EVALUATION OF THE APPROACH RECENTLY PROPOSED FOR ASSESSING ASBESTOS-RELATED RISK IN EL DORADO COUNTY, CALIFORNIA

D. Wayne Berman, Ph.D.
Aeolus, Inc.
751 Taft St.
Albany, CA 94706

Prepared at the request of:
William C. Ford
Senior Vice President
National Stone, Sand & Gravel Association
1605 King St.
Alexandria, Virginia 22314

June 30, 2006

TABLE OF CONTENTS

Section	Title	Page
1	**Executive Summary**	2
2	**Introduction**	4
3	**Background**	5
3.1	Terminology	5
3.2	The Characteristics of Asbestos Dusts	7
3.3	Asbestos Measurements and their Corresponding Exposure Metrics	9
3.4	Issues Associated with Estimating Risk Attributable to Asbestos Exposure	14
3.5	The Nature of Conditions in El Dorado County	16
4	**Evaluating the Proposed EPA Approach in El Dorado County**	16
4.1	The State of the Science	16
4.1.1	The limitations of the PCMe metric	17
4.1.2	General limitations of the Ladd (2005) study	21
4.1.3	Implications from the literature concerning cleavage fragments	26
4.2	Considering Precedent	28
4.2.1	Approaches used at other government-lead sites	29
4.2.2	A Comparison of the relative degree of review of the proposed approach and the Berman and Crump approach	32
4.3	Considering Health Protectiveness	34
5	**Conclusions**	36
6	**References**	37
	Tables and Figures	44

1 EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) recently conducted a multi-media assessment of exposure to naturally occurring asbestos (NOA) in El Dorado County (Ladd 2005). In this study, exposure to asbestos was evaluated by monitoring airborne concentrations obtained both under ambient conditions and while various recreational activities were simulated at locations selected because the soil was believed to contain NOA. An approach was also proposed in this study for assessing the risks associated with the observed exposures.

The merits of the approach proposed by the U.S. Environmental Protection Agency (EPA) for assessing asbestos-related risk in El Dorado County were evaluated. The approach involves assessing asbestos exposures by determining the concentration of airborne structures satisfying a particular set of dimensions defined in what is termed the phase contrast microscopy equivalent (PCMe) metric and combining these with the current EPA-recommended risk factor (IRIS Current) to assess risk.

The evaluation was conducted by considering:

- the current status of science and the limitations of the PCMe metric;
- the historical consistency with which the PCMe metric has been applied;
- the general limitations of the Ladd (2005) study;
- implications from the literature concerning structure sizes and types;
- precedents set by approaches used for assessing risk at other government-lead sites;
- the relative degree of peer and regulatory review for the various steps of the proposed approach and an alternate approach also considered (the approach for assessing asbestos-related risks proposed by Berman and Crump); and
- the degree of overall health protectiveness afforded by the approach proposed for El Dorado County relative to that afforded by the approach proposed by Berman and Crump.

<u>Conclusions</u>

The conclusions from this evaluation are that:

- it appears that the proposed approach satisfies neither of two criteria that are critical for assuring that risk assessments are reliable. First, due to substantial differences in character, exposure concentrations determined in terms of the PCMe metric in El

Dorado County (Ladd 2005) are not directly comparable to the PCM-based exposures evaluated in the epidemiology studies used to derive the risk factor in IRIS (Current). Second, the PCMe exposure metric itself has been shown not to remain reasonably proportional to risk across exposure environments. Given these findings, applying the IRIS risk factor to exposures measured in El Dorado County will not provide reliable estimates of risk;

- the Ladd (2005) study appears to suffer from quality control (QC) problems that will need to be resolved before any attempt is made to interpret the data. Even after the QC issues are resolved, however, it may prove difficult to extrapolate findings that may be gleaned from the study more broadly than to the specific locations at which airborne measurements were collected. This is because no relationship between bulk concentrations and airborne exposure measurements was established in the Ladd study;

- until the quality control issues are resolved and an appropriate statistical analysis of the data is conducted, a proper assessment of risk cannot be completed from the Ladd (2005) data. Thus, it is not possible to tell at this time whether risks estimated using either protocol structures (another exposure metric considered in this report) or PCMe structures will prove to be acceptable for the areas represented by the Ladd study environment. However, assuming that the ratios of concentrations are approximately correct, it appears that the IRIS approach for assessing risk yields a higher risk estimate than the Berman and Crump approach (another approach considered in this report) for the specific locations that were studied;

- as the above observation (should it hold up) is highly unusual, compared to findings based on broad experience at other sites, it reinforces the finding that conditions at these specific locations in El Dorado County are very different from conditions found at most sites where asbestos is a hazard (potentially including other parts of El Dorado County);

- if applied uniformly at sites across the nation (and other parts of El Dorado County), the approach proposed for assessing risk by EPA will be less health protective than if such risks are assessed using the approach proposed by Berman and Crump. This is based on a growing body of experience at multiple, varied sites;

- whatever the relative risks that might be estimated for El Dorado County based, respectively, on the approach proposed by EPA and the approach recommended by Berman and Crump (2001), it appears that the proposed EPA approach is no better supported by precedent; and

- given that (based on discussions with multiple geologists) about 30% of the soil and near-surface rock in the nation may contain amphibole, if the agency intends to apply their asbestos regulations consistently to all areas where amphibole may be present, then it is in everyone's interest to employ an approach that will adequately

distinguish situations that are potentially risky from those that are not. Otherwise, there is a potential either to miss those sites in which true risks exist or, conversely, to *unnecessarily* wreak economic havoc. Neither result is in the public interest, although the first kind of error is clearly the more important to avoid.

2 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) recently conducted a multi-media assessment of exposure to naturally occurring asbestos (NOA) in El Dorado County (Ladd 2005). In this study, exposure to asbestos was evaluated by monitoring airborne concentrations obtained both under ambient conditions and while various recreational activities were simulated at locations selected because the soil was believed to contain NOA. An approach was also proposed in this study for assessing the risks associated with the observed exposures.

The approach that the EPA proposed to assess risk in El Dorado County, if it is to be applied uniformly, may not be generally protective of public health. Given the status of the science, it also appears that the approach may not be as well established by precedent as the approaches that the Agency commonly employs for other hazardous materials.

When evaluating the risks associated with exposure to asbestos, it is important to recognize that the situation with asbestos is particularly complex. Following a brief background discussion highlighting the complexity of the issues involving asbestos sampling, analysis, exposure assessment, and risk assessment as well as conditions in El Dorado County, the remaining sections of this report address:

- scientific considerations concerning the validity and reliability of the proposed approach;
- an overview of relevant precedent;
- implications for health protectiveness;
- conclusions; and
- references.

Note, a sub-section on quality control was also added to highlight what appear to be serious quality control (QC) issues with the data set generated during the recent El Dorado County study (Ladd 2005). When the quality of data can be questioned, it is in everyone's interest to address the problem. Thus, conducting whatever corrective actions might be necessary to examine and address the problems appear to be appropriate.

Importantly, based on the available information, it is possible that the QC problems with the Ladd (2005) study are primarily related to documentation errors. Thus, these problems may be easily correctable. Nevertheless, it is not possible to determine this at this time. Therefore, before anyone should consider the data from this study to be reliable, the QC issues need to be formally addressed. To assist in initiating this effort, a discussion is provided below that is intended to better define the quality control issues that appear to be associated with these data.

3 BACKGROUND

A brief overview of asbestos terminology, the characteristics of asbestos dusts, asbestos measurement methods and their corresponding exposure metrics, and the nature of conditions in El Dorado County is provided in this section.

3.1 Terminology

Asbestos is a term traditionally used to describe a particular fibrous form (asbestiform crystalline habit) of a set of minerals from the serpentine and amphibole mineral groups. The most widely accepted (traditional) definition of asbestos includes the asbestiform habits of six of these minerals (IARC 1977). The most common type of asbestos is chrysotile, which belongs to the serpentine mineral group. Chrysotile is a magnesium silicate. The other five asbestos minerals are all amphiboles (i.e., all partially hydrolyzed, mixed-metal silicates). These are: asbestiform riebeckite (crocidolite), asbestiform grunerite (amosite), anthophyllite asbestos, tremolite asbestos, and actinolite asbestos.

