When mounting a series of filters, wipe the scalpel clean before cutting a sector of each sample [see (5) below].

(3) Apply a small drop of mounting solution onto the center of the slide with a glass rod. It may be necessary to adjust the quantity of solution used or the size of the wedge. The correct amount will result in the solution extending only slightly beyond the filter boundary. If the

quantity is greater than this, adverse particle migration may occur.

(4) With a spatula or a supplemental glass rod, spread the mounting media into a triangular shape. The size of this triangle should coincide with the dimension of the filter wedge.

(5) Separate the middle and bottom sections of the field monitor case to expose the fragile filter. Cut a triangular wedge from the center to the edge of the filter using a scalpel. The size of the wedge should approximate one-eighth of the filter surface. The filter should be handled gently so that no material will be lost.

Grasp the filter wedge with tweezers on the outer area of the filter which was clamped between the monitor case sections. Do not touch the filter with fingers. Place the wedge, fiber-bearing side up, upon the mounting medium.

(7) Lift the cover slip with the tweezers and carefully place it on the filter wedge. Once this contact has been made, do not reposition the cover slip.

(8) Label the slide with the sample number and current date before proceeding to the next filter.

(9) The sample should become transparent after about 15 minutes. If the filter appears cloudy, it may be necessary to press very lightly on the cover slip. This is rarely necessary, however.

(10) Examine the slide within 3 days. The sample mount should be discarded after 3 days if it has not been counted because crystals which appear similar to glass fibers may begin to grow at the mounting media/air interfaces; they seldom present any problems if the slide is examined within 3 days. In any case, do not perform counting or

sizing around the edges of the filter.

(d) Counting and Sizing--Finding and Inspecting Counting Fields

Place the slide on the mechanical stage and position the center of the wedge under the objective lens and focus upon the sample. Nearly all of the particulates (particles and fibers) will be found in the upper 10-15 μm of the filter surface. When counting and sizing, continued use of the fine focus control is required to insure that nothing is missed. Start counting from one end of the wedge and progress along a straight line to the other end (count in either direction from circumference to wedge tip). Haphazard fields are selected without looking into the eyepieces by slightly advancing the slide in one direction with the mechanical stage control.

(e) Achieving Comparable Results

(1) Size only those fibers with a length-to-width ratio equal to or greater than 3:1.

(2) Count only fibers greater than 10 μm in length. (Be as accurate as possible in accepting or rejecting fibers near this length).

(3) Count up to 100 fields if necessary to yield a total count of at least 100 fibers. Count at least 20 fields even if more than 100 fibers are counted.

(4) Select the field of view without looking through the microscope's eyepieces to minimize unconsciously selecting "heavy" or "light" areas.

(5) The fields are selected along the entire length of a radial line running between the outside perimeter and the tip of the wedge.

(6) When an agglomerate (mass of material) covers a significant portion of the field of view (approximately 1/6 or greater), reject the field and select another. (Do not include this field in the number of fields counted.) Record the agglomerated field even though it is not included in the count.

(7) Bundles of fibers are counted as one fiber unless both ends of a fiber crossing another can be clearly resolved.

(8) For fibers that cross either one or two sides of the counting field, the following procedure is used to obtain a representative count. First, arbitrarily select: a) the left and bottom sides, and b) the upper and lower left corners and vertical direction as "decision aids."

Then count any fiber greater than 10 micrometers in length, but only if the fiber:

a. lies entirely within the counting area, or

b. crosses the left or bottom sides, or

c. crosses the upper or lower left corners, or

d. crosses both the top and bottom sides.

Reject and do not count all other fibers.

Calculations of Airborne Concentrations

Glass fiber airborne concentration may be calculated from the following formula:

$$C = \frac{(F-B)(W)}{(A)(V)}$$

where:

C = Airborne fiber concentrations in fibers >10 μm/cu m.

F = Average fiber count in fibers >10 μm/field.

B = Average fiber count of blank(s) or control filter(s) in fibers >10 μm/field. (It is subtracted to eliminate the error or background contamination.)

W = 855 square mm for 37-mm diameter filters (the portion of the membrane filter which is exposed when mounted in the field monitor case, ie, the effective filter area).

A = The area of the counting field of a calibrated reticle expressed in square mm/field.

V = Total air volume collected through filter expressed in milliliters.

XI. APPENDIX III

AIR SAMPLING METHOD - TARED FILTER

Sampling

Breathing zone samples of the total airborne material are collected on a tared 37-mm filter of 0.8-μm pore size, low ash, polyvinyl chloride, mounted in a filter holder with a 4-mm opening. The sample is collected for a 30-minute period at a sampling rate of 2 liters/minute. A personal sampling technique is employed, with the sampler head fastened to the worker's clothing in the breathing zone. Battery-powered personal sampler pumps, such as those used in the sampling train of the Coal Mine Dust Personal Sampling Units, approved under the provisions of 30 CFR 74 or their equivalent are used to draw air through the filters.

Calibration of Personal Sampler

The accuracy of environmental monitoring can be no greater than the accuracy of the volume of air which is measured. Therefore, the accurate calibration of a sampling device is essential to the correct interpretation of an instrument's indication. The frequency of calibration is dependent on the use, care, and handling of the pump. Pumps should also be recalibrated if they have been misused or if they have just been repaired or received from a manufacturer. If the pump receives hard usage, more frequent calibration may be necessary. Regardless of use, maintenance and calibration should be performed on a regular schedule and records of these should be kept.

Ordinarily, pumps should be calibrated in the laboratory. The accuracy of calibration is dependent on the type of instrument used as a reference. The choice of calibration instrument will depend largely upon where the calibration is to be performed. For laboratory testing, primary standards, such as a spirometer or a soapbubble meter, are recommended, although other standard calibration instruments, such as a wet-test meter or dry gas meter, can be used. The actual setups will be similar for all instruments.

Instructions for calibration with the soapbubble meter follow. If another calibration device is selected, equivalent procedures should be used. Since the flowrate given by a pump is dependent on the pressure drop of the sampling device, in this case a filter, the pump must be calibrated while operating with a representative filter in line. The calibration system should be assembled in this order: soapbubble meter, water manometer, filter, and pump.

(a) Check the voltage of the pump battery with a voltmeter to ensure adequate voltage for calibration and charge the battery if necessary.

(b) Turn on the pump and moisten the inside of the soapbubble meter by immersing the buret in the soap solution and drawing bubbles up the inside until they travel the entire buret length without bursting.

(c) Adjust the pump rotameter to provide the desired flowrate.

(d) Check the water manometer to ensure that the pressure drop across the sampling train does not exceed 13 inches of water at 1 liter/minute.

(e) Start a soapbubble up the buret and measure with a stopwatch the time required for it to move between calibration marks.

(f) Repeat the procedure in (e) above at least twice, average the results, and calculate the flowrate from the volume between the preselected marks divided by the time required for the soapbubble to traverse the distance.

(g) Record the volume measured, elapse time, pressure drop, air temperature, atmospheric pressure, serial number of the pump, the date, time, and name of the person performing the calibration.

