FILE NAME: Brakes (BRK)

DATE: 2004

DOC#: BRK140

DOCUMENT DESCRIPTION: Journal Article - Evaluation of the Size and Type of Free Particulates Collected from Unused Asbestos-Containing Brake Components as Related to Potential for Respirability -Journal of Occupational Health & Safety - American Journal of Industrial Medicine

Evaluation of the Size and Type of Free Particulates Collected From Unused Asbestos-Containing Brake Components as Related to Potential for Respirability

Mark A.L. Atkinson, MA, DPhil, **Michael O'Sullivan**, BS, **Sylvia Zuber**, MS, and **Ronald F. Dodson**, MA, PhD, FCCP, FAHA*

Background *Chrysotile asbestos has found multiple applications in the production of friction products. At one point it comprised 40–50% of the composition of brake linings thus generating the potential for the development of asbestos related diseases in millions of workers involved in vehicle repairs. While some attention has been given to the health status of workers involved in the handling of worn components, little has been given to the potential for exposure during the handling and fitting of new (unused) components as replacement parts.*
Methods *Unused brake linings or brake shoes with attached linings from four different sources were gently rinsed with prefiltered water that was then collected on filters for analysis by Analytical Transmission Electron Microscope.*
Results *Large numbers of chrysotile asbestos containing structures, the majority of respirable size, were present in each sample.*
Conclusions *We conclude that any manipulation of new asbestos containing brake components would be expected to yield free dust containing chrysotile asbestos of respirable size. That the vast majority of these fibers and particulates would not be counted as regulated fibers rendering assessment of potential exposures in the work place, based on data of Permissible Exposure Limits or Regulated Fibers, questionable.* Am. J. Ind. Med. 46:545–553, 2004. © *2004 Wiley-Liss, Inc.*

KEY WORDS: asbestos; brakes; dust; electron microscopy

INTRODUCTION

The physical attributes of asbestos have resulted in its widespread use in many applications in industrialized societies [Bowles, 1946]. Over 95% of the asbestos used commercially in the United States has been of the chrysotile form [Anonymous, 1989]. An historically important application of asbestos has been in friction products for the automotive industry. Asbestos has been used in this application for fiber reinforcement, flexibility, and heat resistance [Sheehy et al., 1989]. This DHHS (NIOSH) publication noted that "chrysotile is used almost exclusively and comprises from 40 to 50% of brake linings" in asbestos containing brakes. To give an indication of the historical magnitude of asbestos consumption in these applications Jacko et al. [1973] reported that the calculated annual use was 118 million pounds (prior to grinding and drilling) in brake products and 4.5 million pounds in clutch friction material.

Asbestos has long been recognized as a risk factor for the development of interstitial fibrosis of the lung (asbestosis),

The University of Texas Health Center at Tyler, Tyler, Texas
*Correspondence to: Ronald F. Dodson, Professor of Cell Biology and Environmental Sciences, The University of Texas Health Center at Tyler, 11937 U.S. Highway 271, Tyler, TX 75708. E-mail: ronald.dodson@uthct.edu

Accepted 25 August 2004
DOI 10.1002/ajim.20097. Published online in Wiley InterScience (www.interscience.wiley.com)

pleural thickening, pleural plaques, pleural effusion, lung cancer, and mesothelioma [Craighead et al., 1982]. Rohl and colleagues [1977] estimated that based on federal survey results over one million people had the potential for exposure to asbestos during work with brake repair/replacement in 1977 alone. This estimate is very conservative and would exclude data from the thousands of small garage operations since businesses with 10 or fewer employees are excluded from keeping OSHA injury and illness records unless OSHA or the Bureau of Labor Statistics informs them in writing that they must keep records (U.S. Department of Labor, Occupational Safety and Health Administration Standards—29 CFR 1904.1, Subpart B). The thousands to millions of workers 'collaterally' exposed to 'brake dust' would also not be included in these projections. It is also reasonable to expect that a few blasts of compressed air in non-contained environments would result in the contamination of the work area [Rohl et al., 1976] and exposure to individuals who would not normally be considered as directly involved in the brake repair facet of car repair. Likewise the large number of individuals who replace their own brakes would be excluded. Obviously these numbers must be also considered with a multiplier to reflect the time from the referenced quote to present, the extent of the continued availability of asbestos containing brakes (particularly as replacement parts) not to mention the turnover of numerous mechanics though temporary assignments where their responsibilities included brake repair. Given the time frame for the development of asbestos related diseases, in the order of decades, there is a potentially huge cohort of occupationally exposed individuals who may only now be beginning to show the response to their past exposure.

The process of repair and/or replacement of brake components has been reported by Rohl and colleagues [1976] to produce "a cloud of dust that is visible for several minutes afterwards." They noted that fiber concentrations in the operator's area were appreciable (average 16 fibers/ml) and that "these are significant concentrations at least 20 ft. away" [Rohl et al., 1976]. The description of the brake servicing operations is similarly described in a recent review of historical exposures of mechanics to asbestos in brake dust [Paustenbach et al., 2003]. "Pending repairs, the wheels are elevated, removed, and then inspected. Loose dust is then cleaned from the drums and the brake assemblies by vacuuming, wiping, brushing, using compressed air, or a combination of these methods" [Paustenbach et al., 2003]. The potential for asbestos exposure while working with worn brake components is further clouded by reports that suggest chrysotile asbestos, under certain conditions of increased temperature, such as occur during braking, can be converted to the non-asbestos material—forsterite [Langer, 2003; Lemen, 2004]. Nevertheless, Rohl et al. [1976, 1977] indicated that considerable chrysotile dust was released from worn brakes. Their observations emphasized the need to use analytical transmission electron microscopy in order to reliably detect and, therefore, report most of the smaller chrysotile fibers released from the worn brakes. This same point has been made regarding the detection of chrysotile as well as the thinner and/or shorter amphiboles in various studies, which have been published from our laboratory [Dodson et al., 1991, 1993, 1997, 2003]. Rohl et al. [1976] have correctly concluded, "the present techniques of optically counting asbestos fibers may considerably underestimate the levels of total asbestos exposure." This is not a trivial point as is evident from data in a study by Rood and Scott [1989] of chrysotile asbestos levels in a friction product factory. The comparison of data obtained using analytical transmission electron microscopy with that using phase contrast light microscopy led them to conclude that only between a fifth and a half of the fibers detectable by analytical electron microscopy would be counted by light microscopy. Furthermore, only a "few per cent" of the fibers were longer than 5 μm, the usual length quoted as minimum for inclusion in most counting schemes using light microscopy.