All six of the minerals whose asbestiform varieties are termed asbestos occur most commonly in nonfibrous, massive crystalline habits. While unique names have been assigned to the asbestiform varieties of three of the six minerals (chrysotile and the two amphiboles noted parenthetically above) to distinguish them from their massive forms, such nomenclature has not been developed for anthophyllite, tremolite, or actinolite. Therefore, when discussing these latter three minerals, it is important to specify whether a massive habit of the mineral or the asbestiform habit is intended.

Among the difficulties associated with any discussion of asbestos risk is that the terminology developed for asbestos was designed to address the macroscopic properties of commercially useful materials. However, it is the properties of the microscopic structures that are released from bulk asbestos (when it is disturbed) and their subsequent inhalation that ultimately determine the potential for disease. Thus, the available terminology is limited and can lead to ambiguities if not carefully applied.

Among other things, for example, it has been proposed that the term asbestos be expanded to include the asbestiform habits of a broader range of amphibole minerals (see, for example IRIS Current) and the documents from the Libby, Montana Site (e.g. EPA 2003). This was also recommended by Berman and Crump (2001, 2003). The

reason for this change has been driven by increasing evidence that the asbestiform habits of all amphiboles contribute to the induction of asbestos-related diseases. It should also be noted, however, that the scientific justification for specifically applying the current procedures for assessing asbestos-related risk (e.g. IRIS Current) to these additional minerals has not been formally evaluated or reviewed heretofore.

Another important, but less obvious issue related to the definition of asbestos is the question of the size range of structures that determine biological activity, which is clearly what needs to be regulated. This affects both the measurement of asbestos and the assessment of risk, in addition to the application of regulations. This issue is addressed further in Section 2.3.

To facilitate clarity, definitions for several critical terms used in the remainder of this report are provided below.

Asbestiform means the particular crystalline habit of a mineral that exhibits the common characteristics of asbestos (e.g. highly fibrous, polyfilamentous – existing in bundles, flexible, high tensile strength, and good chemical and thermal resistance). Geologically, the dimensions of fibers formed in this habit are defined by the growth of the crystals (in contrast to cleavage fragments).

Asbestos Minerals means the suite of serpentinite and amphibole minerals currently included in the definition of asbestos when they occur in *any* of their crystalline habits.

Cleavage Fragment means a structure that is formed by physical separation from a larger crystal. Thus, the dimensions of such a structure are defined by the orientation of the weakest cleavage planes in the parent crystal, which is in contrast to the manner in which dimensions are determined for asbestiform structures.

Exposure Metric means the set of sizes, shapes, and morphological types of structures (e.g. fibers, bundles, clusters, or matrices) that are included in the determination of concentration. Sometimes, a particular exposure metric also includes mineralogical constraints (i.e. only structures identified as specific mineralogical types are included). Therefore, exposure metrics for a particular analysis are defined as a function of both the rules of the specific analytical method applied to determine concentration and the limitations of the particular instrumentation employed during the analysis.

Fiber is a relative term that has come to mean any elongated particle that satisfies specific dimensional constraints. The term is relative because the dimensional constraints placed on the definition of the term fiber are specific to the analytical method/exposure metric by which fiber concentrations are determined for a particular application.

Fibril means a single fiber of asbestos (i.e. from an asbestiform population). Single asbestiform fibers cannot be further reduced in width without altering their properties.

Fibrous is a relative term that is used to denote a material composed primarily of fibers. The term is relative because the term for fiber is relative (see above). Note, for example, a dust composed primarily of elongated particles that nevertheless satisfy the dimensional definitions for fibers from a particular application could therefore be defined as fibrous.

Fibrous structure is a collective term used to mean any fiber, bundle, cluster, or matrix. These latter terms for specific types of structures are discussed further in Section 3.2 and concisely defined in ISO (1995).

3.2 The Characteristics of Asbestos Dusts

Structures comprising the dusts from asbestiform minerals come in a variety of shapes and sizes. Not only do single, isolated fibrils vary in length and somewhat in thickness, but such fibrils may be found combined with other fibrils to form bundles (aggregates of closely packed fibrils arranged in parallel), which represent the actual structure of all large “fibers” in an asbestiform population. In turn, fibers may form clusters (aggregates of randomly oriented fibers) or (may be combined with equant particles to form matrices (asbestos fibers embedded in non-asbestos materials). Consequently, asbestiform dusts (even of one mineral variety) are complex mixtures of structures. For precise definitions of the types of fibrous structures typically found in asbestos dusts, see ISO (1995).

In addition to the above, which describes the asbestiform component of a dust, dusts created from asbestos will also contain particles from any material with which the asbestos may be associated. Thus, for example, dusts at mining and milling sites may include particles (including elongated particles that may pass as fibers) that are rock fragments (cleavage fragments) from host minerals. If the mineral being mined is the asbestos itself, likely the host mineral would simply be the massive crystalline habit of the same mineral type as the embedded asbestos.

In environments in which an asbestos dust is derived from an asbestos product (either during manufacture, as a consequence of use, or associated with disposal), the dust may also contain particles (including elongated particles that may pass as fibers) composed of any of the various other component materials of the asbestos product.

Detailed descriptions of the characteristics of dusts typically encountered at environmental and occupational asbestos sites have been reported in the literature and the following summary is based on a previously published review (Berman and Chatfield 1990). Typically, the major components of the dust observed in most environments are non-fibrous, isometric particles. A notable exception to this general observation are the dusts from asbestos textile manufacturing, which is highly fibrous.

The likely reason these dusts are fibrous is that the only major source of dust in such an environment is refined, nearly pure, asbestiform fiber (Walton 1982). However, for asbestos dusts in general, fibrous structures consistently represent only a minor fraction of the total dust. In addition, fibrous structures composed of asbestos minerals typically represent only a subset of the total number of fibrous structures that may be observed in such environments.

The magnitude of the fraction of total dust represented by fibers and the fraction of fibers composed of asbestos minerals vary from site to site. However, the fraction of asbestos in total dusts has been quantified only in a very limited number of occupational and environmental settings (see, for example, Cherrie et al. 1987 or Lynch et al. 1970).

Importantly, as the definition of the term fiber is relative (Section 3.1), the fractional concentration of fibers observed in a particular environment will vary as a function of the analytical methodology employed to determine their concentration. Historically, fibrous structures have been arbitrarily defined as structures exhibiting aspect ratios (the ratio of length to width) greater than 3:1 to distinguish them from isometric particles (Walton 1982). However, alternate definitions for fibers have also been proposed, which are believed to better relate to biological activity (see, for example, Berman et al. 1995 or Wylie et al. 1993).

The gross features of structure size distributions appear to be similar among asbestos dusts characterized to date (Berman and Chatfield 1990). The major asbestos fraction of all such dusts are small fibrous structures less than 5 μm (micrometers) in length. Length distributions generally exhibit a mode (maximum) between 0.8 and 1.5 μm with longer fibers occurring with decreasing frequency. Fibrous structures longer than 5 μm constitute no more than approximately 25% of total asbestos structures in any particular dust and generally constitute less than 10%.

In some environments, the diameters of asbestiform structures (e.g. fibers and bundles) exhibit a narrow distribution that is largely independent of length. In other environments, diameters appear to exhibit a narrow distribution about a mean for each specific length. In the latter case, both the mean and the spread of the diameter distribution increases somewhat as the length of the structures increase. Among asbestiform materials, this increase appears to be due to contributions from bundles. Thus, for example, the increase in diameter with length appears to be more pronounced for chrysotile than for the amphiboles, presumably due to an increase in the fraction of chrysotile bundles contributing to the overall distribution as length increases. This is likely true since a single chrysotile fibril exhibits the thinnest diameter of all asbestiform structures.

Only a few studies have been published that indicate the number of complex structures in asbestos size distributions. The limited data available indicate that complex structures may constitute a substantial fraction (up to one third) of total structures, at least for chrysotile dusts (see, for example, Sebastien et al. 1984). Similar results were

also obtained during a re-analysis of dusts generated from the asbestos samples evaluated in the animal inhalation studies conducted by Davis et al. (Berman et al., in preparation). This is the same re-analysis used to support a study to identify asbestos characteristics that promote biological activity (Berman et al. 1995), which is discussed further in Berman and Crump (2003).