(h) The rotameter reading should be corrected for temperature and pressure, if necessary.

XII. APPENDIX IV

ANALYTICAL METHOD - GRAVIMETRIC ANALYSIS

Principle of the Method

A known volume of air is drawn through a tared polyvinyl chloride filter to collect fibrous glass.

The sample-containing filter is removed from the cassette and dried over a desiccant to constant weight and weighed using a suitable microbalance. If the desiccated sample and filter exceeds the weight of the filter by more than 5 mg then the sample and filter is ashed in a platinum crucible. The crucible is heated to a constant weight and weighed using a microbalance.

Range and Sensitivity

Although this method has not been validated for fibrous glass, it has been validated for other substances, such as carbon black, that have a recommended environmental limit similar to fibrous glass. This method for fibrous glass has been validated for carbon black over the range of 1.86-7.7 mg/cu m at an atmospheric temperature and pressure range of 18-25 C and 749-761 mm Hg, using a 200-liter sample. Under the conditions of sample size (200 liters), the working range of the method is estimated to be 1.5-10 mg/cu m or a 0.3-2 mg total weight of material collected on the filter. It was also validated for a 100-liter sample over the range of 7.8-27.7 mg/cu m at atmospheric temperature and pressure conditons as above.

The method may be extended to higher sample concentrations by collecting a smaller sample volume; however, no more than 1.5 to 2 mg of material should be collected on any filter because greater amounts will be lost due to flaking.

Interferences

The presence of any other particulate material in the air being sampled will be a positive interference since this is a gravimetric method. Those materials that volatilize or combust at 600 C or less will not be interferences.

Information on any other particulate materials present should be solicited. If the concentration of other particles is known, then the fibrous glass concentration can be determined by the difference. If other particulate matter is known to be present and its concentration cannot be determined, then this method will not provide a limited measure of the fibrous glass concentration.

Precision and Accuracy

The precision and accuracy of the total sampling and analytical method has not been determined specifically for fibrous glass; however, it has been determined for other substances, such as carbon black, with a similar recommended limit. For carbon black, the coefficient of variation for the total analytical and sampling method in the range of 1.86-7.7 mg/cu m was 0.056. This value corresponds to a 0.20 mg/cu m standard deviation at the Occupational Safety and Health Administration (OSHA) carbon black

standard level. A collection efficiency of greater than 98.7% was determined for the collection medium at the 2X level; thus, no bias was introduced in the sample collection step. Likewise, no significant bias in the analytical method is expected other than normal gravimetric errors. The coefficient of variation is a satisfactory measure of both accuracy and precision of the sampling and analytical method.

Advantages and Disadvantages of the Method

The analysis is simple but the method is nonspecific and subject to interference due to presence of other nonvolatile or combustible particulates in the air being sampled.

Apparatus

(a) Sampling Equipment

The sampling unit for the collection of personal air samples for the determination of fibrous glass has the following components:

(1) The filter unit, consisting of the filter media, cellulose supported pad and 37-mm three-piece cassette filter holder.

(2) Personal sampling pump: A calibrated personal sampling pump whose flow can be determined to an accuracy of $\pm$5% at the recommended flowrate. The pump must be calibrated with a filter holder and filter in the line.

(3) Thermometer.

(4) Manometer.

(5) Stopwatch.

(b) Polyvinyl chloride membrane filter; 37-mm diameter, 0.8-micrometer pore size.

(c) Plastic Petri dish-filter holder or equivalent for storage and weighing.

(d) Desiccator.

(e) Platinum Crucible.

(f) Platinum-tipped or Nichrome Forceps.

(g) Platinum or Silica Triangles.

(h) Microbalance capable of weighing to 10 micrograms. Particular care must be given to proper zeroing of the balance. The same balance should be used for weighing filters before and after sample collection.

Reagents

Drierite or any other suitable desiccant.

Analysis of Samples

(a) Preparation of Filters

All filters must be dried and weighed prior to use.

(b) Sampling Requirements and Shipping of Samples

(1) To collect fibrous glass, a personal sampler pump is used to pull air through a polyvinyl chloride membrane filter. The filter holder is held together by tape or a shrinkable band. If the filter holder is not tightened snugly, the contaminant will leak around the filter. A piece of flexible tubing is used to connect the filter holder to the pump. Sample at a flowrate of 1.5 to 2 liters per minute. After sampling,

replace small plugs to seal filter cassettes.

(2) Blank

With each batch of ten samples submit one filter from the same lot of filters which was used sample collection to exactly the same handling as the samples except that no air is drawn through it. Label this as a blank.

(3) Shipping

The filter cassettes should be shipped in a suitable container designed to prevent damage in transit.

(c) Analysis of Samples

(1) If the outer surface of the cassette filter holder is heavily coated with dust, carefully swab the outer surface with a moist paper towel before opening the cassette so as to minimize sample contamination. Discard paper towel.

(2) Open the cassette filter holder and carefully remove the polyvinyl chloride membrane filter from the holder and cellulose support pad with the aid of filter tweezers. Transfer filter to a filter holder.

(3) Dry the filter to constant weight in a desiccator containing a dessicant. This takes about 12 hours.

(4) Weigh the filter using a microbalance. If the weight of filter contents exceeds 5 mg then put filter and contents in a clean, dried, and tared crucible.

(5) Put the crucible in a muffle furnace and ash at 600 C to constant weight. When handling the platinum crucible platinum-tipped or nichrome forceps should be used. If it is necessary to hold or stabilize

the crucible platinum or silica triangles should be used. Iron forceps should never be used for crucibles that are above 500 C because iron will alloy with platinum. Very hot crucibles should not be put into the desiccator. The crucible should be allowed to cool in the air until the temperature has fallen below 100 C. Then it may be placed in the desiccator.

(6) Weigh the crucible using a microbalance.

Calibration and Standards

The microbalance should be properly zeroed for all weighings and preferably the same microbalance should be used for weighing filters before and after sample collection. The balance should be maintained and calibrated with National Bureau of Standards (NBS) Class M weights.

Calculations

(a) Record the tare weight, in μg, of the dry filter before sampling.

(b) Record the weight, in μg, of the dried, sample-containing filter.

(c) The difference between these two weights represents the μg of sample.

(d) Corrections for the blank must be made for each sample. (If found to be necessary, corrections should also be made for other particulate matter.)

μg sample = μg found in sample filter

μg blank = μg found in blank filter

(e) The concentration of the analyte in the air sampled can be expressed in mg per cu m (μg/liter = mg/cu m) by the following equation:

$$\text{mg/cu m} = \frac{\mu\text{g found (section (d))}}{\text{Vs}}$$

Vs = Volume of air in liters at 25 C and 760 mm Hg

(f) If the ashing procedure is to be performed record the tare weight, to the nearest μg, of the dry crucible before adding the filter.

(g) Record the weight, to the nearest μg, of the crucible and contents after the sample-containing filter has been ashed.

(h) The difference between these two weights represents the μg of sample.

(i) Corrections for the ashed blank filter must be made for each sample.

