

Review of Research

Visible dust and asbestos: what does it suggest regarding asbestos exposures?

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Abstract

Courts in asbestos litigation in the past decade have increasingly required quantitation of asbestos exposures beyond arguments that the exposures exceeded *de minimis* or background levels. Exposure levels for those in the past were often either not measured or minimally measured. Similar Exposure Groups (SEGs) methods can be considered, however i) the available data to be used for comparison may not well reflect the exposures of the individual of interest and ii) past data/standards were taken in units of million particles per cubic foot of air (mppcf) as opposed to fibers per cubic centimeter (f/cc).¹ The purpose of this work was to research these two issues to determine if exposure to visible dust created from asbestos-containing materials (ACM) (>1% asbestos) likely exceeds recommended asbestos exposure limits. This was accomplished by posing and answering the following three questions regarding asbestos exposures: 1) Was the American Conference of Governmental Industrial Hygienists' (ACGIH) 5 million particles per cubic foot (mppcf) of air threshold limit value, in effect for many years, a total dust standard? 2) Does the presence of visible dust indicate the presence of more than 5 mppcf of dust in the air? 3) Would the presence of visible asbestos-containing dust demonstrate a potential health hazard? The author conducted a review of the available literature to determine the answers to these questions. The author also extensively researched and analyzed the conversion factor or ratio between exposures in units of mppcf and f/cc. The results indicate that: i) the 5 mppcf asbestos standard was based on total dust, not just asbestos dust; ii) the presence of visible dust from ACM operations is likely greater than 5 mppcf; and iii) that the presence of visible asbestos-containing dust likely results in levels above the American Conference of Governmental Industrial Hygienists' (ACGIH) and the Occupational Safety & Health Administration's (OSHA) standards. These results have implications for individuals performing retrospective asbestos exposure analysis.

Introduction

Traditionally, industrial hygienists and those preparing asbestos exposure analyses have simply had to demonstrate that the exposures observed exceeded background levels (i.e., ambient outdoor levels ranging from 1×10^{-8} to 1×10^{-4} and indoor levels ranging from 1×10^{-5} to 1×10^{-4} fibers/cc.)² Thus, the standard to meet was whether or not an individual's exposure level was above these *de minimis*[†] levels or background levels.

Courts in asbestos litigation in the past decade, along with prodding from companies and their representation, have increasingly required quantitation of asbestos exposures beyond arguments that the exposures exceeded *de minimis* or background levels.^{3,4,5,6} For example in *Bannister v. Freemans*,³ the Judge ruled that "The claimant had not established, on a balance of probabilities, that the alleged exposure gave rise to a material increase in the

risk..." Another Judge ruled that the exposure level could not be considered a "material increase in risk" and was therefore *de minimis*.⁴ Others have argued that asbestos exposure levels must be quantitated above *de minimum* levels in terms of finite increased risk or fibers years per cubic centimeter (f-yr./cm³).^{5,6} Thus, increasingly the need has arisen to demonstrate that historic asbestos exposure levels would have been more than background asbestos levels.

One industrial hygiene approach in this situation is to use the concept of Similar Exposure Groups (SEGs) wherein one applies exposure information from other situations that best approximate the exposure(s) of the individual of interest. Two issues arise from this approach: i) the available data to be used for comparison may not well reflect the exposures of the individual of interest and ii) past data/standards were taken in units of million particles per

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[†] An abbreviated form of *de minimis Non Curat Lex*, "the law cares not for small things" - a legal doctrine by which entities like Governmental Regulators and Courts consider such situations to be trifling matters.

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cubic foot of air (mppcf) whereas newer data/standards were taken in units of fibers/cc or fibers/milliliter (f/cc or f/mℓ). Units of f/cc and f/mℓ are equivalent and heretofore the units of f/cc are used. The question of how a set of earlier data/standards compares to that of later data/standards must be addressed. Moreover, this conversion factor or ratio between the older data/standards and newer data/standards have varied considerably.

The purpose of this work was to research these two issues in order to determine if exposure to visible dust created from asbestos-containing materials (ACM) (>1% asbestos) likely exceeds asbestos exposure limits. This was accomplished by posing and answering the following three questions regarding asbestos exposures:

1. Was the ACGIH 5 mppcf threshold limit value (TLV), in effect for many years, a total dust standard?
2. Does the presence of visible dust indicate the presence of more than 5 mppcf of dust in the air?
3. Would the presence of visible asbestos-containing dust demonstrate a potential health hazard?

There has been some suggestion that the 5 mppcf TLV standard was intended to mean 5 mppcf of asbestos particles, not total dust particles.⁷ As will be discussed, it has also been debated whether or not the presence of visible asbestos-containing dust in the workplace constitutes a health hazard. Both of those suggestions will be shown to be false; the ACGIH 5 mppcf TLV standard was a total dust standard and the presence of visible dust emanating from an asbestos-containing source is accepted in the scientific community as constituting a hazard to human health.

Method

The author conducted several literature reviews: the history of approaches used to monitor the airborne levels of asbestos in air; historical asbestos in air Standards and Codes; and a literature review and analysis of conversion factors or the ratio of asbestos exposure data in units of mppcf vs. f/cc to determine the best conversion factor. The author also analyzed the asbestos exposure literature to determine if observing visible dust emissions while working with ACM exceeds acceptable exposure levels.

Results & Discussion

Results, analysis, and discussion for the three questions posed, regarding asbestos exposures based on visible dust, are addressed sequentially below.

Q1: Was the ACGIH Asbestos TLV Standard Based Only on Asbestos Sampling?

ACGIH Nuisance (Total) Dust TLV Standard

Initial efforts to set allowable limits, including those for dust and asbestos, were set by the American Conference of Governmental Industrial Hygienists (ACGIH) beginning in the 1940s. It is informative to compare and understand the differences in both dust and asbestos ACGIH recommended levels with time to illustrate changes in units used (mppcf to mg/m³ for dusts and mppcf to f/cc for asbestos).

The history and evolution of the ACGIH Nuisance (Total) Dust TLV Standard with time is summarized below:^(8,9,10)

- 1964: Nuisance dust introduced – 15 mg/m³ or 50 mppcf, whichever is less.
- 1968: 10 mg/m³, total dust or 30 mppcf.
- 1976: 5 mg/m³, respirable added.
- 1988: Appendix dropped, substances added.
- 1989: Standard changed to Particles Not Otherwise Classified (PNOC).
- 1995: 10 mg/m³, inhalable and 3 mg/m³, respirable (insoluble).
- 2001: Standard changed to Particles Not Otherwise Specified (PNOS).
- 2003: PNOS withdrawn – changed to guidance only.

