Health Complaints and Environmental Glass Fiber

E. R. Crutcher

Microlab Northwest, Redmond, Washington

Corresponding email: russ.c@microlabnw.com

SUMMARY
Glass fiber is defined as any man-made rigid, vitreous fiber, mineral or organic. It is a powerful physical irritant to the mucus membranes, the eye, and the skin. Glass fiber exposure has been associated with a number of respiratory and other symptoms. It has been suggested as a major cause of the sick-building-syndrome. Past studies of the impact of glass fiber on the incidence of health complaints rarely provide adequate sampling and analytical procedures. A sampling and analytical procedure is recommended here involving a minimum of three tapelifts with a cellulose ester tape having an acrylic adhesive and an examination of a minimum of eighteen square centimeters of surface. An alarm level of >2 fibers per square centimeter is suggested. Interferences are listed and links to photographic documentation of a variety of glass fibers and glass fiber look-alikes are provided. Sampling locations and measurement uncertainty are discussed.

IMPLICATIONS
The importance of monitoring indoor surfaces for glass fiber has not been widely appreciated. This paper is the first to present a detailed discussion of the analytical problems associated with glass fiber analysis as related to health complaints in homes, schools, and office buildings.

KEYWORDS

Sick Building Syndrome, Glass Fiber Identification, Tapelifts, Control of Variance

INTRODUCTION
Glass fiber products are widely used in homes, schools and office buildings. Uses include thermal insulation, sound proofing, padding, composite structures, filters, and interior decorator panels. These materials are relatively inexpensive, light weight, and are easily designed to comply with structural or other engineering requirements. Most of these materials can be recycled, which adds to their desirability as a "green" construction material. As a result of this versatility, glass fibers are often a significant environmental contaminant.

Glass fiber has been recognized as a physical irritant to the skin, eyes, and the respiratory system for many years. It is considered a nuisance dust in the occupational regulations, but in indoor environments it has been implicated as a significant agent correlated to the sick building syndrome and to health complaints. An on-line paper cites over twenty of these studies (Crutcher, 2008). All of these studies are clinical in nature and most lack suitable controls, consistent sampling protocols, and well defined methods of measurement. In spite of these limitations there is a consistent pattern. When glass fiber is present on surfaces in the environment at an "elevated" level (generally not well defined) there are health complaints and when the glass fiber is removed by cleaning the complaints stop. If complaints resume then tests show that glass fiber has accumulated again on surfaces in the environment. The

complaints are independent of airborne particle loading and surface dust loading, provided that those loadings are not extreme.

The complaints reportedly associated with exposure to short glass fiber (less than five hundred micrometers in length) includes sinus congestion, sinus headache, dry-irritated eyes, sore throat, chest tightness, nausea, malodor, general fatigue, and skin rashes. These symptoms may occur in any combination and any individual may report only one or two of the symptoms.

The objective of this paper is to provide some common ground for discussion with regard to the sampling procedure, identification criteria, measurement methodology, control levels, and the uncertainties involved in establishing levels of exposure likely to result in health complaints.

GLASS FIBER IDENTIFICATION

The term "glass fiber", as used here, refers to any man-made rigid, vitreous fiber, mineral or organic. "Glass" is a physical state of matter and not a product with a specific chemical composition. To cause health complaints it must be large enough to be trapped by the upper respiratory system. Crystalline fibers, such as the asbestos minerals and other fibrous minerals and vitreous fibers that are small enough to penetrate deeply into the lung are not included here because they do not result in complaints at the time of exposure. All of the thirty plus manufactured products that share these properties are associated with the same basic health complaints. All of these materials are optically isotropic; they are dark in all positions when viewed between crossed polarizing filters. Few of the studies cited in the paper by Crutcher (2008) mention the use of polarized light in their characterization of "glass fiber". The problem is that if polarized light is not used then there are a number of common environmental fibers that look like glass fiber. These include bird feather barbules, insect setae, plant hairs, and other materials. Photographs showing some of these interferences can be viewed at the microlabgallery website (Microlab Northwest 2011). All of these interfering fibers are birefringent to some extent with the exception of life generated opaline silica fibers discussed below.