XIII. APPENDIX V

MATERIAL SAFETY DATA SHEET

(a) Section I. Product Identification

The manufacturer's name, address, and regular and emergency telephone numbers (including area code) are inserted in the appropriate blocks of Section I. The company listed should be a source of detailed backup information on the hazards of the material(s) covered by the MSDS. The listing of suppliers or wholesale distributors is discouraged. The trade name should be the product designation or common name associated with the material. The synonyms are those commonly used for the product, especially formal chemical nomenclature. Every known chemical designation or competitor's trade name need not be listed.

(b) Section II. Hazardous Ingredients

The "materials" listed in Section II shall be those substances which are part of the hazardous product covered by the MSDS and individually meet any of the criteria defining a hazardous material. Thus, one component of a multicomponent product might be listed because of its toxicity, another component because of its flammability, while a third component could be included both for its toxicity and its reactivity. Note that a MSDS for a single component product must have the name of the material repeated in this section to avoid giving the impression that there are no hazardous ingredients.

Chemical substances should be listed according to their complete name derived from a recognized system of nomenclature. Where possible, avoid using common names and general class names such as "aromatic amine,"

"safety solvent," or "aliphatic hydrocarbon" when the specific name is known.

The "%" may be the approximate percentage by weight or volume (indicate basis) which each hazardous ingredient of the mixture bears to the whole mixture. This may be indicated as a range or maximum amount, ie, "10-40% vol" or "10% max wt" to avoid disclosure of trade secrets.

Toxic hazard data shall be stated in terms of concentration, mode of exposure or test, and animal used, ie, "100 ppm LC50 rat," "25 mg/kg LD50-skin-rabbit," "75 ppm LC man," or "permissible exposure from 29 CFR 1910.1000," or, if not available, from other sources of publications such as the American Conference of Governmental Industrial Hygienists or the American National Standards Institute Inc. Flammable or reactive data could be flash point, shock sensitivity, or other brief data indicating nature of the hazard.

(c) Section III. Physical Data

The data in Section III should be for the total mixture and should include the boiling point and melting point in degrees Fahrenheit (Celsius in parentheses); vapor pressure, in conventional millimeters of mercury (mm Hg); vapor density of gas or vapor (air = 1); solubility in water, in parts/hundred parts of water by weight; specific gravity (water = 1); percent volatiles (indicate if by weight or volume) at 70 degrees Fahrenheit (21.1 degrees Celsius); evaporation rate for liquids or sublimable solids, relative to butyl acetate; and appearance and odor. These data are useful for the control of toxic substances. Boiling point, vapor density, percent volatiles, vapor pressure, and evaporation are useful for designing proper ventilation equipment. This information is

also useful for design and deployment of adequate fire and spill containment equipment. The appearance and odor may facilitate identification of substances stored in improperly marked containers, or when spilled.

(d) Section IV. Fire and Explosion Data

Section IV should contain complete fire and explosion data for the product, including flash point and autoignition temperature in degrees Fahrenheit (Celsius in parentheses); flammable limits, in percent by volume in air; suitable extinguishing media or materials; special firefighting procedures; and unusual fire and explosion hazard information. If the product presents no fire hazard, insert "NO FIRE HAZARD" on the line labeled "Extinguishing Media."

(e) Section V. Health Hazard Information

The "Health Hazard Data" should be a combined estimate of the hazard of the total product. This can be expressed as a time-weighted average (TWA) concentration, as a permissible exposure, or by some other indication of an acceptable limit. Other data are acceptable, such as lowest LD50 if multiple components are involved.

Under "Routes of Exposure," comments in each category should reflect the potential hazard from absorption by the route in question. Comments should indicate the severity of the effect and the basis for the statement if possible. The basis might be animal studies, analogy with similar products, or human experiences. Comments such as "yes" or "possible" are not helpful. Typical comments might be:

> Skin Contact--single short contact, no adverse effects likely; prolonged or repeated contact, irritation, and cracking. Readily absorbed through the skin with severe systemic effects.

Eye Contact--some pain and mild transient irritation; no corneal scarring.

"Emergency and First Aid Procedures" should be written in lay language and should primarily represent first aid treatment that could be provided by paramedical personnel or individuals trained in first aid.

Information in the "Notes to Physician" section should include any special medical information which would be of assistance to an attending physician including required or recommended preplacement and periodic medical examinations, diagnostic procedures, and medical management of overexposed workers.

(f) Section VI. Reactivity Data

The comments in Section VI relate to safe storage and handling of hazardous, unstable substances. It is particularly important to highlight instability or incompatibility to common substances or circumstances such as water, direct sunlight, steel or copper piping, acids, alkalies, etc. "Hazardous Decomposition Products" shall include those products released under fire conditions. It must also include dangerous products produced by aging, such as peroxides in the case of some ethers. Where applicable, shelf life should also be indicated.

(g) Section VII. Spill or Leak Procedures

Detailed procedures for cleanup and disposal should be listed with emphasis on precautions to be taken to protect workers assigned to cleanup detail. Specific neutralizing chemicals or procedures should be described in detail. Disposal methods should be explicit including proper labeling of containers holding residues and ultimate disposal methods such as

"sanitary landfill," or "incineration." Warnings such as "comply with local, state, and federal anti-pollution ordinances" are proper but not sufficient. Specific procedures should be identified.

(h) Section VIII. Special Protection Information

Section VIII requires specific information. Statements such as "Yes," "No," or "If Necessary" are not informative. Ventilation requirements should be specific as to type and preferred methods. Specify respirators as to type and NIOSH or US Bureau of Mines approval class, ie, "Supplied-air," "Organic vapor canister," "Suitable for dusts not more toxic than lead," etc. Protective equipment must be specified as to type and materials of construction.

(i) Section IX. Special Precautions

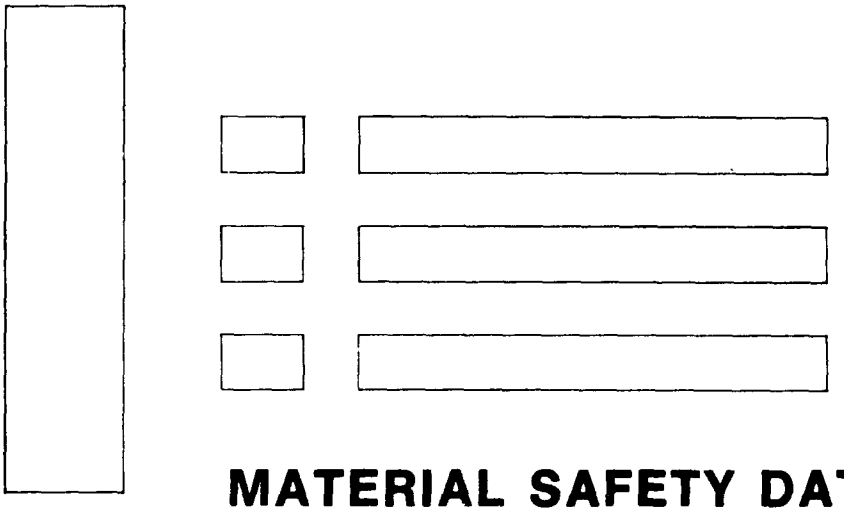
"Precautionary Statements" shall consist of the label statements selected for use on the container or placard. Additional information on any aspect of safety or health not covered in other sections should be inserted in Section IX. The lower block can contain references to published guides or in-house procedures for handling and storage. Department of Transportation markings and classifications and other freight, handling, or storage requirements and environmental controls can be noted.