As can be seen, the total dust standard slowly evolved to Particulates Not Otherwise Specified (PNOS) as it was recognized that certain dust components (e.g., silica and asbestos) were more toxic than other components; by 2003, PNOS, too, was withdrawn. Casserly, representing ACGIH, noted that one of the rationale for the Nuisance (total) Dust Standard was that excessive total dust concentrations would “seriously reduce visibility” (p.15).¹⁰

Similarly, OSHA’s Total Dust Standard is 15 mg/m³ or 50 mppcf – synonyms described as Dust (total); “Inert” dusts; Nuisance dusts; Particles Not Otherwise Regulated (PNOR); and includes all inert or nuisance dusts, whether mineral or inorganic, not listed specifically in 1910.1000.[‡]

ACGIH Asbestos TLV Standard

The history and evolution of the ACGIH Asbestos TLV Standard with time is summarized below:⁸

- 1946-1947: Maximum Allowable Concentration (MAC) – Time-Weighted Average (TWA) – 5 mppcf.

[‡] See: https://www.osha.gov/dts/chemicalsampling/data/CH_259640.html

- 1948-1973: TLV-TWA – 5 mppcf.
- 1978-1999: Specific TLV-TWAs set for individual forms of asbestos (i.e., amosite and tremolite, chrysotile, and other forms and crocidolite).
- 1991: Asbestos, All Forms – Proposed TLV-TWA – 0.2 fibers/cc (fibers longer than 5 µm and with an aspect ratio ≥3:1), A1, Confirmed Human Carcinogen.
- 1997: Asbestos, All Forms – Proposed TLV-TWA – 0.1 fibers/cc (fibers longer than 5 µm and with an aspect ratio ≥3:1), A1, Confirmed Human Carcinogen.
- 1998: Asbestos, All Forms – TLV-TWA – 0.1 fibers/cc (fibers longer than 5 µm and with an aspect ratio ≥3:1), A1, Confirmed Human Carcinogen.

As detailed below, for asbestos ACGIH Standards, it has been determined that the early levels set were likely based on total dust of which asbestos was only a portion of the dust – thus actual exposure levels to asbestos that were the basis of these early standards were actually lower. In addition, to be able to compare older asbestos data/standards with later data/standards, a definitive conversion factor or ratio between information in units of mppcf and f/cc is needed. Both issues are addressed below.

The basis and flaws with the 1946-1973 ACGIH Asbestos TLV Standard of 5 mppcf is well documented in a 1993 Letter to the Editor by Thomas Mancuso.¹¹ One of the major debates regarding the ACGIH Asbestos Standard is whether or not this standard, based on work by Dreessen,⁷ was based on: i) data for only asbestos, ii) data using a percentage of the total dust as asbestos, or iii) was based on total dust measurements.

In this letter, Mancuso noted that the ACGIH 1946 Asbestos TLV of 5 mppcf was based on work by Dreessen, using midget impinger technology that measured “all dust particles seen” (fibrous and non-fibrous), not just asbestos (fibrous) particles. Mancuso concluded by stating:¹¹

In summary, the historical published literature from all sources, governmental and nongovernmental, including the 1986 letter by Cook himself, establish that the TLV of 5 million particles per cubic foot for asbestos for the prevention of asbestosis was for total dust, fibrous and non-fibrous, and was not based upon a percentage of asbestos [...] [Emphasis added; p. 965].

Mancuso supported this opinion with the following statements, reproduced at length here from his letter:¹¹

...The Dreessen dust measurements for total dust was the source for the TLV for asbestos as specified by the ACGIH and was adopted by various states. The ACGIH TLV for asbestos started in 1946 and for all the succeeding years

did not mention nor designate percentage of asbestos in the total dust count as was clearly and repeatedly designated for silica.

1. Fleischer et al.,¹² (1946), in a large scale study of pipe covering operations in shipyards, stated: “There are no established figures for permissible or safe dustiness in pipe covering operations” but added that “In general we feel that dust counts below 5 million particles per cubic foot by Konimeter indicate good dust control” (see also Marr,¹³ 1964). Dreessen et al. in their study of asbestosis in the asbestos textile industry suggested 5 million particles of total dust by impinger as a threshold for that industry.

2. The [1962] ACGIH documentation on Threshold Limit Values states for asbestos: “The present threshold limit value relates to the prevention of asbestosis. It was recommended by Dreessen et al.; counts were from impinger-collected samples in ethyl alcohol and distilled water. Both fibrous and non-fibrous particles were counted, but the latter greatly predominated. While chemical analysis of collected samples of airborne dust corresponded to those of settled dust samples, it is believed that dust counts of particulates by conventional methods can be expected to give only an indirect measure of the risk of asbestosis because of the great relative importance of long fibers.”

3. Schall¹⁴ [1965] presented a critique analysis of the Dreessen et al. report of 1938, which cited an extended series of limitations. This included the basic fact that the method of sampling could not differentiate between cotton and asbestos and that the dust counts were given as average yet the range was enormous. In that analysis, reference was made to total dust, i.e., all particles. It is important to stress that the 5 mppcf value was based upon dust counts of all particles, fibrous and particulate, asbestos or not.

4. Balzer¹⁵ [1967], in a study relative to the TLV and asbestos, stated: “Anyone looking at the present basis for the threshold limit value (TLV) or 5 mppcf as recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) in 1946 realizes that it is not based on solid evidence. The method used in setting the standard includes all dusts (both grains and fibers); and a large portion of the asbestos fibers that were collected had a diameter, when viewed at 100-X magnification, well below the resolving power of the light microscope.”

Again, Balzer and Cooper,¹⁶ reporting on the same study [1968], stated: “To compare our sampling data with the present threshold limit value (TLV) of 5 million particles per cubic foot, we have taken a number of midget impinger samples along with our other methods of sampling. All the samples were counted in accordance with the standard procedures prescribed by the American Conference of Governmental Industrial Hygienists and include both grains and fibers.”

5. The NIOSH¹⁷ recommended standard for asbestos in 1972 in the historical background stated, “In the study of asbestosis conducted by Dreessen et al., midget impinger count data were used as an estimate of dust exposure. All of the dust particles seen, both grains and fibers, were counted since too few fibers were seen to give an accurate measurement. The resulting count concentration was a measure of overall dust levels rather than a specific measurement of the asbestos concentration.”

6. Cook¹⁸, in a letter to Mancuso [1986] acknowledged that prevailing practice of total dust counts for asbestos particles in the prior decades rather than the percentage of asbestos, “In our telephone chat, you wished me to write you concerning my understanding of the inclusion of all dust particles, asbestos and others, in the results of dust counts in the 1930s and on up to the ‘60s when fiber counts over 5 microns in length replaced the dust count of all particles less than 10 microns in diameter. As was the practice at that time, the dust counts reported included both asbestos particles and those of other composition following the procedures of the two above cited publications. This was my practice also.”

Cook further stated in the same letter, “I was interested in reviewing the copy of the Hemeon report of June 1947 for the Industrial Hygiene Foundations of America, prepared during John McMahan’s managing directorship, a report that I had not been aware of even though I was rather close to the Foundation in those years.”

The Hemeon (unpublished) report relative to the TLV and asbestos concluded: “The information available does not permit complete assurance that 5 million is thoroughly safe nor has information been developed permitting a better estimate of safe dustiness. It is nevertheless of the greatest importance either that such assurances be sought or a new yardstick of accomplishment be found for accurately measuring any remaining hazard in the dust zone below five million for the elimination of future asbestosis depends on the degree of control effected now.”