The potential or real exposure settings for mechanics are often based on Time Weighted Averages [Blake et al., 2003; Paustenbach et al., 2003] or Permissible Exposure Limits [Blake et al., 2003] as measured in the work place. Both of these terms are definitions established as air quality measurements in work environments based upon the levels of regulated fibers (U.S. Occupational Safety and Health Administration Regulations—29 CFR: 1910.1001[b]) These levels are defined in analysis of air samples by phase contrast light microscopy [Dodson et al., 2003]. Such a count scheme includes only those fibers that are longer than 5 μm in length, does not differentiate fiber type, and uses an aspect ratio of 3:1 for a fiber to be included in a count. Such a count scheme would also exclude fibers that are 5 μm and longer but are invisible due to the limits of resolution of the light microscope. This limitation alone would likely result in an appreciable underestimation of chrysotile fibers in a given sample since these are most often both short and even when longer are often very thin. The study of Blake et al. [2003] combined analytical transmission electron microscopy in the count scheme of a simulated work environment during brake repairs but included only fibers which are essentially equivalent to those counted by phase contrast light microscopy (longer than 5 μm and greater than 0.25 μm in diameter). The authors indicated that "although the TEM has the capability to resolve the smallest asbestos fibrils they were not counted since NIOSH Method 7402 does not count fibers <0.25 μm in diameter."

Limited number of investigations have been carried out to characterize the potentially respirable material released during work with new brake components as distinct from dust released during the entire replacement process. In one such study Weir and Meraz [2001] concluded, "grinding and drilling may not pose an important source of exposure to respirable fibers." This conclusion was based on an analysis of air samples collected during a simulated test of grinding and drilling. It should be noted that this conclusion was based on data made by counting with light microscopy and based on the dimension of a "regulated fiber." Another significant factor to be borne in mind is that some population of the released particulates contained matrix material. This term is defined by the NVLAP scheme for asbestos fiber counting by analytical transmission electron microscopy. This matrix material serves to increase the sedimentation rate and could, therefore, alter the potential respirability of this type of dust. The opportunity for workplace exposure during this aspect of automotive servicing (with new brake components) can be appreciated by an example offered by Jacko et al. [1973] who projected that in 1973 as much as 15% of asbestos material could be lost during grinding and drilling of new brake friction products. Based on the amount of asbestos utilized in these products during 1973 this assumption would extrapolate to some 15 tons of asbestos containing materials that would be generated by mechanics during the traumatic physical processes of crushing, abrading, and drilling the original material. The likelihood for the release of small respirable particulates is obvious. These levels of exposure in 1973 are significant to patients today given the latency between the time of last exposure and the appearance of disease. Although the use of asbestos in brake products in the USA has declined, replacement parts continue to be imported from overseas where the use of asbestos is not as regulated as in the United States.

The present project was designed to determine if free particulates could be collected from unused asbestos containing brake components and to characterize the types of particles in terms of morphology and sizes of such particulates. The study assesses the potential that such unused materials might have for yielding respirable dust prior to any additional grinding, abrasion, or drilling processes as may be used by a mechanic in adapting the new part as replacement for the worn component. The implication from this study will be discussed from the findings as relative to the additional work practices where the brake components would be subjected to further traumatic manipulation.

METHODS

Unused brake components were obtained for use in this study. Sample one was collected from two unused brake linings for drum type brakes. The linings were identified as A GM 597804 80 and were predrilled for rivets. Sample two consisted of two linings identified as B-50-Marshall for drum type brakes and predrilled for rivets. Sample three consisted of two unused linings for drum type brakes with predrilled rivet holes and identified as Inlite-2006A 292A. Sample four consisted of two unused brake shoes with attached linings and identified as Bendix MGFF.

Samples were collected from each of the brake components by gently rinsing the entire exposed surface of both sides of each unit with a total of approximately 50 ml of water from a squeeze bottle. The water had previously been filtered through 0.2 μm pore Nuclepore filters to exclude any possibility of contamination with particulate material. The entire wash from each unit was allowed to drip off the lining and was collected in a precleaned container and given a laboratory code consistent with the code assigned to the individual brake components at the time of arrival in the laboratory. The entire process was carried out in a chemical fume hood. The wash collected from each brake unit appeared to contain visible particulates. Five to ten milliliters were sampled from each aliquot and filtered through a 0.2 μm Nuclepore polycarbonate filter. The filters were then coated with a carbon film in a vacuum evaporator and prepared through a direct method in order to produce grids suitable for analysis in a JEOL 1200 analytical electron microscope. The scans were carried out at 2,500× to 15,000× with entire grid squares photographed. These were printed and a mosaic was created from which measurements of the particulates were made. This analysis was carried out by measuring each structure in a 25 μm wide sweep from grid bar to opposite grid bar. Multiple parallel sweeps were carried out until 150 structures had been measured. When necessary additional grid squares were recorded and analyzed in the same manner. Structures touching a grid bar were excluded from the database. Measurements are quoted plus or minus one standard deviation. The various structures were categorized as to their morphology.