(j) Signature and Filing

Finally, the name and address of the responsible person who completed the MSDS and the date of completion are entered. This will facilitate correction of errors and identify a source of additional information.

The MSDS shall be filed in a location readily accessible to workers potentially exposed to the hazardous material. The MSDS can be used as a

training aid and basis for discussion during safety meetings and training of new employees. It should assist management by directing attention to the need for specific control engineering, work practices, and protective measures to ensure safe handling and use of the material. It will aid the safety and health staff in planning a safe and healthful work environment and in suggesting appropriate emergency procedures and sources of help in the event of harmful exposure of employees.



MATERIAL SAFETY DATA SHEET

I PRODUCT IDENTIFICATION	
MANUFACTURER'S NAME	REGULAR TELEPHONE NO. EMERGENCY TELEPHONE NO.
ADDRESS	
TRADE NAME	
SYNONYMS	

II HAZARDOUS INGREDIENTS		
MATERIAL OR COMPONENT	%	HAZARD DATA

III PHYSICAL DATA			
BOILING POINT, 760 MM HG		MELTING POINT	
SPECIFIC GRAVITY (H_2O=1)		VAPOR PRESSURE	
VAPOR DENSITY (AIR=1)		SOLUBILITY IN H_2O, % BY WT	
% VOLATILES BY VOL		EVAPORATION RATE (BUTYL ACETATE=1)	
APPEARANCE AND ODOR			

IV FIRE AND EXPLOSION DATA

FLASH POINT (TEST METHOD)		AUTOIGNITION TEMPERATURE	
FLAMMABLE LIMITS IN AIR, % BY VOL.	LOWER		UPPER
EXTINGUISHING MEDIA			
SPECIAL FIRE FIGHTING PROCEDURES			
UNUSUAL FIRE AND EXPLOSION HAZARD			

V HEALTH HAZARD INFORMATION

HEALTH HAZARD DATA

ROUTES OF EXPOSURE

INHALATION

SKIN CONTACT

SKIN ABSORPTION

EYE CONTACT

INGESTION

EFFECTS OF OVEREXPOSURE

ACUTE OVEREXPOSURE

CHRONIC OVEREXPOSURE

EMERGENCY AND FIRST AID PROCEDURES

EYES

SKIN

INHALATION

INGESTION

NOTES TO PHYSICIAN

VI REACTIVITY DATA
CONDITIONS CONTRIBUTING TO INSTABILITY
INCOMPATIBILITY
HAZARDOUS DECOMPOSITION PRODUCTS
CONDITIONS CONTRIBUTING TO HAZARDOUS POLYMERIZATION
VII SPILL OR LEAK PROCEDURES
STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED NEUTRALIZING CHEMICALS
WASTE DISPOSAL METHOD
VIII SPECIAL PROTECTION INFORMATION
VENTILATION REQUIREMENTS
SPECIFIC PERSONAL PROTECTIVE EQUIPMENT RESPIRATORY (SPECIFY IN DETAIL)
EYE
GLOVES
OTHER CLOTHING AND EQUIPMENT

IX SPECIAL PRECAUTIONS

PRECAUTIONARY
STATEMENTS

OTHER HANDLING AND
STORAGE REQUIREMENTS

PREPARED BY

ADDRESS

DATE

XIV. APPENDIX VI

WORK PRACTICES AND ENVIRONMENT CONTROLS FOR SPECIFIC TYPES OF OPERATIONS INVOLVING FIBROUS GLASS

The following sections have been adapted from a report prepared for NIOSH on work practices and engineering controls for occupational exposure to fibrous glass [6].

Basic Manufacturing and Product Formation and Packing by Manufacturer

(a) Bonded Glass 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 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 are effective for gross dust, such as the >7.5 μm-diameter dusts associated with the onset of dermal irritation in most people, but are almost completely ineffective in removing respirable fibers.

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.

Practices and controls that can be used to control excessive dust levels include the following.

(1) 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 fibers should be made in the selection of dust collection systems.

(2) 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 for haulage must be covered. Conveyors and screw augers used for dust removal from plants should be completely enclosed.

(3) 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.

(4) Housekeeping is best accomplished with power vacuum cleaners since most dust is captured by this method. For periodic major housekeeping efforts, when overhead structures are cleaned and vacuuming is not feasible and a dustier process must be used, workers should wear respirators.

(5) 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.

(b) Loose Fiber and Pouring and Blowing Fibrous Glass Wools

Loose industrial fiber and pouring and blowing wools are produced by fibrous 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 as 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 glass and mineral wool producers. However, if dust levels are excessive, the following practices are of merit:

(1) Enclose conveyors, surge bins, tumble screens, shaker tables, rotating screens, and product blenders.

(2) Similarly, chopping stations should be enclosed where scrap is reclaimed for blowing wool.

(3) 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.

(4) 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.

(5) Good housekeeping appears to be a major contributor to maintaining low dust levels in mineral wool plants.

(c) 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/cc) 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 ft/minute range. Typically, these vent through bag filters or precision drum rotary filters.

Product Installation

(a) General Applications

For installation of dry fibrous glass wools in confined spaces such as attics, workers should be furnished reusable or single-use, negative pressure respirators approved by NIOSH or MESA. 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

approved 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; however, use of an approved 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 fibers become airborne. If the material is dried, considerable dust can evolve. An effective measure is to stagger the work hours so 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 vacuum cleaning.

Few applications in which the manmade 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, incidentally, 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 (>232 C) applications such as boilers, chemical plants, and power plants. 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.

(b) 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:

(1) Prefabrication of material in shops under adequate local exhaust to reduce cutting and fitting in confined quarters.

(2) Prewetting of materials to be torn out.

(3) Isolation of areas where "tear-out" is taking place with curtains and portable partitions.

(4) Exclusion of all personnel not involved in the operation in the "tear-out" areas.

(5) Use of portable exhaust blowers and dust collectors with sucker hoses or approved respirators if ventilation equipment cannot be used.

(6) Immediate disposal of scrap fiber in plastic bags or other containers not requiring re-handling of loose scrap. Dust should be vacuumed.

Glass Reinforced Plastic Product Manufacture

In the manufacture of products containing fibrous glass reinforced plastic, 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, in sprayup areas where roving is chopped in 3.8 to 5.1-cm (1.5 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.

(a) Good Practices and Controls

(1) Perform cutting operations on perforated downdraft tables. Provide plastic bags for immediate collection of small remnants to prevent foot trampling. Capture velocities should be 61 to 76 meter/minute (200-250 ft/minute).