7. Merewether¹⁹ [1938], in his extensive report on silicosis and asbestosis, emphasized the importance of the invisible dust and puts into perspective any consideration of dust levels: “That is to say, that the dust particles which are invisible to the naked eye are the important ones; this leads us to the practical point that if a silica or an asbestos process produces visible dust in the air, then the invisible dust is certainly in dangerous concentration.”

Within this context, Mancuso [1993] stated: “The disease itself provides the medical evidence that the nature of the exposure to asbestos was harmful, regardless of any description of limited or intermittent exposures or numerical designations in any regulations.” [p. 963-963]

Specific papers cited by Mancuso, and others, were reviewed independently by the author. Results from this review follow.

Dreessen, et al. and his coworkers, based on a Public Health Service study, studied asbestos exposure levels of 541 workers in three asbestos textile plants located in South Carolina.⁷ Their study was published by the US Public Health Service as *Public Health Bulletin No. 241, A Study of Asbestosis in the Asbestos Textile Industry*. The PHS Bulletin suggested that maintaining total dust particulate exposure below 5 mppcf would protect most workers from asbestosis; but even here, three cases of asbestosis were observed:⁷

Only three cases of asbestosis, all of them diagnosed as doubtful or borderline cases, were found to be exposed to dust concentrations of less than 5 million particles per cubic foot. (These three individuals had dust exposures of about 4 million particles per cubic foot.) Above 5 million particles per cubic foot, numerous cases of well-marked asbestosis were found. It would seem that if the dust concentration in asbestos factories could be kept below 5 million particles (the engineering section of this report has shown how this may be accomplished), new cases of asbestosis probably would not appear. [p. 177]

Now, nearly eighty years later, several flaws can be observed reviewing Dreessen’s work:

1. The dust measurements were for total dust, not just asbestos dust.
2. The percentage of dust that was asbestos varied and was not correlated with cases of disease.
3. The recommended limiting value for asbestos exposures of 5 mppcf was clearly speculative and not protective based on three cited cases of asbestosis at levels of exposure below 5 mppcf.

Merewether, in his 1938 paper entitled *Dusts and Lungs with Particular Reference to Silicosis and Asbestosis*, noted that all dusts are not equal either physically or in terms of harm to the lungs and resulting diseases:¹⁹

For practical purposes, therefore, so far as present knowledge goes, the dusts which cause serious local effects on the lungs and which may and often do cause disablement and death, are those containing free silica and asbestos; other dusts are harmless in this respect unless, as has been said so happily, “inhaled in insulting concentrations.” [...]

With the silica dusts the dangerous particle size range is up to 10 microns, with the lighter asbestos dust it is much greater, extending up to 200 microns [Due to the fibrous nature.] (p. xiii-xiv)

Schall also discussed the 1938 paper by Dreessen et al., stating:¹⁴

It is not commonly appreciated that the five mppcf indicates a total count, including background dust which may vary greatly including cotton, rock dust, asbestos fibers, etc. On page 23 of the Dreessen paper it is stated

“The measurement of dust particles suspended in the air of asbestos textile plants is difficult because of the presence of both asbestos and cotton fibers. The differentiation of these fibers under the microscope is not always possible, especially when the fibers are short and fine. [p. 318-319]

Schall further explained in detail why the TLV was based on total dust. The method was incapable of collecting just asbestos fibers. The method collected both asbestos and cotton fibers (fibrous) and all other particles (nonfibrous):¹⁴

Counts were from impinger-collected samples in ethyl alcohol and distilled water. Both fibrous and non-fibrous particles were counted, but the latter greatly predominated. [p.316]

Finally, Schall commented on the wide variability of asbestos present in the samples that served as the basis for the 5 mppcf TLV:¹⁴

Table 4 on page 23 (of the Dreessen paper) demonstrates that very few fibers were encountered in the samples collected. One to eight percent were observed in crushing, twisting, carding and picking operations, while 12 percent in one plant, 26 percent in another were present in weaving operations. [p. 319]

In 1965, Robert L. Harris Jr., of the Field Investigation Section Abatement Branch, Division of Air Pollution, U.S. Public Health Service, published in the *Transactions of the National Safety Congress*, regarding dust sampling methods:²⁰

All of the sampling methods used in different parts of the world for estimating exposures to mineral dusts are empirical. None is an absolute method which will yield data from which the hygienic significant exposures can be precisely judged. [p. 9]

Lynch, Ayer, and Johnson demonstrated in their work (see Table 9 below) that not all the dust from textile operations is asbestos dust.²¹

Murphy, Jr. et al., analyzing the work by Dreessen, stated:²²

In retrospect, the choice of 5 mppcf, on the basis of the data then available, was open to question; in the dust counts in textile mills, no distinction was made between cotton and asbestos fibers. [p. 1277]

NIOSH, in their criteria document entitled *Criteria for a Recommended Standard – Occupational Exposure to Asbestos*, commented directly on historical standards used to measure asbestos exposures:^{17,23}

In the past, in the United States, asbestos fibers were measured by the impinger method which included counting particles as well as asbestos fibers. [Emphasis added; p.V-1]

It should be noted that considerable research has been conducted on methods for dust sampling (see for example

Breslin et al.,²⁴ LeClare et al.,²⁵ Leidel and Busch,²⁶ Leidel et al.²⁷

Thus, the answer for this first question regarding the basis for the ACGIH TWA-TLV for asbestos of 5 mppcf was that it was based on total dust, not just asbestos dust.

Q2: Is the presence of total dust at 5 mppcf visible and if so, what would be the exposure in f/cc?

Presence of Visible Dust in the Air

Several studies have commented on the levels of dust needed to be visible to the naked eye. These are summarized below.

Arthur S. Johnson, in his 1935 paper entitled, *No Half Way Measures in Dust Control*, published in the *National Safety News*, stated:²⁸

I think we need to digress for a moment to visualize what is meant by 5 million particles of dust of such tiny size. We know it is invisible to the naked eye because it takes 15 to 20 times that much to produce a haze, and even that isn't visible as particles of materials. [p.18]

He further stated: “If you can see the dust you know it to be a terrific hazard” [p. 18].

Arthur S. Johnson, in his 1937 paper entitled *The Engineer's Part in Eliminating Dust Hazards*, published in the *Industrial Dusts 27th National Safety Congress*, stated:²⁹

Five million particles is virtually dust free, and is very difficult and expensive to achieve and maintain. [Emphasis added; p. 3]

Merewether, in his 1938 paper entitled *Dusts and Lungs with Particular Reference to Silicosis and Asbestosis*, stated:¹⁹

...the dust particles which are invisible to the naked eye are the important ones. This brings us to the practical point that if an asbestos or silica process produces visible dust in the air, then the invisible dust is certainly in dangerous concentrations. [Emphasis added; p. xiv]

Warren A. Cook, in his 1942 paper entitled *The Occupational Disease Hazard – Evaluation in the Field*, published in *Industrial Medicine*, stated:¹⁸

In the case of the asbestos dust condition, our evaluation of the exposure should be based on the knowledge that the present toxic limit for asbestos is five million particles of dust per cubic foot of air. This is a very small concentration, so small in fact that the condition may look good even to a critical eye and still present an exposure greater than this low limit. Some indication of the amount of dust present in the air may be obtained by noting the layer of dust on nearby settling places after learning how long a time has elapsed since they were last cleaned. *If* only a thin layer of dust has accumulated over six months or a year and there are no visible puffs of dust escaping

from the operation, it is probable that the condition is satisfactory. [Emphasis added; p. 194]

In the “Optical Properties” chapter of their 1936 (updated 1954) book *Industrial Dusts*, Drinker and Hatch recognize that certain levels of dust suspended in the air are invisible to the naked eye when they discuss methods to demonstrate its presence by using Tyndall Lighting (directing a beam of light through a darkened room) [p. 26].^{30,31} This is the same unique lighting method used to film asbestos release incidents (e.g., Longo³² experiments and work by Compton and Millette³³ and Millette, Compton, and DePasquale³⁴) where releases are above exposure limits.