The degree to which fibers are combined within complex structures in a particular dust may also affect the biological activity of the dust (Berman et al. 1995). Therefore, proper characterization of asbestos exposure requires that the relative contributions from each of many components of exposure be simultaneously considered. Factors that need to be addressed include the distribution of structure sizes, shapes, and mineralogy in addition to the absolute concentration of structures. Such considerations are addressed further in Berman and Crump (2003). Thus, unlike the majority of other chemicals frequently monitored at hazardous wastes sites, asbestos exposures cannot be adequately characterized by a single concentration variable.

3.3 Asbestos Measurement Methods and Their Corresponding Exposure Metrics

Exposure to asbestos primarily involves inhalation of asbestos dust and evidence indicates it is primarily the size and shape of the fibrous structures in the dust that determine potency (in addition to their absolute concentrations). As a result, estimates of asbestos exposure concentrations vary radically as a function of both the particular type of instrumentation employed for analysis and the specific method applied during the analysis (see, for example, Berman and Crump 2003). Consequently, the ability to establish the relationship between asbestos exposure and disease has been confounded by use of multiple exposure metrics and by the fact that the relationships between exposure metrics *do not remain proportional to each other* from one environment to the next.

A variety of exposure metrics have been (and are being) used for the determination of asbestos concentrations. Those most important to the discussion in this report include “PCM”, “PCMe”, and “protocol structures” and each of these are briefly described below. Other potentially relevant exposure metrics are also introduced and briefly described in a table at the end of this section.

PCM is the size range of particles *traditionally* included for the determination of asbestos concentrations when analyzed by phase contrast microscopy (an optical microscopy technique). These are defined as “fibers” longer than 5 µm with an aspect (length-to-width) ratio equal to or greater than 3 and exhibiting largely parallel sides. At the magnification at which this type of asbestos analysis is typically conducted (~400x), PCM fibers are also typically limited to those thicker than approximately 0.25 µm because thinner fibers cannot be seen by the microscopist. Actually, this lower limit on width also varies somewhat as a function of the condition and quality of the microscope,

the visual acuity and training of the analyst, and the type of mineral.[1] Further, because there is no mechanism for distinguishing among mineral types when conducting analysis by PCM, all particles that are observed to satisfy the defined dimensional criteria are counted. Depending on environment, these may include, for example, cellulose and other organic fibers as well as a much broader range of inorganic fibers than have traditionally been included in the definition of asbestos (see last section).

It also needs to be understood that, due to limitations in the resolution of the microscope, the internal details of the structures that are observed by PCM cannot be distinguished. Thus, what may appear to be a simple and solid fiber by PCM may in fact be a complex structure composed of finer components. A fiber visible by PCM may alternately be a component of a larger structure whose other components are too fine to resolve. In fact, it is sometimes due to these differences (as opposed simply to mineralogy) that PCM and PCMe (defined below) concentrations determined for the same sample do not coincide. This complicates the relationship between PCM and PCMe in different environments.

An account of the history of the development of the PCM exposure metric was published by Walton (1982), which traces the origin to its definition back to meetings of a group of asbestos industry personnel in Britain (The Asbestos Research Council) in 1958. Methods suitable for determining concentrations in terms of this metric have been adopted in several countries, including the United States, and the World Health Organization. One version of the method in broad use in the United States is NIOSH Method 7400 (NIOSH 1985, 1994).

PCMe or "phase contrast microscopy *equivalent*" represents a range of particles nominally exhibiting the same range of sizes and shapes as PCM fibers, except that they are adjusted to exclude contributions from any countable particles not composed of the defined set of minerals included in the definition of asbestos[2]. As indicated above, however, mineralogy may not be the only reason for differences in concentrations estimated, respectively, by PCM and PCMe.

Originally, determining a PCMe concentration formally involved use of two, complimentary analytical techniques: phase contrast microscopy (PCM) and transmission electron microscopy (TEM) with the manner in which PCMe

---

[1] The ability to observe a structure using a phase contrast microscope is also a function of the contrast between the structure and the base on which it resides. If the contrast is limited, the structure will be invisible. Contrast in turn is a function of the relative refractive index of the structure and the base, which is therefore a function of the mineralogy (chemical composition) of the structure (Kenny et al. 1987).

[2] As evidence of their ability to cause asbestos-related diseases has increased, the range of minerals proposed for inclusion in the definition of asbestos has been broadened in recent years from what was originally defined in IARC (1977) and even what is defined in the current version of NIOSH Method 7402 (1994) to include virtually all amphiboles.

concentrations are determined described in NIOSH Method 7402 (NIOSH 1986,1994). By this method, asbestos concentrations are determined by analyzing sample filters using both analytical techniques and the concentration estimated by PCM is then modified by a factor derived by TEM to determine a final (adjusted) asbestos concentration expressed in terms of PCMe.

Over the years, some have adapted Method 7402 by using only the TEM component to determine an absolute concentration for PCMe (rather than using it to determine an adjustment factor for the PCM component). Other modifications to the PCMe metric (such as changes to size restrictions) have also been developed over time. In 1995, for example, ISO Method 10312 (ISO 1995) incorporated a definition for PCMe that includes an upper limit of 3.0 µm on the width of a countable particle[3] and also reduces the minimum width to 0.20 µm (from 0.25 µm)[4]. Other modifications to the definition of PCMe have also been proposed in other documents.

Table 1 presents a summary of definitions for PCMe that are provided in several Federal and California sources. In descending rows, the table provides:

- the (current) year of revision for each reference cited;
- the original year that the reference was published;
- the minimum length of structures included in the definition;
- the minimum width;
- the maximum width;
- the aspect (length-to-width) ratio; and
- relevant comments.

As can be seen in Table 1, the size definitions for PCMe vary across the different documents cited. Of these, for example, ISO 10312 incorporates a maximum width. As indicated by the comments, it is also noteworthy that an entirely different procedure is employed for deriving PCMe estimates when evaluating hazards under either California Proposition 65 (COEHHA 2006) or the California Air Resources Board's background document (CARB 1986) for their Asbestos Air Toxics Control Measure (ATCM). By CARB's rules, PCMe is determined by counting total TEM structures (of "all sizes") and dividing the count by between 100 and 1,000 (depending on whether an estimate in the low or high end of their risk range is desired). In fact, another California document that is labeled as "not to be cited or quoted" suggests an intermediate value of 320. Similarly, ATSDR (2001) defines PCMe concentrations as approximately equivalent to the concentration of total TEM structures (of all sizes longer than 0.5 µm) divided by 60.

---

[3] This is also consistent with the definition originally proposed for PCM (see Walton 1982).

[4] While this latter change may appear minor, as shown later, even minor changes in the minimum width for PCMe actually represent critical changes because asbestos structures tend to be particularly numerous in this range of widths and they also tend to be particularly potent (see, for example, Berman and Crump 2003).

It is also interesting that the minimum width defined for PCMe structures in EPA's IRIS is twice the minimum width defined by ISO and IRIS further indicates that the correlation between PCM and TEM fiber counts is "highly uncertain." Note that EPA has applied the ISO rules to determine PCMe concentrations in El Dorado County (Ladd 2005), which suggests inconsistency with IRIS (among other things).

Overall, the information presented in Table 1 suggests a procedure that has been subject to some modification over the years (which may appear minor but can be important)[5]. Given these distinctions, it appears that PCMe concentration estimates for asbestos may not have been derived entirely consistently over time by various parties generating such estimates.

In fact, the variability in PCMe definitions and determinations described in Table 1, does not represent the full range of variability in the manner that PCMe has been defined and applied over the last 20 years. In some studies, for example, PCMe has also been informally defined simply as "all TEM fibers longer than 5 µm", with no minimum width defined. Moreover, the concentration of TEM fibers used to estimate PCMe has sometimes been obtained using methods requiring magnifications of 10,000 and greater, which could result either in the counting of substantially greater numbers of structures or somewhat smaller numbers of structures than what can be seen at the PCM magnification of approximately 400. This depends on whether more "solid" structures become visible at the greater magnification or more structures that appear solid at the lower magnification appear to be non-countable complexes of smaller structures at the higher magnification. Thus, it does not appear that determination of PCM/PCMe ratios for use in risk assessment over the last 20 years has been entirely uniform. Nor is it clear whether any of these approaches have been subjected to formal peer-review at EPA. Thus, it does not appear that an established precedent currently exists.