(2) Bandsaws in finishing areas should be equipped with local exhaust systems. Portable sabre saws are also available with high velocity, low volume capture attachments.

(3) 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 3,048 to 7,620 meters/minute (10,000 to 25,000 ft/minute.

Small Diameter Fiber (less than 3.5 μm) Production and Use

For any operation where excessive small diameter fiber dust levels are encountered, the following techniques are useful:

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

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

(c) For manufacturers packing small diameter fiber into filtration media, workers pleat or form the fiber on tables. If excessive dust is a problem, these operations should be performed on downdraft tables with

capture velocities of 61 to 76 meters/minute (200-250 ft/minute). Trim and waste should be immediately placed into plastic bags or other containers not requiring re-handling of loose scrap to avoid trampling underfoot.

(d) All subsequent forming and cutting of refractory materials manufactured from small diameter fiber should be done under adequate local exhaust systems.

XV. TABLES AND FIGURE

TABLE XV-1

COMPOSITION OF SOME TYPICAL COMMERCIAL GLASS FIBERS

Glass Type	Component, (% by weight)										
	SiO_2	Al_2O_3	CaO	MgO	B_2O_3	Na_2O	K_2O	ZrO_2	TiO_2	PbO	F_2
(Low alkali, lime-alumina borosilicate)	54.5	14.5	22.0	-	8.5	0.5	-	-	-	-	-
(Soda-lime boro-silicate)	65.0	4.0	14.0	3.0	5.5	8.0	0.5	-	-	-	-
(Soda-lime boro-silicate)	59.0	4.5	16.0	5.5	3.5	11.0	0.5	-	-	-	-
(Soda-lime)	73.0	2.0	5.5	3.5	-	16.0	-	-	-	-	-
(Lime-free boro-silicate)	59.5	5.0	-	-	7.0	14.5	-	4.0	8.0	-	2.0
(High lead silicate)	34.0	3.0	-	-	-	0.5	3.5	-	-	59.0	-

Other additives: Phosphorus, iron, barium, copper, cerium, tin, and beryllium oxides

Adapted from Shand [4]

TABLE XV-2

CHARACTERISTIC AND PHYSICAL PROPERTIES OF SOME COMMERCIAL FIBROUS GLASS

Glass Type	Form	Fiber Diameter Range, μm	Density, g/cc	Refractive Index
1 (Low alkali, lime-alumina borosilicate)	Textile, mats	6 - 9.5	2.596	1.548
2 (Soda-lime boro-(silicate)	Mats	10 - 15	2.540	1.541
	Textiles	6 - 9.5		
3 (Soda-lime boro-silicate)	Wool (coarse)	7.5 - 15	2.605	1.549
4 (Soda-lime)	Packs (coarse)	115 - 250	2.465	1.512
5 (lime free boro-silicate)	Wool (fine)	0.75 - 5	2.568	1.537
	(ultrafine)	0.25 - 0.75		
6 (High lead silicate)	Textiles	6 - 9.5	4.3	-

Adapted from Shand [4]

TABLE XV-3

CHEMICAL BINDERS, COATINGS, AND LUBRICANTS USED WITH FIBROUS GLASS

Binders	Coatings and Lubricants*
Phenol formaldehyde resin	Silicone oil
Urea formaldehyde resin	Dyes, carbon pigment
Melamine formaldehyde resin	Starch
Polyvinyl acetate	Ammonium hydroxide
Vinsol resin	Mineral oil
Urea	Vinyl silane
Epoxy resins	Methacrylate chromic chloride
	Dextrin, gelatin
	Polyvinyl alcohol (chloride)

*Comprise between 0.25 and 1.0% by weight of fiber

Adapted from Shand [4]

TABLE XV-4

OBSERVED AND EXPECTED DEATHS AMONG WHITE MALES
IN A FIBROUS GLASS PRODUCTION PLANT

Causes of Death	List Number*	Observed	Expected
Tuberculosis	001-019	0	4.69**
Malignant neoplasms	140-199	54	64.09
Digestive system	150-159	25	22.93
Respiratory system	160-164	16	20.23
Other and unspecified	140-149	13	20.93
Vascular lesions affecting central nervous system	330-334	30	32.84
Diseases of heart	400-443	163	179.86
Nonmalignant respiratory disease	470-527	25	19.96
Influenza and pneumonia	480-493	6	9.92
Other respiratory disease	470-475, 500-527	19	10.04**
Cirrhosis of liver	581	2	8.93**
Violent deaths	800-958	39	34.37
All other known causes		63	59.50
Unknown causes		0	-
Total		376	404.24

*7th Revision of International List of Diseases and Causes of Death
**Significant at $P<0.05$

Adapted from Bayliss et al [55]

TABLE XV-5

OBSERVED AND EXPECTED NONMALIGNANT RESPIRATORY DISEASE DEATHS (LESS INFLUENZA AND PNEUMONIA) BASED ON TIME SINCE ONSET OF EMPLOYMENT IN FIBROUS GLASS PRODUCTION PLANT

Interval Since Onset of Employment (Years)	Observed	Expected
5 to 9	0	0.53
10 to 19	9	2.90
20 to 29	10	6.11
30 or more	0	0.50
After 5 or more years	19	10.04*
After 10 or more years	19	9.51**

*Significant at $P<0.05$
**Significant at $P<0.01$

Adapted from Bayliss et al [55]

TABLE XV-6

RESPIRATORY DISEASE AND RELATED DEATHS FROM CASES AND MATCHED CONTROLS BY EXPOSURE ASSESSMENTS

No Deaths from Respiratory Diseases	Deaths from Respiratory Diseases		
	Potentially Exposed	Not Potentially Exposed	Total
Not potentially exposed	9	38	47
Potentially exposed	0	2	2
Total	9	40	49

Chi-square = 3.27 (.05<P<.10)

Adapted from Bayliss et al [55]

TABLE XV-7

NUMBER OF RATS SHOWING CHANGES IN MESOTHELIAL CELLS AFTER INTRAPLEURAL INOCULATIONS

Cell Change	Exposure Material	
	Fine Glass Fiber (Code 100)	Coarse Glass Fiber (Code 110)
No hyperplasia	1	12
Occasional hyperplasia	3	5
Focal hyperplasia	12	11
Generalized hyperplasia	4	4
Marked hyperplasia	7	0
Suspicion of malignancy	1	0
Mesothelioma	4	0
	32	32

Adapted from Wagner et al [71]

TABLE XV-8

PERCENTAGE OF RATS DEVELOPING MESOTHELIOMAS
AFTER INTRAPLEURAL INOCULATION OF VARIOUS MATERIALS

Material	Percentage of Rats* With Mesotheliomas
SFA chrysolite	66
UICC crocidolite	61
UICC amosite	36
UICC anthophyllite	36
UICC chrysotile (Canadian)	30
UICC chrysotile (Rhodesian)	19
Glass fiber code 100 (Fine)	12
Ceramic fiber	10
Glass powder	3
Glass fiber code 110 (Coarse)	0

*Each group consisted of 96 rats, 48 of each sex.