Another characteristic of manufactured glass fiber is that it has refractive indices above 1.49, with the exception of pure silicon dioxide fiber (quartz fiber). Having the particles mounted in a medium of low refractive index, approximately 1.49, allows for distinguishing between opaline phytoliths and manufactured glass fiber. Opaline phytoliths have refractive indices around 1.46. Assessing the relative refractive index of isotropic fibers discriminates between manufactured glass fiber and naturally occurring opaline phytoliths. It also prevents misidentification of diatom fragments and other forms of opaline spines as glass fiber. The easiest way to assess the relative refractive index of large numbers of particles with respect to the mounting medium is to use oblique brightfield illumination. With this type of illumination, particles with a refractive index higher than the mounting medium will appear dark on the side closest to the illuminating beam and bright on the opposite side. This condition will be reversed if the particle has a lower refractive index. Oblique brightfield illumination can be used effectively with polarized light if one of the linear polarizing filters is rotated eight to fifteen degrees.

Finally, what constitutes a glass fiber large enough to be capture effectively by the upper respiratory system? There are a number of common definitions for a fiber, one being an aspect ratio of one to three (1:3). In the case of glass fiber as a physical irritant, aspect ratios

as low as one to one and a half (1:1.5) seem to be just as irritating. It has been suggested that the morphology of glass fiber causes the irritation. Glass fiber has a circular cross-section and tends to break sharply at right-angles to the long dimension. The membrane tissue is drawn by capillary forces around the smooth circular fiber and is irritated (cut) by the sharp terminal edges. The diameter of the fiber needs to be about two micrometers or more to be effectively trapped by the upper respiratory system.

The combination of these properties proscribes an optimal analytical configuration. A light microscope with linear polarizing filters, one of which is easily rotatable, a substage condenser capable of oblique illumination, and a mounting medium with a refractive index of about 1.485 to 1.50 would be ideal for the analysis of glass fiber.

ENVIRONMENTAL SAMPLING FOR GLASS FIBER

Tapelifts are the most effective method for collecting particles for environmental analysis from surfaces (Crutcher et al., 2007). They have the additional advantage of preserve the particle associations necessary for identifying the source of the fibers and they faithfully retain particle distributions necessary for generating quantitative data. Other collection techniques disturb particle associations, are not as efficient in collecting small particles, and are not as reliable with respect to the area sampled with a given efficiency for the particles of interest.

Selection of Tape for Sampling

The tape recommended for this sampling is three quarter inch (2 cm) wide, 3M Scotch Brand Frosted Magic Tape. This tape is a cellulose ester film with an acrylic adhesive and is readily available in most parts of the world. The advantage of this tape is that the cellulose ester film is dissolved by acetone but the acrylic adhesive is not. This allows the plastic film with its optical defects to be removed completely, leaving the particles fixed on the microscope slide in the acrylic adhesive. The acrylic adhesive has a refractive index of about 1.486. The acrylic adhesive is the effective mounting medium for the particles. A synthetic resin mounting medium with a refractive index of 1.515 is used to mount the coverslip. This makes a permanent mount for future reference.

There are a number of other tapes that have been used for environmental particle analysis. The problem with most of them is that the plastic film used is optically active and often contains optical defect, induced stress birefringence, or scratches. The area of tape required to be examined for this type of analysis is large, as will be seen below, and defects slow the analysis unreasonably or may prevent a reliable analysis.

Sample Location and Size

A tapelift from three different surfaces in the area of interest constitutes one sample. A tapelift from a single location in an environment has limited value, as is explained under the sub-heading “UNCERTAINTY” below. These three surfaces are selected for their proximity to the work space of the individual with the health complaint. A surface on or near their desk, a witness surface nearby with an accumulation of particles, and a secondary work station or area of interest would constitute one sample. The surface with the accumulation of particles records historical exposures. This tapelift can be very useful if the area has been recently cleaned. A section of tape about eight centimeters long would be applied to the surface and then fixed to the inside of a sealable plastic bag. A record of the surface sampled and the number of contacts for the tape would be recorded and a note placed in the bag with the tape from each location.