Wesley Hemeon’s textbooks, *Plant and Process Ventilation – 1st and 2nd Ed.*, demonstrates that it is a generally accepted industrial hygiene principal that the presence of visible dust in the air indicates the dust concentration exceeds 5 mppcf.^{35,36} He states:³⁶

...it is clear by comparing this scale of values (Table 1-8) with threshold concentrations of free silica dust (5 million particles per cubic foot) that hazardous conditions are apparent visually only under the most favorable conditions of illumination. On the other hand, the figure most generally accepted as defining the upper limits of decent working conditions for miscellaneous non-metallic mineral dusts, 50 million particles per cubic foot, will be visually apparent in nearly all common conditions of illumination. [p. 15]

Thus, Johnson, Cook, and Hemeon essentially state that airborne dust is not visible at 5 mppcf levels. More recently, others have made similar observations. In 1958, the US Department of Labor published Bulletin 198, *Occupational Health Hazards, Their Evaluation and Control*, which stated:³⁷

It must be remembered that the dust which cannot be seen by the unaided eye is the most hazardous since it is of respirable size. Dust concentrations must reach very high levels before they are readily visible in the air. The absence of a visible dust cloud does not mean that a dust free atmosphere exists. [Emphasis added; p. 14-15]

In 1965, Robert L. Harris Jr., of the Field Investigation Section Abatement Branch, Division of Air Pollution, U.S. Public Health Service, published the following in the *Transactions of the National Safety Congress*:²⁰

...dust particles which are hazardous to health when inhaled are invisible to the unaided eye. [...]

Small particles, those in the range of 1 micron diameter, behave in air much differently than do particles which are large enough to be seen. [p. 7]

A 1966 Union Carbide memo discussed asbestos dust levels at five million particles per cubic foot as being invisible to the naked eye, stating:³⁸

(T)his concentration of dust is generally not visible in the average work area unless a beam of light causing a Tyndall

effect is present. Usually the dust concentration must be from 8 to 10 million particles per cubic foot before its presence is visible in average lighting conditions. [p.1-2]

Thus, it is apparent from these references that dust levels at/near 5 mppcf are not visible.

Comparison of f/cc to mppcf Levels

To compare and contrast earlier total dust levels reported in units of mppcf to those later reported for asbestos in fibers per cubic centimeter (f/cc), as is often needed in epidemiology studies, a ratio between f/cc and mppcf is needed.

The consensus best approach to determining this ratio would be pair data, where data using an impinger (for mppcf data) and a membrane filter (for f/cc data) were taken side-by-side. Fortunately, in the 1960s and 1970s, a number of such experiments were conducted and the results analyzed, to determine this ratio. Much of the work in this area was completed by the Department of Health, Education and Welfare’s Division of Occupational Health, Public Health Service.

From 1930 to 1975, 5,952 airborne dust samples were taken in textile facilities, mostly in South Carolina. From 1930 to 1965, samples were taken using impinger methods; from 1965 to 1971 using impinger and membrane filter methods; and from 1971 forward, membrane filter methods were used [Dement³⁹; see also McDonald et al.⁴⁰ and McDonald et al.⁴¹]. The earlier impinger methods produced airborne dust results in units of mppcf whereas the membrane filter produced results in either a mass of total dust or when examined under a microscope to determine the number of fibers per cubic centimeter or milliliter of air (f/cc or f/ml). The f/cc value depends on how one defines a fiber (typically with an aspect ratio – length to diameter – of 3) and the length of fibers counted (typically all fibers, fibers >5 µm or fibers >10 µm).

Below is a literature review of past work that attempts to determine this ratio (f/cc to mppcf); that is, what factor(s) one should multiply data taken in units of mppcf to convert the data to units of f/cc.

Ayer et al., 1965:⁴² Ayer and his coauthors completed 230 paired samples at five facilities producing asbestos textiles where the midjet impinger and membrane filter samples “were taken within a few centimeters of one another” [p. 277]. Results for this study, as with most studies, were typically broken down by fiber length: i) all fibers, ii) fibers >5µm in length, and iii) fibers >10 µm in length. The authors summarized these ratios obtained for data from four of the plants as follows:

- All fibers: Ratio (to convert from mppcf to f/cc, multiply mppcf by): 10

- Fibers >5µm in length: Ratio: 6
- Fibers >10µm in length: Ratio: 3

When utilizing optical fiber counting methods, fibers greater than 5 µm in length with an aspect ratio of 3:1 are traditionally defined as asbestos fibers (see Dement, et al.⁴³) although Gibbs and Eng report that only a fraction of amosite, crocidolite, and chrysotile fibers are >5 µm.⁴⁴

Actual data for the all fibers and fibers >10µm in length were presented in the paper and are reproduced as Tables 1 and 2. Thus, while the authors concluded that the value for the ratio (f/cc to mppcf) for all fibers should be 10, the actual overall average value was 9.4, with a range of values from 2 to 27. Again, while the authors concluded a value for the ratio (f/cc to mppcf) for fibers >10µm in length should be 3, the actual overall average value was 2.7, with a range of values from 1 to 8.

*Lynch and Ayer, 1966:*⁴⁵ Lynch and Ayer wrote a follow-up paper of paired sampling results at nine textile plants completed by the Department of Health, Education and Welfare’s Division of Occupational Health, Public Health Service from January of 1964 to June of 1965. The nine plants reportedly covered 80% of the workers (>2,500) in the industry and was comprised of 1,896 membrane filter and 1,115 impinger samples. This time, the authors presented impinger and membrane filter data (Tables 3 and 4), but did not present the ratio of these values.

Again, membrane filter results (Table 4) were: i) all fibers, ii) fibers >5µm in length, and iii) fibers >10 µm in length. Using the data in Tables 3 and 4, one can develop the ratios (f/cc to mppcf) for the three ranges of fiber lengths (Tables 5, 6, and 7).