Adapted from Wagner et al [71]

TABLE XV-9

PROBABILITY OF PLEURAL SARCOMAS IN RATS WITH DIFFERENT DIMENSIONS OF FIBROUS GLASS AFTER INTRAPLEURAL ADMINISTRATION OF A 40-MG DOSE

Predominant Dimensions of Fiber*		Probability (%)
Diameter, μm	Length, μm	
0.5 - 1.5	<64	85.3
0.5 - 2.5	<64	73.9
0.5 - 2.5	8-64 and <64	71.2
0.5 - 8	<64	69.3
0.5 - 8	8-64 and <64	64.4
2.5 - 8	8-64 and <64	21.5
2.5 - 8	8-64 and <64	19.4
1.5 - 4.0	<64	14.3
4.0 - 8.0	4-8 and 8-64	8.3
0.5 - 4.0	1.8	8.1
>4.0	<8	6.7
>4	4-64	5.9
>4	4-64	5.7
4.8	8-64	5.5
1.5 - 4	4.64	4.5
0.5 - 1.5	>8	0
8.0	<64	0

*More complete representation of dimensions can be found in the original paper.

Adapted from Stanton et al [76]

TABLE XV-10

FIBROUS GLASS EXPOSURE AND EFFECTS

Author	Fiber Dimensions, μm Diameter	Length	Exposure Variables	Effects
HUMANS-OCCUPATIONAL				
Mungo [42]	-	-	64 particles/ml, 2 to 4-year exposure	Skin and upper respiratory tract irritation
Studies in the Same Plant				
a) Wright [44]	2 - 10 median 6	16%<20 6%<20	0.93 - 13.3 mg/cu m 0.09-0.32 mppcf (3.2-11.2 particles/cu m), up to 32 years of exposure	Roentgenographic examination showed no distinctive markings
b) Utidjian [46] c) Utidjian and de Treville [47]	-	-	232 male fibrous glass production workers	Pulmonary function tests showed no decrement
d) Nasr et al [51]	-	-	2028 male fibrous glass production workers	Roentgenographic examination showed no distinctive patterns
e) Gross et al [50]	-	-	20 deceased fibrous glass production workers, 16 to 32 years of exposure	Post mortem comparison of deceased urban dwellers and fibrous glass production workers showed no significant differences

TABLE XV-10 (CONTINUED)

FIBROUS GLASS EXPOSURE AND EFFECTS

Author	Fiber Dimensions, μm Diameter	Length	Exposure Variables	Effects
		HUMANS (CONTINUED)		
f) Bayliss et al [55]	Median 1.8	28	0.08 fibers/cc dust 0.3 mg/cu m	Slight excess risk of death from "nonmalignant respiratory diseases"
	1 - 3	-	Case-control study of 49 cases of respiratory related deaths	Increased risk of death from malignant respiratory disease with exposure to small-diameter fibers ($0.05<p<0.10$)
Hill et al [52]	75%<4 34%<2	- -	Total dust, 0.4 to 12.7 mg/cu m in breathing zones; respirable size dust, 1.0 to 4.8 fibers/ml	No differences between exposed workers and controls
Enterline and Henderson [54]	-	-	416 retired workers 65 years of age or older	Slight excess of death in 276 normal retirees due to "diseases of respiratory system" and "all other heart diseases"

TABLE XV-10 (CONTINUED)

FIBROUS GLASS EXPOSURE AND EFFECTS

Author	Fiber Dimensions, μm Diameter	Length	Exposure Variables	Effects
		HUMANS (CONTINUED)		
Murphy [40]	-	-	Several months of exposure	Dry cough, shortness of breath, bronchiectasis of the right lung
Heisel and Mitchell [27]	17.7 - 18.1	2 μm	Patch tests	Small isolated erythematous papules
Heisel and Hunt [28]	>5.3	-		Transient mechanical skin irritation
	<4.6	-		No skin irritation
McKenna et al [29]	-	-	126 workers in hot humid manufacturing operation	Skin irritation, paronychia, folliculitis of the feet
Erwin [24]	-	-	120 workers	All had mild skin irritation, 9 had persistent eczematoid dermatitis

TABLE XV-10 (CONTINUED)

FIBROUS GLASS EXPOSURE AND EFFECTS

Author	Fiber Dimensions, μm Diameter	Length	Exposure Variables	Effects
			HUMANS (CONTINUED)	
Longley and Jones [36]	-	-	Woman worker 1 day/wk for 8 to 9 mon	Itching of skin, acute conjunctivitis, keratitis with sterile corneal abscess
Milby and Wolf [16]			Summary of occupational diseases attributed to fibrous glass in California, 1960-62	691 cases, 38 due to respiratory tract irritation, 653 due to skin irritation
			ANIMAL EXPERIMENTS	
Davis [70]	0.05	200	10 mg, ip, mice	Large granulomas, fibrosis
	0.05	<20	10 mg,ip, mice	Small granulomas
	3.5	200	10 mg,ip, mice	Large granulomas, fibrosis
	3.5	<20	10 mg,ip, mice	Small granulomas
Gross et al [58]	0.5	5-20	100 mg/cu m, 24 mon of inhalation, rats, hamster	Accumulation of dust filled macrophages in rats; no fibrosis

TABLE XV-10 (CONTINUED)

FIBROUS GLASS EXPOSURE AND EFFECTS

Author	Fiber Dimensions, μm Diameter	Length	Exposure Variables	Effects
		ANIMALS (CONTINUED)		
Stanton et al [76]	0.5 - 1.5	>64	40 mg intrapleural administration	Pleural sarcomas occurring with a probbability up to 85%
Botham and Holt [59]	<1	<20	"High" single exposure, guinea pigs	Many fibers cleared within 1 wk, red blood cells migrated from capillaries, intracellular fibers coated with ironcontaining material
Wagner et al [71]	<0.12	1.7 with 2%>20	20 mg intrapleural,	Mesotheliomas in 12% no
	1.8	22	Rats	No mesotheliomas
Pott et al [68,69]	50%<0.2	50%<11	2 mg, 10, 50 mg ip, rats	Tumor rates of 24, 53, 71%
	50%<1	50%<28	20 mg, rats, ip	Tumor rate of 37%

TABLE XV-10 (CONTINUED)

FIBROUS GLASS EXPOSURE AND EFFECTS

Author	Fiber Dimensions μm Diameter	Length	Exposure Variables	Effects
		ANIMALS (CONTINUED)		
Kuschner and Wright [64]	<1	7%>10	3-25 mg in 2 to 6 guinea pigs	No fibrosis, alveoli filled with macrophages
	<1	7%<10	Intratracheal exposure	Interstitial fibrosis at 1 yr
	<0.3	<5		No fibrosis
	<0.3	>10		Interstitial fibrosis
	2	<10(12%>10)		Some fibrosis
	2	>10		Interstitial fibrosis
Schepers and Delahant [56]	6	20-50	0.143-0.146 mg/cu m, 1.4 to 2.2 mppcf, 20 mon to glass wool followed by 20 mon to glass cotton, guinea pigs and rats, no controls	Epithelial hyperplasia, cellular desquamation in smaller bronchioles, kyperplasia of parenchymal pulmonary lymph nodes