- Fibril: Fibrils were defined morphologically based upon their diameter dimension representing the thinnest individual unit of chrysotile (approximately 0.05 μm or less).
- Bundle: A bundle was defined as a structure whose composition consisted of multiple parallel fibrils collected together and whose fibrils in its central internal structure contained no separation greater than the diameter of one of the fibrils.
- Cluster: A cluster was considered as a structure comprised of fibrils with greater than three intersections and could not be defined morphologically as comprised of independent fibrils.
- Matrix: Pleomorphic structures considered as representative of matrix material.
- Matrix plus: Pleomorphic structures considered as representative of matrix material. That also contained visible components of bundles or fibrils.

The length of each structure was defined by it longest dimension and its width as its thinnest. Each type of structure was further characterized as respirable or non-respirable. The selected upper limit for respirablity used in this study was 10 μm for non-fibrous structures which included determinations of respirability for clusters of asbestos, matrix material, and matrix plus material [Anonymous, 1966; Lee, 1985]. A diameter equal to or less than 3.5 μm was used to define the respirable component of the long fibrous particulates (fibrils and bundles) [Lee, 1985].

Representative structures from each of the samples were analyzed by X-ray energy dispersive analysis and Selected Area Diffraction techniques for confirmation of chrysotile asbestos. Representative fibers were also selectively evaluated at higher magnification for determination as to their morphological features (i.e., tubular configuration of chrysotile).

RESULTS

Appreciable numbers of asbestos structures, defined as fibrils, bundles, or clusters were found in all samples (Figs. 1–4). The highest percent of asbestos particulates in any sample was found in sample 1 with 76.1%, followed by sample 3 with 62.7%, sample 2 with 50.7% and sample 4 with 44.7% (Table I). It was common to see structures that were classified as matrix plus material these had either bundles or fibrils extending from the central mass of matrix plus (Fig. 2). The occurrence of such structures made up from 16% of the total particulates in sample 4 to a low of 11.6% in sample 1 (Table I).

The mean length of fibrils in all groups was less than 4 μm, with the highest average length being found in sample 3 (3.73 μm) and the smallest average length in sample 4 (2.42 μm) (Table II). The mean width of fibrils in all samples was 0.03 μm. There were some longer fibrils seen in each group. The proportion of fibrils greater than 5 μm varied from 22.5% in sample 3 to 4.8% in sample 2. Sample 1 contained 10.3% and sample 4 contained 6.7%.

The mean length of bundles found in sample 4 was approximately twice that of the mean length of bundles found in the other three samples (Table II). The longest bundle was found in sample 4 and had a length of 99.2 μm and a width of 1.17 μm at its thickest point. The 30.8% of the bundles in sample 1, 33.3% in sample 2, 40.4% in sample 3, and 55.8% in sample 4 were over 5 μm in length. The 50.8% of those in sample 1, 47.1% of those in sample 2, 59.6% of those in sample 3, and 75.0% of those in sample 4 were sufficiently thick (>0.25 μm) to be detected by light microscopy. The 24.6% of the total bundles in sample 1, 23.5% of the total bundles in sample 2, 32.7% of the total bundles in sample 3, and 44.2% of the total bundles in sample 4 met both criteria

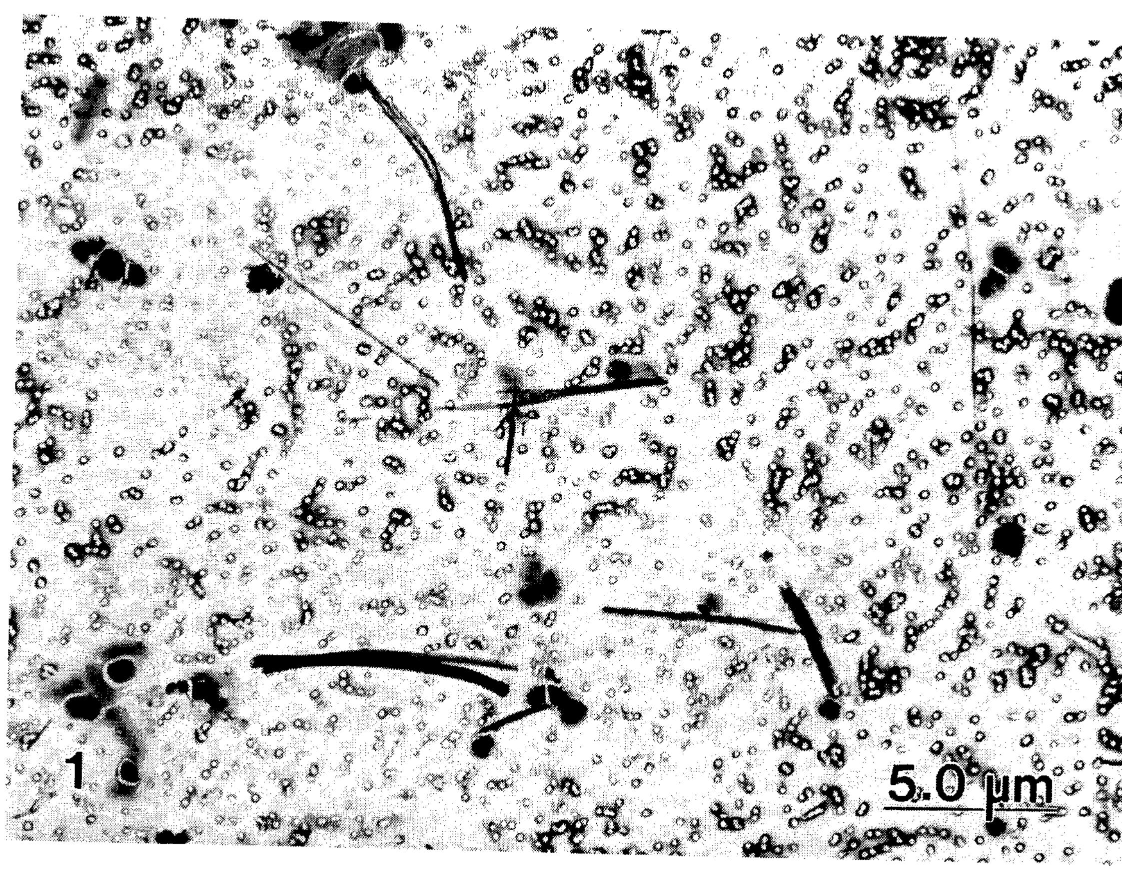

FIGURE 1. The low magnification field from sample 2 illustrates the mixture of structures found in the samples. These include free chrysotile bundles, matrix material (with attached bundles), and free fibrils. 5,500 ×.