Protocol Structures represent a size range of asbestos structures that is expected to better correspond to those that contribute to the induction of cancer than PCM structures.[6] Implications regarding the relationship between various exposure metrics and disease induction are addressed further below. A detailed presentation of the

---

[5] For example, Hwang and Gibbs (1981) suggest that the median fiber diameter for amosite asbestos observed in mining environments lies at approximately 0.35 µm (for fibers longer than 2.5 µm and remains approximately constant for longer fibers). This suggests that the fraction of such fibers that would be alternately included or excluded in an analysis may vary radically as the minimum width to be included changes between 0.2 and 0.4 µm. Thus, the ratio between PCM and PCMe may also vary radically, depending on which cutoff is selected for PCMe.

[6] Importantly, the defining dimensions of protocol structures were also somewhat constrained by limitations in the published size distributions available for applying this exposure metric in the meta analysis used to evaluate its utility (Berman and Crump 2001).

rationale for the definition of protocol structures is also available (see Berman and Crump (2001).

Protocol structures are defined as a weighted average of two size ranges of structures, whose concentrations are separately determined and then combined using the following equation:

$$C_{protocol\ structures} = 0.003*C_{size\ A} + 0.997*C_{size\ B} \qquad \text{(Equation 1)}$$

where:

$C_{protocol\ structures}$ is the concentration of protocol structures;

$C_{size\ A}$ is the concentration of structures between 5 and 10 µm in length with widths less than 0.5 µm; and

$C_{size\ B}$ is the concentration of structures longer than 10 µm with widths less than 0.5 µm.

The concentration of protocol structures is typically determined by analyzing a sample by TEM using ISO Method 10312 (ISO 1995) and incorporating a modification to include only structures of the above-indicated sizes in the structure count. Importantly, the rigorous procedures defined in the ISO Method for considering contributions from both simple structures (i.e. fibers and bundles) and complex structures (i.e. clusters and matrices) and their components are incorporated into the determination of the concentration of protocol structures.

Note that including instructions for detailed characterization of complex structures contrasts with the determination of PCMe, which involves only consideration of fibers and bundles. Such lack of detailed instructions for handling the analysis of complex structures represents a further means by which inconsistency may have been introduced into determinations of PCMe.

Other exposure metrics are also considered in this report in a variety of contexts. A summary of the characteristics of all of these exposure metrics is presented in Table 2.

In Table 2, successive rows provide the following information for each exposure metric:

- the structure dimensions defining each exposure metric;
- the associated instrumentation and method required for sampling and analysis;
- the origin of the metric;
- the theoretical basis linking the metric to risk;
- other evidence supporting/refuting the relationship between the metric and risk;
- the original (design) intent of the metric;
- pre-requisites for applying the metric to assess risk; and
- the strength of evidence supporting application of the metric to environments in which asbestos may be naturally occurring.

Note that the last row is provided to indicate the degree to which the metric might be considered to be applicable to assess risks in places such as El Dorado County.

3.4 Issues Associated with Estimating Risk Attributable to Asbestos Exposure

As with any hazardous material, asbestos-related risks are typically estimated by multiplying exposure concentrations determined in a site study (such as the study conducted in El Dorado County) with an exposure/response (risk) factor that is derived from one or more control studies (such as an epidemiology study)[7]. However, asbestos is unlike other hazardous materials because the exposure metrics employed for determining and reporting its concentration are necessarily complex.

For most hazardous materials, concentrations are expressed by a single exposure metric (e.g. mass per unit volume) incorporating a single parameter: mass. In contrast, there are multiple exposure metrics for asbestos and they each necessarily incorporate multiple parameters (i.e. dimensional limitations on a range of structures). Moreover, risk can only be reasonably estimated for asbestos when the particular exposure metric used to estimate concentrations is properly matched to the exposure metric in which the corresponding risk factor is expressed. This is because concentrations estimated in each of the multiple exposure metrics that have been used for asbestos may vary by orders of magnitude for the same sample (see, for example, Berman and Crump 2003).

Choice of the particular exposure metric is also critical to the proper estimation of risk. This is because asbestos exposure metrics do not remain proportional to one another from one environment to the next. Of course, this is simply another way of saying that the size distribution of airborne structures in an asbestos dust do not remain proportional from one environment to the next (Section 3.2).

Importantly, to successfully extrapolate risk from control studies (in which potency is determined) to a site study (in which risk must be ascertained), the metric chosen to characterize exposure must satisfy *both* of two criteria:

(1) asbestos must be measured in a comparable manner in the two environments; *and*

(2) such measurements must remain reasonably proportional to the characteristics of exposure that contribute to risk.

---

[7] Actually, the manner in which risk is evaluated for asbestos is somewhat more complicated than for other materials in that the relationship between exposure and risk involves a complex function of time as well as exposure level so that, strictly, risk factors and exposure concentrations may not be simply multiplied together (see, for example, Berman and Crump 2003). However, the details of such complexities are not directly relevant to the issues at hand. Thus, they will not be addressed further in this discussion.

These requirements derive from common sense (as illustrated below) and are universal. Moreover, the importance of satisfying these criteria was clearly demonstrated in a mathematical model developed by Chesson et al. (1990). If they are not satisfied, risks estimated in the traditional manner (described above) are not valid.

Satisfying the above criteria is trivial for most chemical toxins because their effects remain proportional to mass in all environments. Thus, this single exposure metric supports valid risk assessment for these toxins. Not so for asbestos. This is a direct consequence of the nature of asbestos exposure metrics (Section 3.3) and the characteristics of asbestos dusts (Section 3.2).

To illustrate how the first of the above two criteria needs to be addressed for asbestos, consider that one would clearly not apply a risk factor for nickel (derived from dose-response studies in which exposure concentrations are determined explicitly for nickel) to assess the risks from exposure concentrations measured for chromium. That is because the two exposure metrics are not comparable. Similarly, risk factors derived for one particular exposure metric (incorporating a specific size range of asbestos structures) should not be applied to exposure concentrations determined using a different exposure metric (incorporating a different size range of structures).

To illustrate how the second of the above two criteria needs to be addressed for asbestos, consider that measuring the concentrations of nickel in various study environments (each containing dusts of mixed metals) tells one nothing of the relative concentrations of chromium in those environments; there is clearly no reason to expect that the concentrations of nickel and chromium will remain proportional from one environment to the next. Thus, it would be absurd to attempt to assess chromium-related risks based on measurements of nickel. This is true even though the relationship between the risk factors for nickel and chromium is known. It is not the relative potency, but the unknown relationship between exposure concentrations that prevents extrapolation in this case.

Similarly, because different exposure metrics for asbestos do not remain proportional from one environment to the next, unless risk is assessed using an exposure metric that specifically remains proportional to biological activity, one cannot reliably assess risk. This is because, if a particular exposure metric does not remain proportional to biological activity, the relationship between this metric and the truly biologically active fraction of an asbestos dust will vary in an undefined manner between control and study environments. Thus, a risk factor defined for such a metric in a control environment will not relate in the same manner to an exposure concentration determined for that same metric in a study environment. Therefore, it would not be valid to apply such a risk factor to the exposure determined in that study environment.

Given the above, to assess asbestos-related risk, it is therefore critical that exposures determined in terms of a particular exposure metric be combined *only* with a risk factor

that is properly matched to that particular exposure metric *and* the two must be appropriate for the environments in which they are applied.

3.5 The Nature of Conditions in El Dorado County

Conditions in El Dorado County have raised concern for years. It is an established fact that asbestiform amphibole is present in the soil and rocks of El Dorado County. The real question is whether it is ubiquitous or "patchy." Thus, there are areas of El Dorado County where various kinds of activity restrictions are prudent, but there are likely other areas where they may not be required. Thus, a reliable procedure is needed to distinguish among such areas. It is also important to consider the need to be able to distinguish "clean" fill (which might be brought in from elsewhere) from either asbestos-containing fill or local, asbestos-containing soil. In fact, these needs are common to every area of the nation in which the presence of asbestos is a concern.