Table 1: Ratio of f/cc to mppcf – All Fibers Ayer et al.⁴² – Table 1

Operation	Plant				Avg. Ratio by Operation
	A	B	C	D	
Preparation	11	8	4	11	8.6
Carding	9	14	6	27	12.7
Spinning	6	6	3	13	8.3
Twisting	6	2	7	14	6.5
Weaving	6	20	4	15	12.5
Avg. Ratio by Plant	8.0	8.6	5.2	15.5	9.4

Table 2: Ratio of f/cc to mppcf – Fibers >10µm in length Ayer et al.⁴² – Table 2

Operation	Plant				Avg. Ratio by Operation
	A	B	C	D	
Preparation	5	4	1	3	1.7
Carding	2	5	2	6	3.5
Spinning	2	4	1	4	2.5
Twisting	2	1	3	5	2.5
Weaving	3	8	4	4	3.8
Avg. Ratio by Plant	2.2	2.7	1.2	4.5	2.7

Table 3: Impinger Mean Dust Concentrations (mppcf) by Plant and Operation - Lynch and Ayer⁴⁵ – Table II

Impinger Mean Dust Concentration by Plant and Operation (mppcf)										
Operation	Plant									
	A	B	C	D	E	F	G	H	I	All
Fiber Prep.	5.0	1.5	2.6	2.5	-	0.5	1.7	2.5	0.6	2.3
Carding	2.2	1.2	2.7	1.8	-	0.6	0.7	3.2	0.3	1.2
Spinning	2.2	0.7	3.4	3.0	-	0.5	2.0	1.3	1.1	1.2
Twisting	1.3	2.3	2.5	5.4	-	0.4	3.9	1.5	0.4	1.9
Winding	1.2	0.9	2.0	1.7	-	0.4	3.0	0.4	0.4	1.0
Weaving	1.3	0.5	0.4	3.7	0.6	0.3	1.1	0.4	0.3	0.8
All	2.7	1.3	2.2	2.8	0.6	0.5	1.7	1.1	0.5	1.3

Table 4: Membrane Filter Mean Dust Concentrations (f/cc) by Plant and Operation - Lynch and Ayer⁴⁵– Table III

Membrane Filter Mean Dust Concentration by Plant, Operation, and Fiber Size (fibers/cc or f/cc or f/ml)											
Operation	Plant										
	Fiber Size	A	B	C	D	E	F	G	H	I	All
Fiber Prep.	Total	38.1	12.3	23.3	34.0	-	8.1	7.6	35.5	11.8	21.2
	>5 μ	15.0	10.0	13.3	18.3	-	3.0	4.5	17.0	2.6	7.6
	>10 μ	7.1	3.4	5.8	8.2	-	1.1	2.0	9.3	1.2	4.2
Carding	Total	18.1	13.6	20.6	32.9	-	6.0	17.2	28.2	8.3	14.9
	>5 μ	10.2	9.2	13.3	15.2	-	3.5	8.1	13.4	2.0	7.0
	>10 μ	4.3	4.1	5.9	8.4	-	1.6	3.2	7.1	0.9	3.7
Spinning	Total	9.6	4.1	20.2	29.8	-	5.1	24.8	20.8	7.4	12.3
	>5 μ	6.6	3.2	18.9	15.7	-	3.5	10.8	10.5	1.8	6.2
	>10 μ	3.2	1.9	6.4	10.3	-	1.8	6.3	6.1	1.1	3.6
Twisting	Total	9.3	6.9	15.8	51.4	-	4.8	25.9	16.7	3.1	14.0
	>5 μ	6.4	5.2	7.5	22.4	-	3.3	12.9	7.2	1.1	6.7
	>10 μ	3.7	3.3	4.7	18.8	-	1.9	7.8	4.1	0.7	4.7
Winding	Total	11.7	4.4	9.6	28.6	-	4.5	25.7	7.9	3.6	9.9
	>5 μ	7.5	3.9	8.9	17.5	-	3.2	11.7	2.7	1.3	4.6
	>10 μ	4.7	1.7	3.4	11.9	-	2.0	7.3	1.6	0.9	3.4
Weaving	Total	7.7	7.0	2.9	33.8	4.5	2.9	9.5	8.1	2.9	8.0
	>5 μ	4.8	3.1	2.3	17.8	3.9	2.2	5.7	3.0	1.5	3.6
	>10 μ	2.9	2.8	1.1	9.8	1.4	1.2	3.3	1.8	0.7	2.5
All	Total	17.3	10.2	15.7	34.7	4.5	4.6	16.2	14.4	5.9	12.5
	>5μ	8.5	7.5	9.4	12.1	3.9	3.0	8.1	6.3	1.7	5.6
	>10μ	4.4	3.4	4.7	10.5	1.4	1.5	4.4	3.6	0.9	3.5

Table 5: Ratio of f/cc to mppcf by Plant and Operation – All Fibers

Ratio of f/cc to mppcf: Mean of Results by Plant and Operation – All Fibers										
Operation	Plant									
	A	B	C	D	E	F	G	H	I	All
Fiber Prep.	7.62	8.20	8.96	13.60	-	16.20	4.47	14.20	19.67	9.22
Carding	8.23	11.33	7.63	18.28	-	10.00	24.57	8.81	27.67	12.42
Spinning	4.36	5.86	5.94	9.93	-	10.20	12.40	16.00	6.73	10.25
Twisting	7.15	3.00	6.32	9.52	-	12.00	6.64	11.13	7.75	7.37
Winding	9.75	4.89	4.80	16.82	-	11.25	8.57	19.75	9.00	9.90
Weaving	5.92	14.00	7.25	9.14	7.50	9.67	8.64	20.25	9.67	10.00
All	6.41	7.85	7.14	12.39	7.50	9.20	9.53	13.09	11.80	9.62

Table 6: Ratio of f/cc to mppcf by Plant and Operation – Fibers >5 µm in Length

Ratio of f/cc to mppcf: Mean of Results by Plant and Operation – Fibers >5 µm in Length										
Operation	Plant									
	A	B	C	D	E	F	G	H	I	All
Fiber Prep.	3.00	6.67	5.12	7.32	-	6.00	2.65	6.80	4.33	3.30
Carding	4.64	7.67	4.93	8.44	-	5.83	11.57	4.19	6.67	5.83
Spinning	3.00	4.57	5.56	5.23	-	7.00	5.40	8.08	1.64	5.17
Twisting	4.92	2.26	3.00	4.15	-	8.25	3.31	4.80	2.75	3.53
Winding	6.25	4.33	4.45	10.29	-	8.00	3.90	6.75	3.25	4.60
Weaving	3.69	6.20	5.75	4.81	6.50	7.33	5.18	7.50	5.00	4.50
All	3.15	5.77	4.27	4.32	6.50	6.00	4.76	5.73	3.40	4.31

Table 7: Ratio of f/cc to mppcf by Plant and Operation – Fibers >10 µm in Length

Ratio of f/cc to mppcf: Mean of Results by Plant and Operation – Fibers >10 µm in Length										
Operation	Plant									
	A	B	C	D	E	F	G	H	I	All
Fiber Prep.	1.42	2.27	2.23	3.28	-	2.20	1.18	3.72	2.00	1.83
Carding	1.95	3.42	2.19	4.67	-	2.67	4.57	2.22	3.00	3.08
Spinning	1.45	2.71	1.88	3.43	-	3.60	3.15	4.69	1.00	3.00
Twisting	2.85	1.43	1.88	3.48	-	4.75	2.00	2.73	1.75	2.47
Winding	3.92	1.89	1.70	7.00	-	5.00	2.43	4.00	2.25	3.40
Weaving	2.23	5.60	2.75	2.65	2.33	4.00	3.00	4.50	2.33	3.13
All	1.63	2.62	2.14	3.75	2.33	3.00	2.59	3.27	1.80	2.69