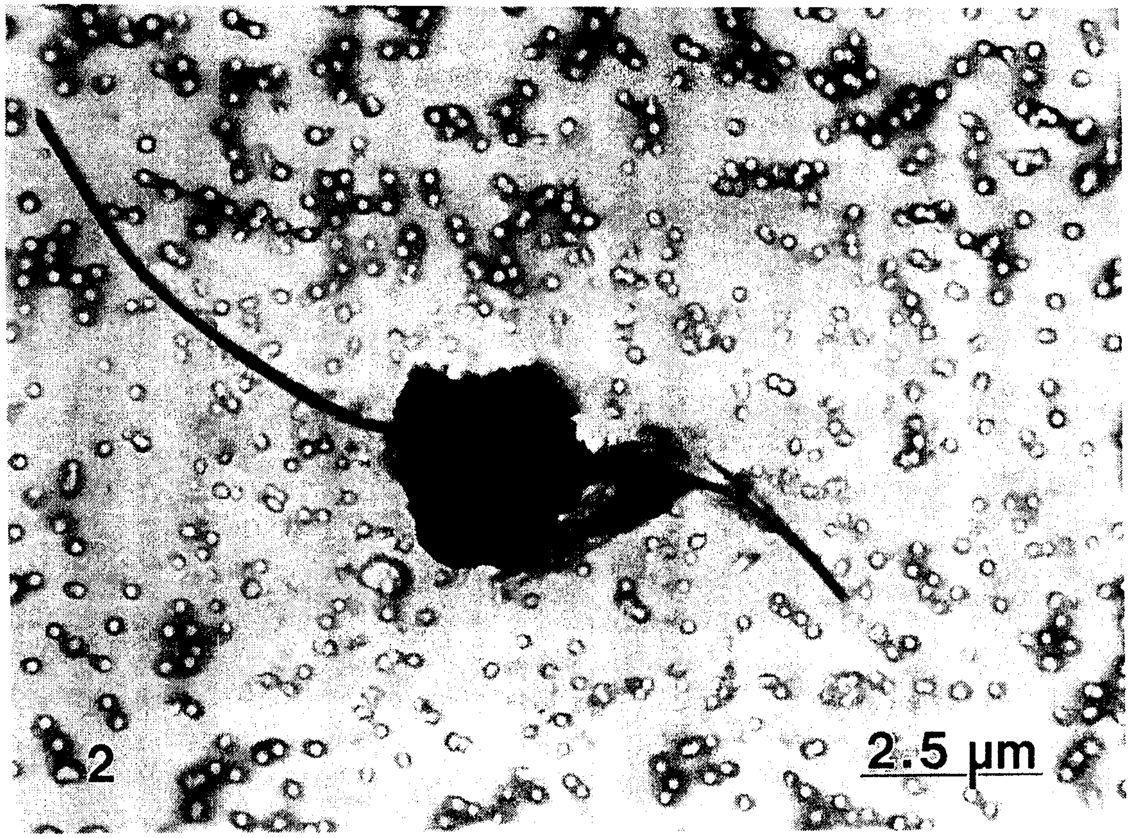

FIGURE 2. This field from sample 1 illustrates a particle of matrix material with free bundles of chrysotile extending from opposite sides of the central structure. 11,500 ×.