TABLE XV-10 (CONTINUED)

FIBROUS GLASS EXPOSURE AND EFFECTS

Author	Fiber Dimensions, μm Diameter	Length	Exposure Variables	Effects
		ANIMALS (CONTINUED)		
Wenzel et al [61]	3	5-8	Single 50-mg intratracheal injection in rats	Bronchial wall lesions, hyperplasis of bronchiolar mucous membrane, chronic bronchitis, peribronchiolar hyperplasia of lymphatic tissue
	30	30-100	Single 50-mg intratracheal injection in rats	Chronic bronchitis, stenosis of bronchial lumen with hyperplasia of peribronchial lymphatic tissue, atrophic emphysema, atelectasis

TABLE XV-11

DUST CONCENTRATIONS AND DIMENSIONS IN FIBROUS GLASS PRODUCTION PLANT

Sampling Position	Respirable Dust (fibers/cc) Mean	Respirable Dust (fibers/cc) Range	Total Dust (mg/cu m) Mean	Total Dust (mg/cu m) Range
		Operators' Breathing Zones		
Edge trimming				
Take-off position	2.3	1.1-4.8	11.6	10.0-12.7
Feed position	1.3	1.1-1.5		
Batch splitting operator	1.4	1.0-2.0	7.1	7.0-7.2
Navyboard sander operator	2.0	2.0	0.6	0.4-0.7
Emptying extractor sander	5.5	5.5		
		2 Ft Below Operators' Breathing Zones		
Edge trimming				
Bench level	10.4	10.0-10.7	185	185
2 ft from dust course horizontally	-	-	30	26-33
Batch splitting				
Bench level	3.4	3.4	-	-

Fiber Dimensions

Diameter (μm)	(%)	Length (μm)	(%)
0.5	11	> 12	80
1.5	33	> 25	70
2.5	14	> 50	50
3.5	17	> 100	18
4.5	12		
5.5	5		
> 5.5	9		

Adapted from Hill et al [52]

TABLE XV-12

OCCUPATIONAL EXPOSURE SUMMARY - PRIMARY MANUFACTURERS

Exposure	Source	Mean Fiber Concentrations (fiber/cc)	No. of Samples	Basis for Inclusion in Fiber Count	Mean Total Dust Concentration (mg/cu m)	No. of Samples
Centrifugal-forming glass wool building insulation (4 plants)	Dement [5]	0.08	54	Diameter <10 μm	1.44	39
Centrifugal-forming glass wool appliance insulation (2 plants)		0.05	35	"	0.81	17
Glass wool pipe insulation formation (3 plants)		0.10	16	"	1.74	19
Scrap reclamation-glass pouring wools (4 plants)		0.07	26	"	1.44	19
Flame attenuated forming-glass insulating wools (2 plants)		0.37	16	"	0.69	17
Other manufacturing operations - product fab, pack, etc. 3 plants (mg/cu m); 4 plants (f/ml)		0.08	26	"	0.63	41

TABLE XV-12 (CONTINUED)

OCCUPATIONAL EXPOSURE SUMMARY - PRIMARY MANUFACTURERS

Exposure	Source	Mean Fiber Concentrations (fiber/cc)	No. of Samples	Basis for Inclusion in Fiber Count	Mean Total Dust Concentration (mg/cu m)	No. of Samples
Centrifugal-forming glass wool (6 plants)	Konzen [87].	0.15	63	Total fiber count	1.66	59
Centrifugal-formed glass wool packing and fab		0.16	246	"	2.02	259
Scrap reclamation-glass pouring wools		0.11	37	"	1.09	37
Bonded glass mat formation (an attenuation of textile bushing fiber)	Konzen [87]	0.22	18	Total fiber count	1.12	13
Flame-attenuated glass wool formation includes wools with nominal fiber diameters of 1-4 μm		0.38	8	"	1.33	35
Continuous glass textile fiber formatiom		0.20	6	"	2.99	18

TABLE XV-12 (CONTINUED)

OCCUPATIONAL EXPOSURE SUMMARY - PRIMARY MANUFACTURERS

Exposure	Source	Mean Fiber Concentrations (fiber/cc)	No. of Samples	Basis for Inclusion in Fiber Count	Mean Total Dust Concentration (mg/cu m)	No. of Samples
Glass textile yarn fabrication	Konzen [87]	0.37	205	Total fiber count	1.19	228
Stable (carded) glass fiber formation (1 plant)		0.35	2	"	5.49	10
Stable fiber fabrication (1 plant)		0.20	1	"	2.25	7
Glass wool insulation manufacture (method of formation not specified) (4 plants)	Johnson et al [85]	0.37	*	Total fiber count	0.32	*
Continuous glass textile fiber formation (1 plant)		0.20	*	"	0.06	*
Glass textile fiber - spinning and twisting		0.33	*	"	0.16	*
Glass textile fiber - waste recovery		0.33	*	"	0.11	*

TABLE XV-12 (CONTINUED)

OCCUPATIONAL EXPOSURE SUMMARY - PRIMARY MANUFACTURERS

Exposure	Source	Mean Fiber Concentrations (fiber/cc)	No. of Samples	Basis for Inclusion in Fiber Count	Mean Total Dust Concentration (mg/cu m)	No. of Samples
Plant A - Glass wool (personal)	Corn et al [93]					
Flame attenuated fiber rollup		0.12	4	Total fiber count	3.5	4
Rigid duct manufacture		0.07	3	"	2.3	3
Filter packer		0.10	10	"	4.8	1
Bond mat rollup		0.12	2	"	2.1	2
Scrap reclamation		0.08	2	"	3.4	2
Mold and pipe manufacture		0.12	4	"	3.6	4
Wool plant selector packer		0.12	4	"	3.1	4

TABLE XV-12 (CONTINUED)

OCCUPATIONAL EXPOSURE SUMMARY - PRIMARY MANUFACTURERS

Exposure	Source	Mean Fiber Concentrations (fiber/cc)	No. of Samples	Basis for Inclusion in Fiber Count	Mean Total Dust Concentration (mg/cu m)	No. of Samples
Plant A - glass wool (environmental)	Corn et al [93]					
Acoustic tile plant		0.11	3	Total fiber count	1.2	3
Flexible duct formation		0.12	3	"	2.0	2
Filter fiber formation		0.13	4	"	3.0	4
Bonded mat plant		0.06	2	"	0.7	2
Textile mat formation		0.17	4	"	2.3	4
Scrap reconditioning		0.13	2	"	3.2	2
Warehouse		0.06	2	"	1.5	2
Flame attenuated fiber formation		0.07	2	"	1.3	2
Wool plant - hot end		0.09	4	"	2.3	4

TABLE XV-12 (CONTINUED)