SAMPLE PREPARATION AND ANALYSIS

A section of the two centimeter wide tape about four centimeters long is mounted on the microscope slide for analysis. That retains another four centimeters for quality assurance or for other analyses that may be desired following the optical analysis. Approximately six square centimeters of the tape on each of the three slides is scanned with an objective having a numerical aperature of at least 0.25 (10X objective) and a 10X ocular. The width of the field of view at that magnification will require about 25 passes across the width of the tape to cover the six square centimeters on each slide. Each pass across the slide is made in steps, the slide is moved to a field of view in that pass and that field is examined. The slide is then moved to the next field in that pass, etc. The total number of fields examined for the three slides will be around 1,400. That may be reduced if the number of glass fibers on any one slide exceeds 50. That is a sufficient number to determine the relative contribution of glass fiber from different sources. The search for glass fibers on that slide can stop and one of the other slides can be examined. To analyze this set of three slides in a reasonable period of time the particles of interest must stand out in strong contrast and be clearly distinct from other particles that may initially appear similar. This time-to-recognition factor is addressed with reference to contrast and resolution in an excellent series of articles by Van Duijn (1958-1959). An optically clean sample with proper illumination is critical to an accurate and timely analysis. The large number of fields is required because of the magnification needed to see the small glass fibers and to analyze a sufficient number of glass fibers to have a reasonable sense of the most active sources for the fibers.

The microscope is configured for polarized light and oblique brightfield illumination. Circular polarized light has the advantage of eliminating the extinction positions of birefringent particles and may be used if two quarter-wave compensator plates are available. If linear polarized light is used then the stage will have to be rotated to check suspect fibers for birefringence.

CONCENTRATIONS ASSOCIATED WITH HEALTH COMPLAINTS

A quantitative analysis is of no use if alarm levels are not established. In a two year study conducted by this author of a printed circuitboard manufacturing facility in the mid 1970's it was found that health complaints began whenever the concentration of short glass fiber exceeded twelve per six square centimeter sample (>2/cm^2). When the values were less than that then there were no complaints. Nearly forty years of environmental sampling and analysis seems to support that level as a reasonable control value. It is quite possible to have that concentration of glass fibers or more and have no health complaints, but when a complaint has been registered and the surface in the environment exceed that number of glass fibers then glass fiber exposure is a likely candidate as the causative agent.

Based on many years of experience in Europe, Schneider (2001) suggests a value of three or more glass fibers per square centimeter (3/cm^2 or more) are associated with health complaints. How the counting was done and the configuration of the microscopes used in performing those counts was not clear in any of his papers but this value is in reasonably good agreement with the value used by the authors.

UNCERTAINTY

The property being measured is the exposure of the individual to glass fiber in the environment. The intent is to use that value as a predictor of the likelihood of an individual in that environment having a complaint related to that exposure. A review of the variability

inherent in attempting to sample an individual's exposure to an agent in the environment was documented by Kromhout et al. (2001) and Symanski et al. (2006). Part of this variability is the result of how different individuals interact with their environment. Great care was taken in both of these summary studies to remove data that addressed or involved the effects of the exposure on the workers. The goal in this case is further confounded by attempting to address the likelihood of a specific response by at least one individual in that environment to the presence of glass fiber. A Poisson model has been used in the past to predict the likelihood of a complaint but if a complaint has already been registered it only remains to test the environment, a difficult enough task.

All studies have shown that health complaints track with glass fiber concentrations on surfaces and not in the air (Hedge et al. 1993, Schneider 2001, Crutcher 2008). This suggests that the exposure is due to mechanical transport of the glass fiber into the personal envelope of the affected individual. Shuffling of papers or books with accumulated dust, collection on the hands or forearms by contacting contaminated surfaces, or similar activity seems to be involved. An important part of the total uncertainty is how well our sampling plan models an individual's behaviour in the environment. Individuals in an environment are not passive receptors but rather active samplers of their environment. To assess their exposure while ignoring their role in that exposure is to miss a major source of variability. The sampling protocol makes an attempt to approximate this exposure by sampling: first, the work station; second, an area witness surface; and third, a secondary work station for the individual with the health complaint. The actual exposure presumably lies somewhere between the values seen in these three samples. The variance seen in these samples provides a measure of the sampling uncertainty. These values may vary by a factor of ten or more. The value of the variance can sometimes be reduced by normalizing the count to a total surface particle loading of fifteen percent (15%). This procedure compensates for a recent cleaning of the surface or some other process that affected the particle loading, provided that the dominant particles in the tapelift are clothing fiber, skin flakes, and paper fiber.