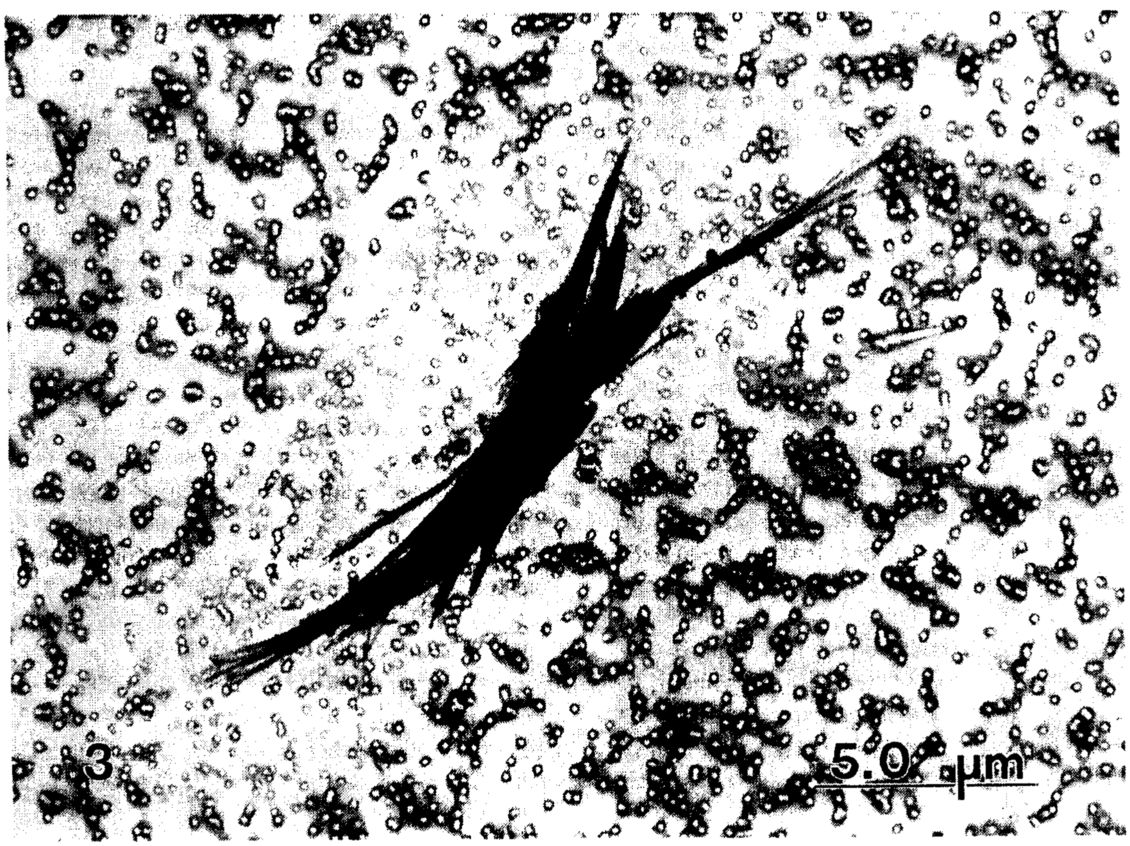

FIGURE 3. The bundle of chrysotile from sample 4 illustrates the potential for separation into smaller units as evident by the fragmentation of smaller bundles extending from the central mass. 6,900 ×.

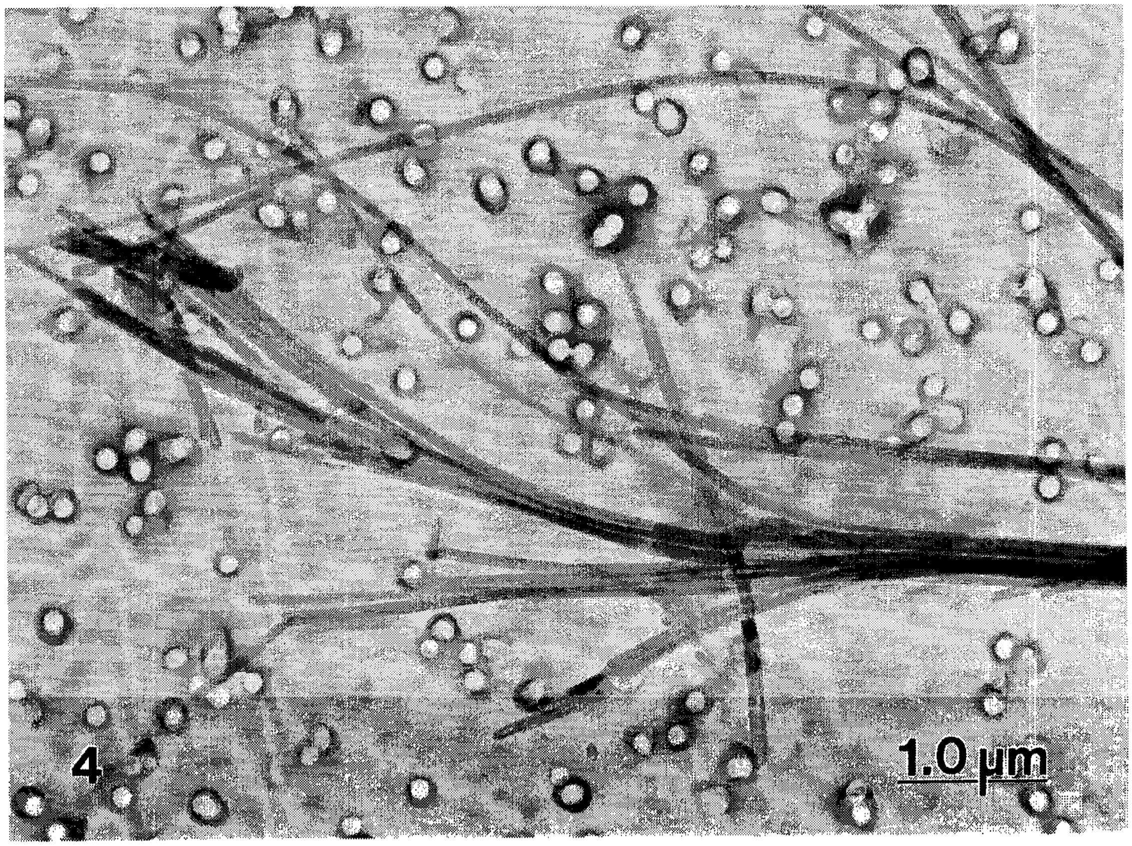

FIGURE 4. The higher magnification field in this micrograph from sample 1 indicates the tendency of bundles to separate into fibrillar units. The internal tubular structures are characteristic of chrysotile fibrils. 23,000×.

being of sufficient length (>5 µm) and width (>0.25 µm) that they theoretically would have been visible and counted in a light microscopy (NIOSH) counting scheme.

Clusters were found in samples 1, 2, and 3. These ranged in size of the largest mean dimension from 5.05 µm in sample 2 to 2.77 µm in sample 3. The average width of clusters in all samples was less than 3.5 µm.

The mean greatest dimension of the clumps of matrix was less than the length of bundles in all samples (Table II). Matrix material that had protruding bundles and/or fibrils (defined as Matrix plus) were measured at their longest dimension (which included the extended fibers) since this factor would determine their theoretical respirability in an air stream. Such structures ranged from a mean largest dimension of 11.74 µm in sample 1 to 6.56 µm in sample 2 (Table II).

As described in "Methods," fibrous particulates (fibrils and bundles) were considered potentially respirable if their diameter was <3.5 µm. Under these parameters, 100% of the fibrils would have been respirable (Table III). Similarly 98.5% of the bundles in sample 1, 98% of those in sample 2, 96.2% of those in sample 3, and 88.5% of those in sample 4 were also considered to be potentially respirable. The category of clusters, matrix, and matrix plus (those with fibrils and/or bundles extending from them) were considered as potentially respirable if they measured less than 10 µm in their longest dimension. By these criteria 100% of the clusters were potentially respirable (Table III). The percent of matrix particles that were respirable ranged from a high of 97.2% in sample 3 to a low of 88.2% in sample 2. These same criteria for respirability were applied to those particles defined as matrix plus. The percentage of these structures that were potentially respirable ranged from a high of 82.6% (sample 2) to a low of 66.7% (sample 4) (Table III).