OCCUPATIONAL EXPOSURE SUMMARY - PRIMARY MANUFACTURERS

Exposure	Source	Mean Fiber Concentrations (fiber/cc)	No. of Samples	Basis for Inclusion in Fiber Count	Mean Total Dust Concentration (mg/cu m)	No. of Samples
Plant B - glass wool and textile fiber (personnel)	Corn et al [93]					
Fiber formation, winding		0.07	6	Total fiber count	2.6	6
Hot fiber handling - chopped, bonded mat		0.15	3	"	1.0	3
Hot fiber handling - helix formation		0.76	2	"	2.4	2
Microfiber formation - cold end		0.17	3	"	0.6	3
Microfiber fleting and leaching		0.74	3	"	0.9	4
Filter tube manufacture - socking station		2.40	2	"	2.8	4
Filter tube manufacture - saw operator		1.39	2	"	1.2	2

TABLE XV-12 (CONTINUED)

OCCUPATIONAL EXPOSURE SUMMARY - PRIMARY MANUFACTURERS

Exposure	Source	Mean Fiber Concentrations (fiber/cc)	No. of Samples	Basis for Inclusion in Fiber Count	Mean Total Dust Concentration (mg/cu m)	No. of Samples
Plant B - (environmental)						
Textile fiber roving, weaving, chopped strand manufacture		0.09	5	"	1.1	5
Bonded mat, helix formation		0.05	3	"	0.7	3
Microfiber formation - hot end		0.04	1	"	0.1	1
Chopped mat formation		0.02	2	"	0.2	2
Filter tube formation		0.15	2	"	0.7	2
Bonded mat formation		0.03	2	"	0.5	2

*Not reported

Adapted from Schneider and Pifer [6]

TABLE XV-13

OCCUPATIONAL EXPOSURE SUMMARY - SECONDARY MANUFACTURERS

Exposure	Source	Mean Fiber Concentrations (fiber/cc)	No. of Samples	Basis for Inclusion in Fiber Count	Mean Total Dust Concentration (mg/cu m)	No. of Samples
Fibrous glass reinforced plastics						
Plant A						
Spray-up	Dement [5]	0.07	7	<10 μm	2.23	7
Flashing removal & finish		0.03	3	"	3.55	3
Non-corrosive products plants several using spray-up, filament winding and hand layup; data not differentiated by job codes	Konzen [87]	0.12	38	Total fiber count	3.49	43
Plant C	Corn et al [93]					
Molded glass reinforced plastic products finishing and trimming (personal)		0.15	5	"	3.9	5

TABLE XV-13 (CONTINUED)

OCCUPATIONAL EXPOSURE SUMMARY - SECONDARY MANUFACTURERS

Exposure	Source	Mean Fiber Concentrations (fiber/cc)	No. of Samples	Basis for Inclusion in Fiber Count	Mean Total Dust Concentration (mg/cu m)	No. of Samples
Plant C (environmental)	Corn et al [93]					
Mat cutting		0.17	4	"	3.3	3
Large reform area		0.17	4	"	1.3	4
Small preform area		0.14	4	"	2.4	4
Panel department		0.09	8	"	2.6	8
Custom molding		0.16	8	"	2.2	8

Adapted from Schneider and Pifer [6]

TABLE XV-14

OCCUPATIONAL EXPOSURE SUMMARY - FINE FIBER PRODUCERS AND USERS

Exposure	Data Source	Mean Fiber Concentrations (fiber/cc)	No. of Samples	Mean Total Dust Concentration (mg/cu m)	No. of Samples
Fine fiber manufacturers	Dement [5]				
Plant 1					
Production and bulk handling		1.0 (0.1-1.7)	5	0.4 (0.1-.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	Dement [5]				
Plant 1					
Fiber mixing		5.8 (4.7-6.9)	2	*	
Trimming/folding		1.9 (1.6-2.1)	2	*	
Plant 2					
Fiber blending		21.9 (8.9-44.1)	3	*	
Fiber trimming		10.6	1	*	

TABLE XV-14 (CONTINUED)

OCCUPATIONAL EXPOSURE SUMMARY - FINE FIBER PRODUCERS AND USERS

Exposure	Data Source	Mean Fiber Concentrations (fiber/cc)	No. of Samples	Mean Total Dust Concentration (mg/cu m)	No. of Samples
Aircraft Insulations manufacture	Dement [5]				
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 (0.4-0.9)	10
Plant 2					
Bulk fiber handling		14.1 (3.2-24.4)	3	*	
Fabrication and finishing		2.1	1	*	

*Not taken

Adapted from Schneider and Pifer [6]

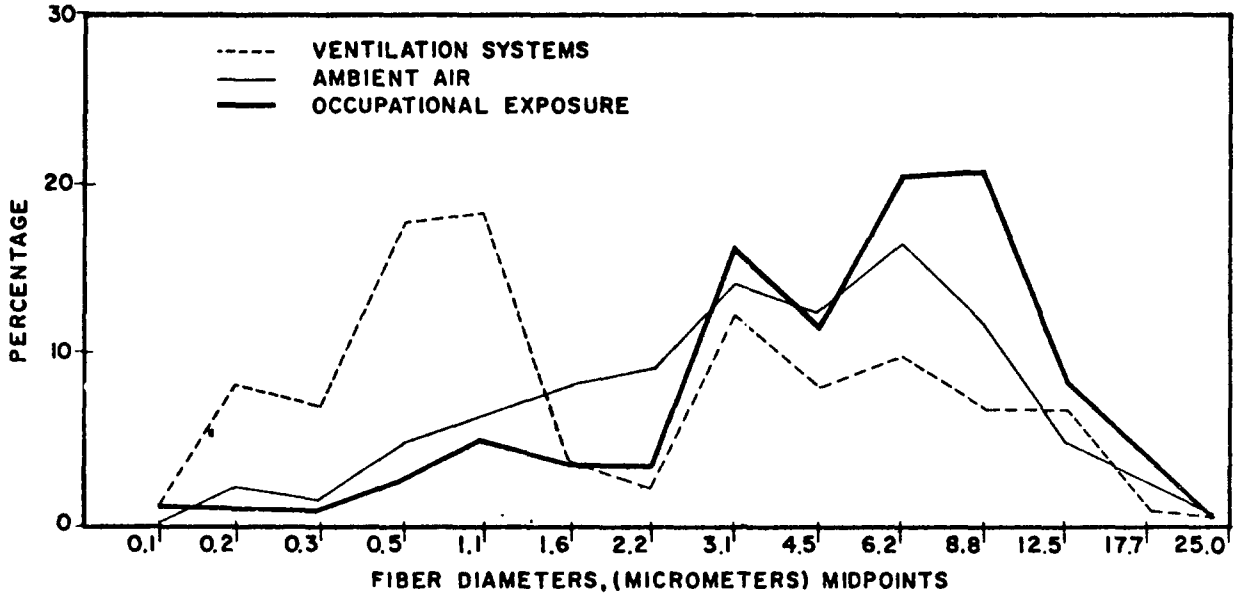


FIGURE XV-1

GLASS FIBER DISTRIBUTION BY DIAMETER
FOR THREE TYPES OF SOURCES

Adapted from reference 91

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