Based on results from Tables 5, 6, and 7 findings for the ratio of f/cc to mppcf are:

- All fibers: Ratio (f/cc to mppcf):
 - Overall average: 9.6
 - Overall range of values: 3.0 to 27.7
- Fibers >5µm in length: Ratio (f/cc to mppcf):
 - Overall average: 4.3
 - Overall range of values: 1.6 to 11.6
- Fibers >10µm in length: Ratio (f/cc to mppcf):
 - Overall average: 2.7
 - Overall range of values: 1.0 to 7.0

Although not specified in this paper, it is clear that not all these sample results were paired results based on later work;²¹ and these ratios are slightly different when only using paired results (see Lynch, Ayer, and Johnson analysis below).

Balzer and Cooper, 1968.¹⁶ Balzer and Cooper completed impinger and membrane filter sampling of northern California and northern Nevada insulation workers using asbestos-containing materials (ranging from 10 to 100% amosite, chrysotile or amosite/chrysotile asbestos) under six tasks (prefabrication, application, finishing, tearing out, mixing, and general). A total of 64 impinger samples and 153 membrane filter samples were taken. Samples included both area and personal samples, but the paper does not explicitly state samples were paired.

Sample results, and the ratio of f/cc to mppcf calculated, are shown in Table 8. Note that the overall mean and median ratios are 1.22 and 0.70 respectively.

Lynch, Ayer, and Johnson, 1970.²¹ Lynch, Ayer, and Johnson wrote a follow-up paper of paired sampling from three industries (textile, friction, and pipe) as part of their ongoing work completed by the Department of Health, Education and Welfare’s Division of Occupational Health, Public Health Service. This included additional analysis of the textile data found in their 1965 and 1966 publications

Table 9: Ratio of f/cc to mppcf by Industry Along with Plant Characteristic Asbestos Data [based on Tables II & IX of Lynch et al.²¹]

Industry/Product	# of Sets of Paired Data	Ratio of f/cc to mppcf by Fiber Size			Asbestos Content (%)		
		All Fibers	>5µm	>10µm	Product	Total Dust	Respirable Dust
Textile	500	10.3	5.9	2.7	75 to 85	68	64
Friction	200	3.7	2.2	1.0	30 to 60	22	36
Pipe	100	4.8 ^a	1.9 ^a	0.7	10 to 30	12	18
Shingle	N/A	-	-	-	10 to 30	25	28
Insulation	N/A	-	-	-	5 to 15	4	6

^a Correlation Coefficient not significant at 95%.

Table 10: Ratio of f/cc to mppcf from the Quebec Chrysotile Industry – Gibbs⁴⁴

Mine	Overall Mean	Ratio of f/cc to mppcf by Mine and Operation								
		Under-ground	Open Pit		Dryer and Crusher		Mill			
			Drill	Shovel	Dryer	Crusher	Rock Screen	Fiber Screen	Bagging	Storage
A	4.5	1.7	8.0	5.4	3.2	2.5	4.9	3.5	8.1	3.3
B	11.4	-	9.1	2.4	29.8	3.7	29.8	8.5	6.1	2.0
C	21.9	-	5.2	7.9	15.9	12.5	32.6	47.4	31.1	22.8
D	5.9	-	-	-	2.0	8.8	10.4	4.3	3.8	-
E	1.7	-	0.6	0.5	0.4	1.1	0.3	5.3	4.5	0.8
All Mines	-	1.7	5.3	4.6	9.5	5.3	14.2	11.0	10.4	8.1

reviewed earlier. A summary of their findings on the ratio of f/cc to mppcf for these three industries, using paired sampling data, are summarized in Table 9. Note that textile ratios of 10.3, 5.9, and 2.7 (all fibers, >5 µm and >10 µm respectively) represent paired data; the values of 9.6, 4.3, and 2.7 calculated from all data (Tables 5, 6, and 7) clearly suggest that not all the data taken were paired. The authors concluded:

The preferred index of asbestos exposure is fibers longer than 5 microns counted on membrane filters at 430x phase contrast. The method of counting is convenient and practical, and fibers >5 microns constitute a direct index of asbestos exposure. [Emphasis added; p. 604]

Gibbs, 1974.⁴⁴ Gibbs wrote a paper including paired sampling of dust samples from the Quebec chrysotile industry. Area sampling was completed at nine sites in each of five mines and mills using paired midget impinger and membrane filter samplers. A total of 78 paired samples were taken. Any particle having a length to width ratio of 3:1 was counted as a fiber. Results are reproduced in Table 10.

Gibbs noted that a plot of all the impinger vs. membrane filter data did not result in an acceptable correlation coefficient. This is not unexpected as the data in Table 10 clearly suggests widely variable levels for the same operation between plants. Moreover, the basis for the fiber counts was simply any particles with an aspect ratio (L:W) of 3:1 rather than particle length (e.g., >5 µm). Although the data are paired, the method for counting fibers, without regard to fiber length, is inconsistent with other work cited.

Dement et al., 1982.⁴³ Dement et al. reported on ratios of f/cc to mppcf. While the raw data were not explicitly referenced or provided, they cited U.S. Public Health Service data from 1965 (120 sets of paired) and from 1968-1971 (986 sets of concurrent) as the basis for the following conclusions:

Paired Data (1965) and Concurrent Data (1968 to 1971):

- Textile industry – all operations except preparation:
 - Ratio of f/cc to mppcf: 3
 - 95% confidence interval: ~2.0 to ~3.5

Concurrent Data (1968 to 1971):

- Textile industry – preparation only operation:
 - Ratio of f/cc to mppcf: 8
 - 95% confidence interval: ~5 to ~9

These data were based on fibers >5µm in length.

Dement et al., 1983.³⁹ Dement et al. reported on ratios of f/cc to mppcf. Based on their citations, it is apparent that they drew on U.S. Public Health Service data from 1965 (120

sets of paired) and from 1968-1971 (986 sets of concurrent) as the basis for their further analysis and comments on ratio factors considered in this paper. The authors concluded:

Paired Data (1965):

- Textile industry – all operations except preparation:
 - Ratio of f/cc to mppcf: 2.9 for fibers > 5 µm
 - For α = 0.05, no statistical differences found by plant operation or increasing impinger concentration

Concurrent Data (1968-1971):

- Textile industry – all operations except preparation:
 - Ratio of f/cc to mppcf: 2.5 for fibers > 5 µm
 - For α = 0.05, no statistical differences found by calendar time nor plant operations – except preparation
- Textile industry – preparation only operation:
 - Ratio of f/cc to mppcf: 7.8 for fibers > 5 µm

The authors noted that for conversion work in their paper, they used ratios of 3 f/cc to mppcf (all operations except preparation) and 8 f/cc to mppcf (preparation) and that these factors would be conservative as they were on the upper end of the 95% confidence intervals.^{39,46}

McDonald et al., 1983.⁴⁷ McDonald et al., like many studies completed in this era, focused on the epidemiology of workers to asbestos exposure in South Carolina textile plants making asbestos-containing products. As part of their paper, they needed a ratio between f/cc to mppcf and relied on/interpreted much of the same data relied on by Dement and others.