When the fibrous burden of samples are evaluated to determine the population of "regulated fibers" a phase contrast light microscopy counting scheme is used to determine the fiber burden or used in calculating Time Weighted Averages and Permissible Exposure Limits. Extrapolating these criteria [an aspect ratio of greater than 3:1, longer than 5 µm, and visible by light microscopy (in other words a diameter greater than 0.25 µm)] it was found that none of the fibrils would have been detected (Table IV). A similar comparison of the other fibrous category (bundles) revealed that such a count scheme would include only 44.2% of the bundles in sample 4, 32.7% in sample 3, 24.6% in sample 1, and 23.5% in sample 2 (Table IV). Therefore, between 55.8% and 76.5% of the bundles present would not have been

TABLE I. Type of Structures by Percent Found in Each Sample

	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)	Sample 4 (%)
Fibrils	28.3	14.0	26.7	10.0
Bundles	47.1	34.0	34.7	34.7
Clusters	0.7	2.7	1.3	0
Matrix	21.0	34.0	24.0	39.3
Matrix plus	11.6	15.3	13.3	16.0

A total of 150 structures were analyzed from each sample in accordance with the count scheme and assigned to a particular morphological structure class as described in "Methods" and the footnote below.

Sample 1: Two unused brake linings for drum type brakes predrilled for rivets (identified as A GM 597804 80). Sample 2: Two linings for drum type brakes and predrilled for rivets (identified as B-50-Marshall). Sample 3: Two unused linings for drum type brakes with predrilled rivet holes (identified as Inlite-2006A 292A). Sample 4: Two unused brake shoes with attached lining (identified as Bendix MGFF).

Fibril: Fibrils were defined morphologically based upon their diameter dimension representing the thinnest individual unit of chrysotile (approximately 0.05 μm or less).

Bundle: A bundle was defined as a structure whose composition consisted of multiple parallel fibrils collected together and whose fibrils in its central internal structure contained no separation greater than the diameter of one of the fibrils.

Cluster: A cluster was considered as a structure comprised of fibrils with greater than three intersections and could not be defined morphologically as comprised of independent fibrils.

Matrix: Pleomorphic structures considered as representative of matrix material.

Matrix plus: Pleomorphic structures considered as representative of matrix material that also contained visible components of bundles or fibrils.

included in the defined count scheme by light microscopy. If we consider just the fibrils and bundles from all four samples combined then 13.0% of the fibrils and 39.5% of the bundles met the inclusion criterion of "longer fibers >5 μm," but none of those in the former group would have been counted by light microscopy (because of their diameter being below the resolution limit of the light microscope) and only limited numbers in the latter group. (Table IV). Again combining the data of all fibrils and bundles from all four samples (Table III), 92.8% were respirable, ranging from 89.3% in sample 4 to 94.7% in samples 1 and 3. The point being that while very few particulates would have been 'counted' under these counting schemes they were almost all respirable.

DISCUSSION

The present study has shown that high percentages of respirable particulates are readily removable from the surface of unused brake components. It would seem self evident that any additional manipulations as might occur in preparation for replacement of worn parts would serve to increase the number of such particulates. Logically if the characteristics of the dust freed by gentle wash yields the data as presented, certainly additional grinding, beveling, and sanding would be expected to yield the end results as reported by Lorimer et al. [1976] of eventual clinical changes in exposed individuals. Interestingly, in the present study the lowest proportion of asbestos containing particles were recovered from sample 4 that comprised unused brake shoes with the linings already mounted. All of the remainder were unmounted and had holes drilled for mounting. This serves to support the contention that processes such as drilling would increase the amount of freed dust.

"Natural levels" or background occurrences of 1–2 cases of malignant mesothelioma per million/year in the general population have been cited [Hillerdal, 1999]. However, as Hillerdal himself pointed out that there is "no proof" of this and he suggested that in reality the levels are probably much lower, reinforcing his belief in the association of asbestos exposure with the development of mesothelioma. Interestingly, Butnor et al. [2003] presented findings from 1900 referrals of cases with malignant mesothelioma. Ten of these were listed as having occupational exposures where "brake dust was the sole recognized source of asbestos

TABLE II. Size of Structures by Mean Length and Width (Diameter)

	Sample 1		Sample 2		Sample 3		Sample 4	
	Length, μm	Width, μm	Length, μm	Width, μm	Length, μm	Width, μm	Length, μm	Width, μm
Fibrils	2.51 ± 1.76	0.03 ± 0.02	3.07 ± 3.03	0.03 ± 0.01	3.73 ± 5.67	0.03 ± 0.01	2.42 ± 1.30	0.03 ± 0.01
Bundles	5.44 ± 8.04	1.39 ± 7.46	6.59 ± 9.30	0.65 ± 1.15	6.17 ± 2.35	1.27 ± 3.19	13.00 ± 19.30	1.73 ± 3.79
Clusters	2.84	1	5.05 ± 2.26	3.44 ± 1.72	2.77 ± 0.61	2.09 ± 0.12	None	None
Matrix	3.24 ± 2.95	1.63 ± 1.08	4.24 ± 4.45	2.91 ± 3.43	3.89 ± 2.55	2.49 ± 1.67	3.45 ± 2.39	2.40 ± 1.94
Matrix plus	11.74 ± 18.36	3.52 ± 3.84	6.56 ± 5.31	4.30 ± 4.43	8.92 ± 8.73	4.82 ± 5.36	8.93 ± 7.59	5.24 ± 4.94

The length and thickness of a total 150 structures were measured on enlarged photographic prints from each sample as described in the "Methods." Sizes were calculated based on the total magnification. The various classes of structures are as described in the "Methods" and the footnote below.