4 EVALUATING THE PROPOSED EPA APPROACH IN EL DORADO COUNTY

It appears that the EPA is planning to assess risk in El Dorado County primarily by applying the current EPA slope factor for asbestos (IRIS current) to estimates of PCMe exposure derived from the Ladd (2005) study. Assuming that the QC issues that are discussed in 4.1.2 are first resolved, there still appear to be several potential problems with this approach so that the Agency needs to consider:

- the state of the science informing the validity and reliability of the proposed approach, especially as applied in El Dorado County and including considerations concerning QC;
- the degree with which the proposed approach appears to be supported by precedent; and
- the associated implications concerning the general health protectiveness of the proposed approach.

4.1 The State of the Science

Relevant issues that need to be considered to address the potential validity and reliability of the proposed approach for El Dorado County are:

- the limitations of the PCMe metric;
- more general limitations of the Ladd (2005) study; and
- implications from the literature concerning cleavage fragments.

4.1.1 The limitations of the PCMe metric

The limitations of the PCMe exposure metric are reasonably well documented and include:

- that the metric does not appear to satisfy the second of the two criteria identified in Section 3.4 that are required to support reliable risk assessment (i.e. it does not remain reasonably proportional to risk across environments of interest); and

- at least when applied at sites exhibiting the specific characteristics of the areas studied by Ladd (2005), the metric may not satisfy the first of the two criteria articulated in Section 3.4 (i.e. it is not comparable to the concentrations determined in the control studies evaluated to develop the IRIS risk factor).

Regarding the first of the above, evidence that PCMe does not remain adequately proportional to risk across environments comes from a diverse variety of sources. First (and perhaps simplest), one should consider that PCMe is intended to mimic the dimensional range of structures counted by PCM. However, the dimensional range counted by PCM was never designed or intended to reflect the characteristics of asbestos that contribute to disease. Rather it was simply designed as an arbitrary index of exposure.

A history of the development of the PCM exposure metric, at least up to the time of its publication by Walton (1982), clearly indicates that the dimensions chosen for defining PCM (by a British Council in 1958) were *arbitrary* and designed primarily to facilitate analysis. Moreover, while the minimum length may have been selected with some thought for the range of structures believed to contribute to disease (although the primary motivation was to promote analytical reproducibility), the minimum width was entirely arbitrary, as it was an artifact of the choice of magnification and the type of microscope.

Further evidence that PCMe may not adequately track the characteristics of asbestos that contribute to risk also comes from a study of animal inhalation experiments (Berman et al. 1995). In that study, the ability of various exposure metrics to predict risk (including PCM/PCMe) was formally tested. In that study, PCM/PCMe was shown to provide a *statistically significant lack of fit*.

Perhaps the most compelling evidence comes from the meta analysis reported in Berman and Crump (2003). In this study, the range of variation in risk factors reported across available epidemiology studies is compared with exposure expressed, respectively, in terms of PCM (which is considered to be equivalent to PCMe in this case) and expressed in terms of long protocol structures (defined in Section 3.3 above). The results of this comparison are illustrated in Figure 1.

In Figure 1, the ratios of the maximum to the minimum values of the risk factors derived from the set of available epidemiology studies (excluding a single, negative study) are presented. The ratios for lung cancer are presented on the left and mesothelioma on the right. The ratios labeled “PCM” are derived using the PCM exposure metric and preserves the current EPA policy of a common risk factor for chrysotile and the amphiboles. The ratios labeled “protocol” are derived using long protocol structures as the exposure metric and incorporate distinct risk factors for chrysotile and the amphiboles (which is recommended in the Berman and Crump protocol).

As can be seen in Figure 1, when exposure is expressed in terms of PCM/PCMe, risk factors derived from the available epidemiology studies range over almost two orders of magnitude (by a factor of 90) for lung cancer and over more than three orders of magnitude (by a factor of 1100) for mesothelioma. With such variability across the known studies, the confidence that can be placed in extrapolating risk estimates derived from these control studies to new environments is limited.

In contrast, when the risk factors from the same set of studies is adjusted to reflect exposure in terms of the long protocol structures metric, the range of lung cancer factors drops to about 60x (a modest improvement) and the range for mesothelioma factors drops to about 30x (a substantial improvement). Thus, the confidence that risk factors derived in terms of long protocol structures can be extrapolated to new environments is substantially improved. Note, that a more formal statistical analysis (conducted without omitting the one negative study) is also presented in Berman and Crump (2003) and the results are similar.

To address whether the PCMe exposure metric satisfies the first of the two criteria needed to assure reliable risk assessment (Section 3.4), one needs to consider two issues. The first is the relationship between PCMe and the various metrics employed to assess exposure in the original epidemiology studies and the second is the relationship between the characteristics of the dusts studied in those control environments and the character of the dusts observed in El Dorado County (or at least the specific sites in El Dorado County studied by Ladd).

Table 3 presents a comprehensive list of the quantitative epidemiological studies used to support development of the slope factor for asbestos that is currently recommended by EPA (IRIS Current). In Table 3, the eight columns respectively indicate:

- the type of asbestos: chrysotile, amosite, or mixed;
- the type of operation studied;
- the specific cohort studied;
- the potency factor for lung cancer;
- the potency factor for mesothelioma;
- the majority of the types of measurements relied on to estimate exposure;
- the study reference; and
- relevant comments.

As can be seen in the sixth column of Table 3, concentrations were initially determined based on three different methods of measurement, which resulted in three different exposure metrics among these studies. These include:

- MI or midget impinger, which is a device used to determine concentrations of total respirable particles in the air;

- PCM; or

- TP or thermal precipitator, which is another device used to determine concentrations of total respirable particles in the air. Note that MI and TP measurements are not entirely comparable (Walton 1982).

The fourth designation in the sixth column of Table 3, “NS” means non-specific. To derive a dose/response factor from the Selikoff et al. (1979) study, Nicholson simply assumed that exposures to the entire cohort could be considered equal to the average exposure concentration estimated for the entire industry at the time.

As can be seen in this same column of the Table, of the 13 available risk factors for lung cancer that were considered, nine (70%) were derived primarily by measurements other than PCM and thus had to be converted. Moreover, of these, five (60%) used factors to convert the measurements to PCM that were non-study specific.

As indicated in Walton (1982), La Ville de Thetford Mines (1994), and Smith, G.W. (1968), as well as based on general commercial considerations regarding the need for pure product material, the processes that were used to separate and isolate fiber product from the ore in asbestos mills was very efficient. Thus, the fraction of host rock fragment remaining in most commercial asbestos fiber product was extremely small. This is particularly true of the textile grade material, although it is possible that slightly greater amounts of grit and dirt (left over from mining and milling) might remain with the lower grade fiber products (especially the lowest grade fiber primarily used in the manufacture of friction products).

Given the above, the last column of Table 3 indicates the potential for rock fragments (i.e. non-asbestiform cleavage fragments) composed of asbestos minerals to be present in the various control environments studied. As can be seen in the table, the only environment in which a substantial fraction of any such fragments (primarily serpentinite fragments in this case) could potentially be present is in the Quebec mine and mill environment. Yet this environment was in fact excluded from the analysis conducted to derive the recommended EPA slope factor (EPA 1986, IRIS Current).

It should also be noted from the table that most of the control environments (other than for textiles or mining/milling) potentially contain some kind of non-asbestiform fragments, but these are generally expected to be composed of materials not related to the asbestos minerals. In such environments, therefore, the potential relationship

between PCM and PCMe will be very different than what is observed in places where large numbers of amphibole rock fragments exist (such as in El Dorado County). Further evidence for this is provided by Lynch et al. (1970). Also, see Section 3.3.

Given the above and because no study of any amphibole mining or milling operation was available at the time that the analysis was conducted (EPA 1986), there are no control environments among those studied to support development of the current EPA risk factor in which amphibole rock fragments were more than a very minor component of dust exposures. Therefore, given the radically contrasting conditions in the specific locations of El Dorado County studied by Ladd (in which amphibole rock fragments appear to be plentiful), PCMe does not satisfy the first of the criteria listed in Section 3.4 when applied to environments such as that found at these specific sites.