The collection and delivery efficiency of the individual is another variable and helps to explain some of the selectivity of health complaints. The variability between individuals doing the same work in the same area can be at least a factor of five (Kromhout et al., 1993; Symanski et al., 2006). Eurachem (2007) published a guide to assessing measurement uncertainty arising from sampling. Using their model, the fundamental sampling error (FSE) for a single tapelift would be about 1200% for glass fiber analysis. The use of three tapelifts per sample reduces the variance to about 600% (Crutcher et al. 2007). Although this number may seem high it is consistent with most single environmental samples.

Studies assessing the variability of manual counts of particles by trained analysts vary by less than 15% within a laboratory and by less than 20% between laboratories(ASTM F25M-09). While this may seem high for an analytical procedure it is low with regard to the variability of exposure to glass fiber on surfaces within an indoor environment.

DISCUSSION

Glass fiber is a major cause of the sick-building-syndrome and of health complaints in homes, schools and offices, as documented by over twenty large scale studies in both North America and Europe. These studies have shown that health complaints due to glass fiber exposure correlate to glass fiber on surfaces in the environment and not to airborne glass fiber (Schneider, 2001).

Exposure to glass fiber in an environment can vary significantly between workers in that environment. People may be considered a sampling device and the way they experience their environment determines their exposure. Kromhout et al. (1993) found that in 49 of the 165 groups of workers studied it was necessary to use a 10-fold range to cover 95% of the exposures within the group.

A single sample is not sufficient to evaluate an environment (Eurachem, 2007). To assess glass fiber exposure in an indoor environment a minimum of three different areas need to be sampled and at least six square centimeters of surface should be examined microscopically in each area (Crutcher et al. 2007).

CONCLUSIONS

Glass fiber exposure is rarely treated adequately in assessing health complaints in indoor environments though it is commonly associated with those complaints. Even when it is addressed, most indoor environmental specialists are not aware of the low levels of exposure that are related to those complaints. The impact of glass fiber on the occupants of a building should be considered in the selection of construction materials and in determining their application and use. When the reasons for health complaints are not obvious a detailed analysis of surface particles should be considered.

REFERENCES

ASTM. 2009. *ASTM F25/25M-09*, Standard test method for sizing and counting airborne particulate contamination in cleanrooms and other dust-controlled areas. ASTM International.

Crutcher ER, Warner K, Crutcher HK. 2007. Chapter 5: "Project design and presentation" and Chapter 6: "Sampling", *Particles and Health: Environmental Forensic Analysis*, pp. 65-82 and pp. 83-105. Available on line at: http://www.microlabnw.com/index/ParticlesAndHealth.pdf. (149 pages)

Crutcher, ER. 2008. Glass fiber and health complaints. Available on line at: http://www.microlabnw.com/index/Glass%20Fiber%20and%20Health%20Complaints.pdf (8 pages)

EURACHEM. 2007. *EURACHEM/CITAC Guide.* Measurement uncertainty arising from sampling: a guide to methods and approaches. Available on line at http://www.eurachem.org/guides/pdf/UfS_2007.pdf. (111 pages)

Hedge A, Erickson WA, Rubin G. 1993. Effects of man-made mineral fibers in settled dust on sick building syndrome in air-conditioned offices. *Indoor air 1993*.

Kromhout H, Symanski E, Rappaport SM. 2001. A comprehensive evaluation of within-worker and between-worker components of occupational exposure to chemical agents. *Ann Occup Hyg*, Vol. 45, Nu. 3, pp. 253-270.

Microlab Northwest. 2011. http://www.microlabgallery.com/GlassFiberFile.aspx.

Schneider, T. 2001. Synthetic vitreous fibers. In: Spengler J, Samet JM, and McCarthy J (eds.) *Indoor Air Quality Handbook*, McGraw-Hill, pp. 39.1-39.29.

Symanski E, Maberti S, and Chan W. 2006. A meta-analytic approach for characterizing the within-worker and between-worker sources of variation in occupational exposure. *Ann. Occup. Hyg.*, Vol 50, Nu. 4, pp. 343-357.

VanDuijn C. 1958-1959. Visibility and resolution of microscopical detail. *The Microscope*, Vol 11-12