Sample 1: Two unused brake linings for drum type brakes predrilled for rivets (identified as A GM 597804 80). Sample 2: Two linings for drum type brakes and predrilled for rivets (identified as B-50-Marshall). Sample 3: Two unused linings for drum type brakes with predrilled rivet holes (identified as Inlite-2006A 292A). Sample 4: Two unused brake shoes with attached lining (identified as Bendix MGFF).

See Table I for definitions.

TABLE III. Respirability—Percent of Structures in Each Class That Meets the Criteria for Respirability

	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)	Sample 4 (%)
Fibrils	100	100	100	100
Bundles	98.5	98.0	96.2	88.5
Clusters	100	100	100	None present
Matrix	93.1	88.2	97.2	96.6
Matrix plus	68.8	82.6	75.0	66.7

All of the measured samples in each class were analyzed for potential respirability based on the definition explained above. Briefly respirablity was defined as less than 10 μm in any dimension for non-fibrous matrix material, matrix plus and clusters of asbestos and a diameter equal to or less than 3.5 μm for long fibrous particulates (fibrils and bundles).
The various classes of structures are as described in the "Methods" and the footnote below.
Sample 1: Two unused brake linings for drum type brakes predrilled for rivets (identified as A GM 597804 80). Sample 2: Two linings for drum type brakes and predrilled for rivets (identified as B-50-Marshall). Sample 3: Two unused linings for drum type brakes with predrilled rivet holes (identified as Inlite-2006A 292A). Sample 4: Two unused brake shoes with attached lining (identified as Bendix MGFF).
See Table I for definitions.

exposure." It is probably salient that the size of the asbestos particles reported in the present study is within the range, which constitute fiber burden most readily inhaled into the deeper parts of the respiratory system. Similarly the sizes of asbestos particles found in the present study overlap with the sizes found in the lung tissue of mesothelioma cases [Dodson et al., 2002; Suzuki and Yuen, 2002]. Possibly of more importance is the fact that the sizes of these fibers are consistent with the sizes of asbestos fibers found in areas outside of the lung in those sites where mesothelioma originate [Sebastien et al., 1980; Dodson et al., 1990, 2000a,b; Suzuki and Yuen, 2001, 2002].

The data we have presented in this study reinforces the point made by Rohl, Langer, and colleagues [Rohl et al., 1976] that counting asbestos fibers by light microscopy may considerably underestimate the actual fibers present. Data presented previously by researchers based on air sampling and NIOSH counting schemes have been reported to indicate that areas in which brake repairs are conducted are below the "current applicable limit of 0.1 fiber/ml (8 hr time weighted average)" [Weir et al., 2001; Blake et al., 2003]. This may be very true based on the count of "regulated fibers" but as we have recently pointed out in a review article [Dodson et al., 2003], regulated fibers should be considered on their own merit for determining assessment of air quality and not taken as a definitive representative of respirable fibers or of fibers capable of causing disease. The fact that short and longer but thin fibers are not counted by light microscopy or in electron microscopy count schemes where the inclusion criteria dictate that they are preferentially ignored does not imply they have no potential impact to health once inhaled [Dodson et al., 2003]. These shorter and longer/thinner fibers are those which are more readily inhaled in larger numbers and are deposited deeper into the respiratory system. While it is correct that they are more easily cleared from the lung it is also true that they are more easily relocated to extra pulmonary sites [Dodson et al., 1991, 2000a,b; Suzuki and Yuen, 2001, 2002]. It is also pertinent that repetitious exposure to high levels of respirable particulates can result in "lung particle overload" in which clearance is compromised and there is, therefore, a greater potential for chronic inflammation, pulmonary fibrosis, and tumors to occur [Oberdorster, 1995].

The emphasis of air monitoring in the work place is in determining the numbers of regulated fibers per a unit of time as factored with a unit of volume of collected air and this has also been the focal point of most studies involving occupational exposure to brake dust during automotive repair. However in the present study non-fibrous components of the brake dust were also determined to be respirable. There is no information to our knowledge as to the inflammatory potential of inhaled matrix material and other dust released during the disturbance of the brake material. However, there is ample information for concern with respect to the inhalation of matrix with exposed fibrils and/or bundles. These extended fibrous components offer the potential for cellular/biochemical interactions with the components of the lung milieu similar to their freed counterparts. A potential also exists for the matrix deposited in the work environment

TABLE IV. Detectability and Countability—Percent of Structures in Each Class That Meets the Criteria for Detection by PLM and For Counting Under NIOSH Standards

	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)	Sample 4 (%)
Fibrils	0	0	0	0
Bundles	24.6	23.5	32.7	44.2
Clusters	N/A	N/A	N/A	N/A
Matrix	N/A	N/A	N/A	N/A
Matrix plus	N/A	N/A	N/A	N/A

All of the measured samples in each class were analyzed for potential inclusion based on the NIOSH criteria for counting by phase contrast light microscopy as explained above (briefly an aspect ratio of greater than 3:1, longer than 5 μm and visible by light microscopy, in other words a diameter greater than 0.25 μm).
The various classes of structures are as described in the "Methods" and the footnote below.
Sample 1: Two unused brake linings for drum type brakes predrilled for rivets (identified as A GM 597804 80). Sample 2: Two linings for drum type brakes and predrilled for rivets (identified as B-50-Marshall). Sample 3: Two unused linings for drum type brakes with predrilled rivet holes (identified as Inlite-2006A 292A). Sample 4: Two unused brake shoes with attached lining (identified as Bendix MGFF).
See Table I for definitions.

after settling, to split and continue to yield free fibrils and bundles into the air as a consequence of further mechanical disturbance by tools or being crushed under foot.

In summary the present study clearly indicates the presence of free asbestos structures on the surface of new brake components and of the potential for large numbers of these to be of respirable size. These findings further raise concern for the potential development of asbestos related disease in individuals occupationally exposed to work environments where these components are used.