Further references: Many of the standard references and more modern references tend to select an overall ratio of 6, which was likely derived from the work of Ayer et al.⁴² and McDonald et al.⁴⁵

Source	Year	Ratio or Conversion Factor (f/cc to mppcf)
ACGIH ⁸	1968	6
NIOSH ^{17,23}	1972	3
NSC ⁵³	1984	6
Mangold ⁴⁹	2004	6 to 10
MSHA citing OSHA ⁵⁰	2008	1.4
Williams ⁵¹	2007	6 (from ACGIH)
Kopelovich ⁵²	2013	6 (from ACGIH)
Adams ⁴⁸	2015	6

A summary of the authors’ findings discussed above, regarding the ratio (i.e., f/cc to mppcf), follows:

- Mining and milling operations:
 - The ratio factors varied greatly.
 - For equivalence of fibers >5 µm in length and lung cancer mortality, a ratio of f/cc to mppcf of 3.64 appeared to them to be appropriate.
- Textile Mill operations (fibers >5 µm in length):
 - Dement et al.³⁹ used a Ratio of 3 for all operations except Preparation, where a ratio of 8 was used.
 - Ayer et al.⁴² used a ratio of 6 for all operations.
 - McDonald et al.⁴⁷ used an overall ratio of 6 (range from 1.3 to 10.0) for all operations.

The authors noted that the overall average ratio (f/cc to mppcf) between mining/milling and textile operations was a factor of ~2 and viewed this as “relatively minor.”

Nevertheless, the consensus best method for determining a conversion factor (f/cc to mppcf) comes from sources using paired experimental data (i.e., where both f/cc and mppcf values were measured at the same time).

The paired experimental data, for fibers >5 µm or fiber L/W ratio >3, are summarized below:

Source	Scenario	Ratio or Conversion Factor (f/cc to mppcf)
Ayer et al. ⁴²	Textiles	6
Lynch and Ayer ⁴⁵	Textile Plants (9)	4.31 (1.6 to 11.6)
Balzer and Cooper ¹⁶	Insulation Workers / ACM Present	1.22 (0.29 to 3.43)
Gibbs ⁴⁴	Mines – Underground	1.7
	Mines – Open Pit	4.45 (0.5 to 9.1)
	Operations – Dry/Crush	7.4 (0.4 to 29.8)
	Operations – Mill	10.9 (0.8 to 47.4)
Lynch et al. ²¹	Textile	5.9
	Friction	2.2
	Pipe	1.9
Dement et al. ³⁹	1965 – Textile except prep.	2.9
	1968-1972 – Textile except prep.	2.5
	1968-1972 – Textile – prep.	7.8

Based on this analysis, a mean overall average ratio (f/cc to mppcf) of paired sampling results summarized above is 4.55 with a range of 1.22 to 10.9. Note that these values cover textile, mining, mining processing, insulation, friction, and piping areas but do not cover every industry, occupation, or task.

Thus, if one converts 5 mppcf to f/cc, the range of values are 6.1 to 54.5 f/cc with an average value of 22.75 f/cc. Moreover, the literature implies that either no visible dust is present at these levels or it is present under only special lighting conditions.

In sum, the presence of total dust at 5 mppcf is likely not to be visible except in cases of special lighting. The presence of asbestos dust at 5 mppcf implies a fiber count of at least 6.1 to 54.5 f/cc with an average value of 22.75 f/cc.

Q3: Does the presence of visible asbestos dust in the air pose a likely hazardous situation?

As noted in the previous section, dust present at 5 mppcf is not reported to be visible and at this level correlates to levels of between ~6.1 and ~54.5 f/cc (median of ~22.5 f/cc). Thus, actual f/cc counts when visible asbestos-containing dust was present would be even higher.

While it is now generally agreed that any asbestos exposure poses a health hazard, this question primarily regards retrospective dust exposure analyses, where a question of hazard is determined by exposures in excess of the recommended standards for allowable levels of asbestos in the air. In the United States, these are:⁵³

Source	Limit (f/cc)
ACGIH TLV	0.2 f/cc for crocidolite; 0.5 f/cc for amosite, & 2 f/cc for chrysotile
NIOSH REL	0.1 f/cc
OSHA PEL	0.1 f/cc; 1 f/cc for 30 min. excursion
MSHA	2

Thus, these values (6.1 to 54.5 f/cc) are factors of 61 to 545 above the OSHA PEL value. Even if one assumes that not all the 5 mppcf dust was asbestos, but was as low as 64% to as low as 4% of the total dust (see Lynch, Ayer, and Johnson²¹ – Table 9 above), these values are still factors of 2.4 to 349 above the OSHA PEL value. In fact, a visible dust cloud containing as little as 0.3% asbestos would still correspond to a f/cc level in excess of the 0.1 f/cc OSHA PEL value. Thus, if asbestos dust is visible, it would present exposure levels well above current ACGIH and OSHA values for airborne asbestos exposures, thereby presenting a hazardous situation. Note that regulatory values like the OSHA PEL or ACGIH TLV reflect the value occurring for an eight-hour work period.

Comparison of f/cc to mg/m³

Total and respirable dust are often reported in terms of mg/m³ for nuisance dusts, but not generally for asbestos. However, to further evaluate this conclusion regarding visible dusts likely exceeding exposure limit values, comparisons of the f/cc to dust levels in units of mg/m³ were completed. For instance, the United States National Research Council (NRC) Consensus Study Report on *Asbestiform Fibers: Nonoccupational Health Risks* (1984) provided a PCM value of 30 f/cc per 1 mg/m³ dust (see NRC Table 4-2).⁵⁴ The author of this paper reviewed the references, and found that the paper by Davis et al. provided specific data and conditions.⁵⁵ Davis et al. reported that 0.1 mg dust/m³ was equivalent to 19.5 f/cc, 8.6 f/cc, and 5.5 f/cc for amosite, chrysotile, and crocidolite, respectively. This implied 1 mg/m³ equals 195, 86, and 55 f/cc for pure (100%) amosite, chrysotile, and crocidolite, respectively. Note NRC's Table 4-2 used a slightly lower value of 30 f/cc per mg/m³, the basis of which is indeterminate. Since this work involved pure (100%) amosite, chrysotile, and crocidolite, one can compute the dust levels at which 0.1 f/cc would occur. This correlates to 0.05%, 0.11%, and 0.18% asbestos in the dust to reach 0.1 f/cc for amosite, chrysotile, and crocidolite, respectively. Even using the NRC Table 4-2 value of 30, the equivalent allowable percent asbestos in the dust would be 0.33%. Thus, low levels of asbestos in the dust result in exceedances of the 0.1 f/cc level based on data from these two studies.