In contrast, the exposure metric recommended by Berman and Crump should be considered applicable to the environment in El Dorado County for two reasons. First, the Quebec mining studies (e.g. Liddell et al. 1997) were not excluded from the analysis used to evaluate the metric (Berman and Crump 2003). Second, and perhaps more importantly, the more recent studies of crocidolite (amphibole asbestos) miners in Wittenoom, Australia (de Klerk et al. 1994) and the Vermiculite miners in Libby (e.g. Amandus and Wheeler 1987) were also included. Note that the vermiculite mined in Libby is contaminated with amphiboles that include both rock fragments and what appears to be particularly hazardous forms of asbestiform amphiboles (most likely due to size).

In fact, there is direct evidence of the kinds of differences in the various environments that are described in the previous paragraphs. It comes from the examination of data from every environment characterized in a set of readily available studies in which PCMe and protocol structures were simultaneously determined (including airborne dusts from asbestos products, dusts at sites in which the source of asbestos is known to be debris from commercial asbestos products, and dusts at sites in which the source of asbestos was a minor, natural contaminant of a matrix composed of a non-asbestos mineral). In virtually all of these environments, protocol structure concentrations were comparable to or greater than that of PCMe concentrations. Among other things, the above confirms that asbestiform structures are almost exclusively thin, as the thinnest structures are included in the protocol structure metric but excluded from the PCMe metric.

In contrast, the data from the Ladd (2005) study show samples in which the concentration of PCMe fibers is *two orders of magnitude* greater than the concentration of protocol structures. Based on the size distributions reported by RJ Lee for the data from Ladd (2005), only 4% of the structures longer than 5 µm are protocol structures while 96% are PCMe (although only 25% of these are respirable). Even if one assumes a greater width cutoff than the respirable limit (such as the 1.5 µm proposed by the peer review committee of the Berman and Crump protocol, ERG 2003), almost 50% of the PCMe fibers would still be excluded. Clearly, something is very different about these

samples relative to samples that have been collected in environments known to be contaminated with asbestos.

4.1.2 General limitations of the Ladd (2005) study

There appear to be two important limitations that need to be addressed before the data from the Ladd (2005) study can be properly interpreted. These are:

- QC-related issues; and
- the extent to which the results of the study can be considered generally applicable to conditions within El Dorado County (i.e. beyond the specific locations studied).

These are each addressed below.

Quality Control Issues. Based on interpretation of the data reported from the analysis of QC samples from the Ladd study, there appear to be potentially serious laboratory quality control issues.

It appears that a number of QC analyses have been performed in which either the same analyst has re-analyzed a sample by examining the same set of grid openings twice (replicate analysis) or two different analysts have independently examined the same set of grid openings from the same sample (duplicate analysis). In several cases, such analyses were also conducted in triplicate for the same sample.

Although the EPA analyses were not conducted in a fashion allowing interpretation using the formal rules of verified counting (see, for example, Turner and Steel 1994; Steel and Small 1985; and Turner and Steel 1991), their results can still be evaluated to test whether the same sets of structures were observed over the same area scanned during each analysis. If one is to have faith that analyses have been properly conducted and documented, it is critical that one be able to show that analysts see the same structures when scanning the same areas of a sample.

Importantly, the QC evaluation discussed here is based simply on an independent interpretation of the results reported in Ladd (2005) for the analyses of QC samples. This is not a case in which an independent microscopist is working to verify specific results. Thus, direct access to the samples is not required. Rather, the role being filled here is simply one of a data analyst evaluating the performance that is to be expected when data become available from multiple analyses of the same set of grid openings on the same sample.

The procedure by which the QC results are evaluated here represents a *less* severe test of the comparability of the analyses than are typically performed for verified counting. Therefore, the degree of agreement one should expect should be at least as good as what is commonly achieved during verified counting. This means that false

positives (i.e. observation of a structure by one analyst that cannot be verified by another) should represent no more than 5% of the total number of structures reported and true positives (i.e. observations of the same structure by each analyst) should represent no less than 85% of the total number of structures reported[8,9]. Yet, across the five sets of replicate or duplicate analyses that were examined, substantially worse agreement was observed.

The evaluation was conducted simply by comparing the number of primary structures that each analyst reported for each specific grid opening. If the numbers disagreed, it would be concluded that there was an error in counts on that grid opening. Since whether one value reported by a particular analyst was higher or lower than the other was not considered in this evaluation, each observed error could be due either to a false positive or a false negative. Thus, this represents the total error that might occur on a particular grid opening and the total error should be less than 20% = (1 - 85%) + 5% where the number of false negatives is assumed to be the total number minus the number of true positives (see Turner and Steel 1994).

Clearly, this is the most general possible comparison, as it entirely ignores comparisons involving specific features of any of the structures (such as type, mineralogy, or dimension). Even multiple count errors were ignored (i.e. errors in counts from particular grid openings that differ by more than one unit were still counted as a single error).

Results for the set of five samples evaluated are presented in Table 4. Note that, when the same grid openings were analyzed by three (rather than two analysts), the error rate for each analyst is reported as the number of grid openings for which a disparate number was recorded against the average of the other two analysts.

---

8 Importantly, comparing results of analyses across the same areas of a scanned surface is qualitatively different than simply comparing structure counts across multiple analyses (or independent preparations) of the same sample when each analyst analyzes unique areas of the scanned surface (i.e. different grid openings). In the latter case, at best, one can expect agreement across analyses to be no better than what is predicted based on Poisson statistics. This is because the distribution of asbestos structures on a filter are random so that the chance of encountering a certain number of structures on any particular area of the filter exhibits a statistical distribution. In contrast, however, if multiple analysts scan the same area of a sample (i.e. the same grid openings), they should observe the same, unique set of structures that were deposited on that particular area. Thus, ideally, their counts and observations should be identical.

9 Based on the performance shown to be achievable for verified counting in general (Steel and Small 1985 and Turner and Steel 1991), the targets defined above appear reasonable for analysts counting structures in support of the Ladd study and this is especially true given the extremely favorable manner in which performance is evaluated (see main body of text).

In Table 4:

- the first column provides the Sample Identification Number;
- the second column indicates the number of analyses conducted on the specific set of grid openings from the indicated sample;
- the third column indicates the total number of grid openings analyzed;
- the fourth column indicates the number of differences in counts observed between the indicated analysis and the other analyses of the sample;
- the fifth column indicates the total error rate; and
- last column indicates whether the counts are consistent (i.e. whether they exceed the total error rate).

As can be seen in Table 4, analyses from four of the five samples that were evaluated are inconsistent. That there are problems with four of these five samples, indicates that further investigation is warranted. Moreover, although the remaining 18 QC analyses conducted on the same grid openings that were reported by Ladd are not further evaluated here, the findings reported by RJ Lee (RJ Lee 2005) concerning these remaining samples suggests that the same kind of QC problems are more prevalent than what has been reported here.

Table 5 is provided both to illustrate how the estimates in counts of differences were derived for Table 4 and to illustrate the strength of the evidence that QC problems may be even worse than what is indicated by the data in Table 4.

Table 5 displays the sets of structures observed over the same set of 15 grid openings during each of three analyses conducted for sample SRA-R05-110604. Note that the data are presented in such a manner so as to line up corresponding structures in the same rows, to the extent possible. When not possible, however, a series of arrows between the columns representing each analysis are also displayed to connect structures in different rows that, however unlikely due to clear differences in character, were assumed to be equivalent. Thus, each analyst was given every possible benefit of the doubt in the evaluation described above.

For each analysis presented in Table 5, the 10 columns respectively present:

- the grid specimen number (typically, analyses are spread across grid openings from each of two grid specimens);
- the sequential number of each grid opening scanned;
- the code identifying the particular grid opening scanned;
- the code representing the manner in which the mineralogy of a particular structure was identified (see ISO 1995);
- the sequential number of each primary (isolated) structure encountered;
- the sequential number of the total number of structures encountered (including structures embedded in larger, complex structures);
- the class (type) of each structure encountered (i.e. fiber, bundle, cluster, matrix, matrix-fiber, etc., see ISO 1995);
- the length of the structure (µm);

- the width of the structure (μm); and
- the aspect ratio of the structure.