REFERENCES

Anonymous 1966. Task Group on Lung Dynamics: Deposition and retention models for internal dosimetry of the human respiratory tract. Health Phy 12:173–207.

Anonymous 1989. Non-occupational exposure to mineral fibres. In: Bignon J, Peto J, Saracci R, editors. World Health Organization International Agency for Research on Cancer. Lyon, France: IARC Scientific Publication No. 90, p 330–335.

Blake C, Van Orden D, Banasik M, Harbison R. 2003. Airborne asbestos concentration from brake changing does not exceed permissible exposure limit. Regul Toxicol Pharmacol 38:58–70.

Bowles O. 1946. Asbestos. The silk of the mineral kingdom. New York: The Ruberoid Co.

Butnor K, Sporn T, Roggli VL. 2003. Exposure to brake dust and malignant mesothelioma: A study of 10 cases with mineral fiber analysis. Ann Occup Hyg 47(4):325–330.

Craighead JE, Abraham JL, Churg A, Green FHY, Kleinerman J, Pratt PC, Seemayer TA, Vallyathan V, Weill H. 1982. The pathology of asbestos-associated diseases of the lungs and pleural cavities: Diagnostic criteria and proposed grading schema. Arch Pathol Lab Med 106: 544–596.

Dodson RF, Williams MG, Corn CJ, Brollo A, Bianchi C. 1990. Asbestos content of lung tissue, lymph nodes and pleural plaques from former shipyard workers. Am Rev Respir Dis 142:843–847.

Dodson RF, Williams MG, Corn CJ, Brollo A, Bianchi C. 1991. A comparison of asbestos burden in lung parenchyma, lymph nodes, and plaques. Ann NY Acad Sci 643:53–60.

Dodson RF, O'Sullivan MF, Corn CJ. 1993. Technique dependent variations in asbestos burden as illustrated in a case of nonoccupational exposed mesothelioma. Am J Ind Med 24:235–240.

Dodson RF, O'Sullivan M, Corn C, McLarty JW, Hammar SP. 1997. Analysis of asbestos fiber burden in lung tissue from mesothelioma patients. Ultrastructural Patholog 21:321–336.

Dodson RF, Huang J, Bruce JR. 2000a. Asbestos content in the lymph nodes of nonoccupationally exposed individuals. Am J Ind Med 37: 169–174.

Dodson RF, O'Sullivan M, Huang J, Holiday DB, Hammar SP. 2000b. Asbestos in extrapulmonary sites—Omentum and mesentery. Chest 117:486–493.

Dodson RF, O'Sullivan M, Brooks DR, Hammar SP. 2002. Quantitative analysis of asbestos burden in women with mesothelioma. Am J Ind Med 43:188–195.

Dodson RF, Atkinson MAL, Levin JL. 2003. Asbestos fiber length as related to potential pathogenicity: A critical review. Am J Ind Med 44:291–297.

Hillerdal G. 1999. Mesothelioma: Cases associated with non-occupational and low dose exposures. Occup Environ Med 56:505–513.

Jacko MG, DuCharme RT, Somers JH. 1973. Brake and clutch emissions generated during vehicle operation. New York, NY: Society of Automotive Engineers, Inc. 730548.

Langer A. 2003. Reduction of the biological potential of chrysotile asbestos arising from conditions of service on brake pads. Reg Tox Pharm 38:71–77.

Lee KP. 1985. Lung response to particulates with emphasis on asbestos and other fibrous dusts. CRC Crit Rev Tox 14:33–86.

Lemen RA. 2004. Asbestos in brakes: Exposure and risk of disease. Am J Ind Med 45:229–237.

Lorimer WV, Rohl A, Miller A, Nicholson W, Selikoff I. 1976. Asbestos exposure of brake repair workers in the United States. Mt Sinai J Med 43:207–218.

Oberdorster G. 1995. Lung particle overload: Implications for occupational exposures to particles. Reg Tox Pharm 27:123–135.

Paustenbach D, Richter R, Finley B, Sheehan P. 2003. An evaluation of the historical exposures of mechanics to asbestos in brake dust. App Occ Env Hyg 18:786–804.

Rohl AN, Langer A, Wolff MS, Weisman I. 1976. Asbestos exposure during brake lining maintenance and repair. Env Res 12:110–128.

Rohl AN, Langer A, Klimentidis R, Wolff MS, Selikoff I. 1977. Asbestos content of dust encountered in brake maintenance and repair. Proc R Soc Med 70:32–37.

Rood AP, Scott RM. 1989. Size distributions of chrysotile asbestos in a friction products factory as determined by transmission electron microscopy. Ann Occup Hyg 33(4):583–590.

Sebastien P, Janson X, Gaudichet A, Hirsch A, Bignon J. 1980. Asbestos retention in human respiratory tissues: Comparative measurements in lung parenchyma and in parietal pleura. In: Wagner JC, editor. Biological effects of mineral fibers. Lyon: IARC. p 237–246.

Sheehy J, Cooper T, O'Brien D, McGlothlin J, Froehlich P. 1989. Control of asbestos exposure during brake drum service. [Anonymous] 89-121. US: Department of Health and Human Services, p 1–70.

Suzuki Y, Yuen SR. 2001. Asbestos tissue burden study on human malignant mesothelioma. Ind Health 39:150–160.

Suzuki Y, Yuen SR. 2002. Asbestos fibers contributing to the induction of human malignant mesothelioma. Ann NY Acad Sci 1:1–14.

Weir F, Meraz L. 2001. Morphological characteristics of asbestos fibers released during grinding and drilling of friction products. App Occ Env Hyg 16(12):1147–1149.

Weir F, Tolar G, Meraz L. 2001. Characterization of vehicular brake service personnel exposure to airborne asbestos and particulate. App Occ Env Hyg 16(12):1139–1146.