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 <u>Industrial Ventilation, a Manual of Recommended Practices</u>, published by the American Conference of Governmental Industrial Hygienists [94], or in <u>Fundamentals Governing The Design and Operation of Local Exhaust Systems</u>, Z9.2 (1971), published by the American National Standards Institute [95]. Useful information is also available in the NIOSH publication <u>Recommended Industrial Ventilation Guidelines</u> [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% SiO_2 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% SiO_2 [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.