To determine the number of primary structures reported on a particular grid opening by a particular analyst (in support of the evaluation reported in Table 4), the number of primary structures (denoted by having a numerical entry in Column 5 of Table 5) for each unique grid address (denoted by the combination of grid specimen in Column 1 and the specific grid opening location in Column 3) were simply counted. These values were then compared across analysts and the total number of grid openings for which a disagreement was observed was summed (with the results presented in Column 5 of Table 4). This sum was then divided by the total number of grid openings included in each analysis to derive the fraction (percentage) of total errors that are reported in Column 6 of Table 4.

Also in Table 5, rows representing missed structures in a particular analysis (false negatives) are highlighted in pink and rows representing an unconfirmed structure (false positives) are highlighted in green. Mismatches between dimensions or structure types are highlighted in blue. Note that, although *none* of this information was used in the evaluation of performance conducted as described above (and reported in Table 4), the degree of color observable in the table suggests substantially greater problems than what is reported in Table 4. For example, as indicated at the bottom of Table 5:

- for the Original Analysis reported on the left, of the 11 structures observed during this analysis:
  - four (Nos. 3, 8, 9, and 11) are unconfirmed during either of the other analyses (rows highlighted in green);
  - two (Nos. 1 and 7) are disputed (identified during only one of the two other analyses);
  - 6 structures identified during the other analyses were entirely missed during this analysis (rows highlighted in pink); and
  - although these structures were nominally matched with other structures, the character and/or dimensions of four structures (Nos. 1, 6, a component of 6, and 7) reported in this analysis do not even reasonably match the character and/or dimensions reported for these structures during the other analyses. These discrepancies are highlighted in blue;

- for QC Analysis No. 1 (in the middle of Table 5), of the 14 structures observed during this analysis:
  - three (Nos. 3, 7, and 9) are unconfirmed during either of the other analyses (rows highlighted in green);
  - seven (Nos. 1, 2, 4, 11, 12, and 13) are disputed (identified during only one of the two other analyses);
  - 1 structures identified during the other analyses were entirely missed during this analysis (rows highlighted in pink); and

- although these structures were nominally matched with other structures, the character and/or dimensions of 12 structures (Nos. 2, 4, a component of 4, 6, 8, 10, a component of 10, 11, a component of 11, 12, 13, and 14) reported in this analysis do not even reasonably match the character and/or dimensions reported for these structures during the other analyses. These discrepancies are highlighted in blue; and

- for QC Analysis No. 2, of the 19 structures observed during this analysis:
  - 12 (Nos. 1, 4, 5, 6, 7, 8, 9, 12, 14, 15, 17, and 18) are unconfirmed during either of the other analyses (rows highlighted in green);
  - three (Nos. 2, 3, and 16) are disputed (identified during only one of the two other analyses);
  - 2 structures identified during the other analyses were entirely missed during this analysis (rows highlighted in pink); and
  - although these structures were nominally matched with other structures, the character and/or dimensions of 12 structures (Nos. 3, a component of 3, 10, 11, 13, a component of 13, a component of 15, 16, a component of 16, a component of 17, a component of 18, and 19) reported in this analysis do not even reasonably match the character and/or dimensions reported for these structures during the other analyses. These discrepancies are highlighted in blue.

The source of the errors indicated in Table 4 is not immediately apparent. However, an evaluation of all of the 57 paired analyses reported in the Ladd (2005) data set show statistical agreement among pairs. This suggests that the errors may be associated with reporting and documentation, rather than the actual performance of the analysts. Nevertheless, these problems are still serious. One cannot consider data reliable until one has confidence not only that analyses are correct, but that the results have been properly documented. Therefore, until these problems are addressed through some appropriate corrective action, one cannot place confidence in the concentrations reported in the Ladd (2005) study. This is simply because there is otherwise no independent means of confirming whether the analysts in fact saw what they reported.

The general applicability of the Ladd study. Exposures linked to a small number of specific areas within El Dorado County were studied by Ladd (2005). These include, for example, specific school yards and a nature trail (among other places). If broader conclusions concerning asbestos exposure in El Dorado County (beyond those linked exclusively to the specific areas studied) are to be derived from this study, however, the degree with which the specific locations studied reflect broader conditions in El Dorado County needs to be characterized.

It is expected that conditions in El Dorado County will vary substantially from one location to the next. This is likely true both in terms of the concentrations of serpentinite and amphibole minerals in local soils and rock as well as the fraction of such minerals

that are truly asbestiform.[10] For example, despite evidence that the fraction of true asbestiform amphibole is small in soils in the areas specifically studied by Ladd (Sections 4.1.1, 4.2.1, and 4.3), it is known that asbestiform amphibole exists in at least some parts of the county (see, for example, Davis et al. 1991).

Given the above, without tying exposure estimates from the Ladd (2005) study to bulk determinations of asbestos in the soil (e.g. through some type of appropriate modeling validated with field confirmation from a robust and properly designed study), any results derived from the Ladd study cannot be extrapolated beyond the bounds of the specific areas within which the study was actually conducted. Moreover, without developing some type of general approach to link airborne measurements to bulk measurements, it will prove impractical to conduct simulations in every area of concern around El Dorado County (let alone the nation) in which the presence of amphibole or serpentinite minerals may suggest concern with regard to the presence of asbestos.

4.1.3 Implications from the literature concerning cleavage fragments

A wealth of studies have been published that potentially provide information distinguishing the relative potencies of amphibole cleavage fragments and true asbestiform structures. These include, for example, the studies cited by Ilgren (2004)[11] and those included in the docket supporting the OSHA final rule (OSHA 1992). However, the interpretation of these studies remains controversial.

It is true that many of these studies suffer from the various kinds of limitations that commonly plague similar studies typically associated with true asbestos, including primarily the inadequate manner in which the relevant exposures have been characterized in many studies. Also, individual studies exist that “appear” to contradict the impressions gleaned from the majority of these studies. However, the apparent contradictions simply suggest a robust database that may actually provide an opportunity to evaluate and identify exposure models capable of reconciling these disparate results (see below). It is expected that a single unified model can ultimately be developed that adequately predicts the risk associated with exposure to elongated particles of serpentine and amphibole, whether asbestiform or not.

In fact, it appears that the protocol developed by Berman and Crump (2003), perhaps with minor modifications, may be close to achieving the goal of reconciling this set of literature studies. However, further study is clearly required to test this possibility.

---

[10] This will also radically affect overall size distributions and thus the relationships between various exposure metrics. Thus, exposure and risk estimates will be affected, no matter how one chooses to assess risk.

[11] Importantly, it is primarily the citations reported in Ilgren (2004), rather than the specific findings reported by Ilgren that should be the focus here.

Taken as a whole, the evidence from the available literature is strongly suggestive either that cleavage fragments (structure for structure) are less potent than true asbestiform structures or that populations composed primarily of cleavage fragments contain fewer structures within the size range that induces biological activity than populations containing substantial fractions of asbestiform material.

In fact, this general impression is consistent with the findings by OSHA. In their final rule, OSHA (1992) concluded that the evidence from these studies was insufficient to regulate cleavage fragments as asbestos. Nevertheless, controversies persist and these need to be thoroughly explored and reconciled.

In fact, the best interpretation of the literature may be that controversies concerning the distinction between the hazards associated with cleavage fragments and true asbestiform structures are driven primarily by use of an inappropriate metric for characterizing asbestos-related exposures. There is ample evidence that the size range represented by "regulatory fibers" (i.e. those included in the PCM/PCMe metrics) does not adequately reflect the size range of asbestos structures that predict risk (Section 4.1.1).

That the controversies surrounding cleavage fragments are largely a function of size and the associated need to employ an appropriate exposure metric when evaluating asbestos risk is directly supported by the findings of both the American Thoracic Society (ATS 1990) and the expert panel that contributed to the peer consultation workshop on the Berman and Crump protocol (ERG 2003). Both of these groups explicitly question the appropriateness of "regulatory fibers" as an exposure metric for asbestos. Moreover, given such comments, it is clear that neither the ATS nor the expert panel explicitly supports the approach proposed by EPA for assessing risks in El Dorado County.

Many studies (including the extensive work documented by Berman and Crump) point to longer and thinner structures (thinner than PCMe fibers) as the ones that contribute most to disease. Thus, once an appropriate exposure metric (which focuses on these structures) can be fully evaluated and optimized:

(1) the disparate results of the existing epidemiology studies will be fully reconciled by a unified model of exposure and risk; and

(2) the need to distinguish true fibers from cleavage fragments will be unimportant in this model. Thus, the entire controversy surrounding the differences between true fibers and cleavage fragments may simply disappear.