Similar conclusions are found in published and unpublished literature, including deposition testimony. These are outlined below.

Merewether, 1938:¹⁹ Merewether, in his paper entitled *Dusts and Lungs with Particular Reference to Silicosis and Asbestosis*, stated:

...the dust particles which are invisible to the naked eye are the important ones. This brings us to the practical point that if an asbestos or silica process produces visible dust in the air, then the invisible dust is certainly in dangerous concentrations. [Emphasis added; p. xiv]

Schall, 1965:¹⁴ Shall also discussed the 1938 paper by Dreessen et al. (the paper that provided the basis for the ACGIH recommended asbestos control level of 5 mppcf), stating:

It is important to stress that the five mppcf value is based upon dust counts of all particles, fibrous and particulate, asbestos or not. Therefore, it cannot be presumed to represent a safe limit of asbestos in all applications. [p.320]

Dick Wolf (Westinghouse Memo), 1975:⁵⁶ Dick Wolf, a Westinghouse Safety Inspector, in a document produced by

Westinghouse during litigation, was asked to investigate the potential hazards associated with the materials used to make gaskets. In a June 1975 memo, he reported:

It has been the experience of the industrial hygiene laboratory that any of the visible dust produced by operations on asbestos-containing materials produces excessive quantities of airborne asbestos fibers. [p. 1]

Longo et al., 2002:³² Longo et al. noted that in a work practice study involving the release of asbestos dust during gasket removal, Tyndall lighting was utilized to demonstrate the presence of dust in the workplace, which was otherwise not observable to the naked eye. As a result of this study, published in the peer reviewed literature, the authors concluded: "under normal lighting, airborne dust is invisible even though the asbestos levels measured are above OSHA excursion limits" [p. 60].

Compton and Millette, 2012:³³ Compton and Millette, conducting a pressing operation using J.T. Baker Powminco Asbestos (~98% tremolite/actinolite and possibly anthophyllite), observed no visible dust unless Tyndall lighting was utilized even though the level of airborne asbestos was 1.18 f/cc. Again, this demonstrated a presence of asbestos dust in the workplace above exposure limits, which was otherwise not observable to the naked eye. Videos of this experiment are used by training professionals to warn sample collectors that a lack of visible dust does not mean there is no hazard.

Marjorie Drucker Deposition Testimony, 2004:⁵⁷ Marjorie A. Drucker was a GE corporate representative who has also testified in 2004 as an expert witness on behalf of General Electric in 2004 in Re: New York State Asbestos Litigation in the Supreme Court of New York for all counties. As part of her preparation for her testimony, Ms. Drucker was asked by GE to look into historical aspects of industrial hygiene, state-of-the-art matters, and asbestos in relation to GE. She acknowledged that GE knew as early as 1935 that while 5 mppcf was an invisible level of dust, it still posed a hazardous level of exposure. [p.812-817]

Robert Adams Deposition Testimony, 2015:⁴⁸ Robert Adams, a Certified Industrial Hygienist (CIH), testified "yes" to the question "so the 5 million particles per cubic foot of air exceeds any PEL that ever existed, correct?" [p. 141].

Use of visible dust as a clearance criteria

The US Environmental Protection Agency (EPA) National Emission Standard for Hazardous Air Pollutants, (the NESHAP) 40 CFR 61.145 *et seq.*, prohibits visible

emissions of asbestos-containing material.^{37,58,59,5} The EPA was created by Congress in 1970. Asbestos was one of the first substances EPA regulated. EPA commented on its website:

On March 31, 1971, EPA identified asbestos as a hazardous pollutant, and on April 6, 1973, EPA promulgated the Asbestos NESHAP, currently found in 40 CFR Part 61, Subpart M.

The NESHAP, at 40 CFR § 61.150, Standard for waste disposal for manufacturing, fabricating, demolition, renovation, and spraying operations, states:⁵⁹

Each owner or operator of any source ... shall comply with the following provisions:

Discharge no visible emissions to the outside air during the collection, processing (including incineration), packaging, or transporting of any asbestos-containing waste material generated by the source or use one of the emission control and waste treatment methods specified in paragraphs (a) (1) through (4) of this section... [Emphasis added; p.117]

The discharge of visible emissions has resulted in numerous criminal and civil enforcement actions. US EPA routinely charges persons who release visible emissions of asbestos dust into the air both criminally and civilly.^{60-62,**}

Finally, it should be noted that it is standard practice on asbestos clearance inspections to perform a visual inspection first; no clearance sampling is to be completed if dust or residual dust is found in the air or on surfaces in the abated area to be cleared after blowing off surfaces (typically with a leaf blower). If visible dust is found, re-cleaning must occur, and the visual inspection successfully completed before any clearance sampling is performed.

The US EPA, under the NESHAPS Standard (40 CFR Part 61, Subpart M) for asbestos emissions noted that the purpose of the regulation was to: “minimize the release of asbestos fibers during activities involving the handling of asbestos.”⁵⁹ This standard, first promulgated on April 3, 1973 and last updated in 1995, required no visible dust be discharged into outside air for “collection, mixing, wetting and handling operations.” Other portions of the Standard require reporting of visible dust emissions. Clearly, as early as 1973, the US EPA wanted to prevent exposures to visible asbestos-containing dusts.

In sum, the presence of visible levels of dust created by the use of a material that contains asbestos will likely result in excessive exposure levels.

Conclusion

This paper posed the following three questions regarding asbestos exposures:

1. Was the ACGIH 5 mppcf TLV, in effect for many years, a total dust standard?
2. Does the presence of visible dust indicate the presence of more than 5 mppcf of dust in the air?
3. Would the presence of visible asbestos-containing dust demonstrate a potential health hazard?

Analysis of the literature found that i) the 5 mppcf asbestos standard was based on total dust, not just asbestos dust; ii) the presence of visible dust from asbestos-containing materials (ACM) operations is likely greater than 5 mppcf; and, iii) that the presence of visible asbestos-containing dust likely results in levels above ACGIH and OSHA standards.

These results have implications for individuals performing retrospective asbestos exposure analysis where the presence of visible dust from operations or the disturbance of asbestos-containing materials (ACM) occurred and provide a method to quantitate such exposures which often were not monitored and/or measured.^{44, 63, 64}

Limitations

This work is limited by available information regarding paired experimental (measured) data for conversion of mppcf and mg/m³ to f/cc as well as literature and experimental work regarding levels of visible asbestos-containing dust in the air to this author.

⁵ Available from: <https://www.gpo.gov/fdsys/pkg/CFR-2011-title40-vol8/pdf/CFR-2011-title40-vol8-sec61-150.pdf>

** see, e.g., U.S. v. Anthony Dell'Aquila, Enterprises and Subsidiaries, 150 F.3d 329 (C.A.3, 1998); U.S. v. Midwest Suspension and Brake, 49 F.3d 1197 (C.A.6, 1995); U.S. v. Walsh, 8 F.3d 659 (C.A.9, 1993); U.S. v. Ho, 311 F.3d 589 (5th Cir. 2002).

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