The exposure metric proposed by Berman and Crump (2003), even though not fully optimized (due to the limitations of the data available for supporting such optimization) already provides substantial improvement toward reconciliation of the disparate epidemiology studies (relative to that observed when exposure response factors from

these studies are expressed in terms of the regulatory fiber metric). In fact, the improvement is statistically significant for mesothelioma (Section 4.1.1).

Although it is recognized that the data set recently studied by a team from NIOSH (Kuempel et al. 2006) has limited power to evaluate such questions, the results that they report support the findings of Berman et al. (1995) and the overall direction for optimization proposed by Berman and Crump. This direction is ultimately to consider exposure metrics focusing on even longer structures than currently considered. Kuempel et al. (2006) also proposed better evaluating the cutoff for width, once an adequate data set can be found for supporting such an evaluation. Unfortunately, the available exposure characterizations are insufficient to adequately evaluate the effects of width across the published epidemiology studies (Berman and Crump 2003).

It should also be pointed out that (absent the ability to identify or manufacture study environments in which exposures are known to be pure) the best and most definitive way to resolve the controversies involving cleavage fragments would be by:

(1) reconstructing the characteristics of the historical exposures in the available epidemiology studies conducted in the complete set of environments in which exposure is known to have been almost exclusively composed of pure asbestiform structures (i.e. in the various asbestos product factories studied historically), in environments in which exposures have been demonstrably mixed (i.e. the various mining environments studied historically), and in environments in which exposures appear to have been primarily (but not necessarily exclusively) to non-asbestiform amphiboles; and

(2) conducting a meta analysis over this entire suite of studies incorporating the data derived from (1) that provides an improved characterization of the associated exposures.

If, as expected, the result of such a study would be the identification of a single exposure metric (with multiple risk factors) that would explain the observed variation in dose-response across all three sets of studies, this would provide reasonable confidence that the studies had been adequately reconciled so that risks for all of these types of sites can be adequately predicted by a single model.

4.2 Considering Precedent

To evaluate the degree with which the approach proposed by EPA for evaluating asbestos-related risk in El Dorado County is supported by precedent, it is important to consider:

- the overall consistency of approaches used to evaluate asbestos exposure and risk at government-lead sites; and

- a comparison of the relative degree of review of the proposed approach and the Berman and Crump approach.

4.2.1 Approaches used at other government-lead sites

Table 6 presents information about a set of government-lead studies in which the EPA played a major role. In fact, EPA was the lead agency on all of the projects listed except the Southdown Project for which the lead was shared with the New Jersey Department of Environmental Protection (NJDEP). These studies were selected primarily to indicate the diversity of approaches that EPA has recently taken to assess asbestos-related risk[12].

In Table 6, the studies are presented in chronological order (based on the date of the respective reports from which the information about each project was derived). Successive rows of the upper portion of the table respectively indicate:

- the year that the study was reported;
- the source of asbestos at the studied site (e.g. natural or commercial products);
- the nature of the surrounding matrix in which the asbestos is found;
- the type of asbestos;
- the types of microscopic structures associated with each matrix;
- the specific versions of the definition(s) employed for the PCMe exposure metric;
- the analytical method(s) employed to determine the concentrations of asbestos structures in the samples collected from the site; and
- the approach(es) employed to assess asbestos-related risks.

The middle portion of Table 6 provides information on the relative magnitude of risks estimated using each of the various approaches adopted in each study. This, in turn, provides a general indication of the relative degree of health protectiveness afforded by the various approaches. Rows in this section of the table respectively indicate:

- whether the ratios of risk presented in this section were observed or estimated. Risk ratios were considered to be observed if they were derived directly from risks reported in the study indicated for each of the exposure metrics considered. Risk ratios were considered to be estimated if the relevant risk estimates were not reported directly but the ratios could be extrapolated from information on the distribution of structure sizes observed in the analyses conducted to support each study;

- the ratio of risks estimated by combining PCMe concentrations with the risk factor in IRIS to risks estimated for a selected, baseline case. Because this approach also

---

[12] Importantly, while the set of studies presented in Table 6 are neither comprehensive nor statistically representative of the broader range of studies conducted by EPA over the years, their review is nevertheless instructive. Moreover, the findings presented in this section requires neither comprehensiveness nor representativeness for validity.

(approximately) represents the baseline case, all the ratios in this row are reported as one;[13]

- the ratio of risks estimated by combining PCMe (as defined by COEHHA) with the risk factors recommended by COEHHA to risks estimated for the baseline case. The COEHHA definition of PCMe is provided in Table 1 under the heading: "CA Proposition 65." Note that the COEHHA definition of PCMe was only considered in the first study listed in the table (i.e. Diamond XX);

- the ratio of risks estimated using the approach recommended by Berman and Crump (2001) to the risks estimated for the baseline case; and

- based on the ratios presented in the previous rows, whether risks derived using Berman and Crump (2001) or those derived using IRIS would be expected to be larger and thus drive risk management decisions. The procedure providing the greatest estimates of risk would generally be expected to drive these decisions.

It should be noted that the ratios presented in this section of the table for El Dorado County (the last column of Table 6) are all listed in parentheses to highlight the fact that they are especially uncertain due to a need to resolve QC issues associated with the data from this study as well as the need to address other study limitations (Section 4.1.2).

The lower portion of Table 6 provides information on the risk levels equivalent to an AHERA benchmark criterion that was used in some studies to support risk management decisions. Details concerning the manner in which this benchmark was established for the various sites in which it was applied (i.e. Libby and the World Trade Center) are provided in the respective studies cited in the table for those sites.

Depending on the availability of data from a particular study, the level of risk that would be equivalent to the concentration represented by the AHERA benchmark were derived using both the risk approach employing the IRIS risk factor and for the approach

---

[13] In fact, the baseline case is intended to be one in which PCMe concentrations with dimensions *matching* those indicated in IRIS would be combined with the IRIS risk factor (see Table 1). In contrast, PCMe concentrations derived in the studies presented in Table 6 actually represent PCMe structures with the dimensions defined either by NIOSH or by ATSDR, which include thinner structures than those included in the IRIS definition (see Table 1). This makes the exposure concentrations slightly larger than what would have been determined in the strict manner defined in IRIS. Thus, the ratios presented in the "IRIS (Current)" row of the table should all be somewhat smaller than one. Unfortunately, however, without access to the raw data from each study (and the time required to conduct the requisite calculations), it is not possible to determine the exact value of this ratio. Thus, they are all presented as "one" in the table, with footnotes indicating the problem.

recommended in Berman and Crump (2001)[14]. For the former, the concentration of PCMe structures equivalent to the AHERA benchmark (given the characteristics of the asbestos structures at each particular site) was first determined from the data and this was then multiplied by the risk factor in IRIS. Similarly for the Berman and Crump approach, the concentration of protocol structures (and the fraction of long protocol structures) equivalent to the concentration represented by the benchmark were first determined from the site data and the protocol structure concentration was then multiplied by a risk factor appropriate for the type and size distribution of asbestos, as described in Berman and Crump (2001). IRIS-based risk estimates and Berman and Crump-based risk estimates are presented, respectively, in the last two rows of Table 6.

A number of findings can be gleaned from the information presented in Table 6. It is apparent, for example, that the EPA has been applying the Berman and Crump protocol (or a forerunner to the protocol) to assess asbestos-related risks at least at some sites as far back as 1994. Interestingly, the Diamond XX study was also the first of several studies of asbestos roads commissioned by the EPA in which highly robust and statistically significant results were obtained (ICF Technology 1994).

It is also interesting to note that, at least at the Southdown site, the EPA supported distinguishing contributions to risk from true asbestiform structures and cleavage fragments. Thus, it appears that this issue has received past attention.

The information presented in the middle portion of Table 6 indicates that, except for the El Dorado County Study, risks estimated using the Berman and Crump protocol are equivalent to or higher than those estimated using IRIS. In fact, for sites in which amphibole asbestos is present, the Berman and Crump protocol provides risk estimates that are substantially higher than those estimated using IRIS. This observation is further supported from observations at virtually all other sites in which both approaches have been applied to assess risk. These include both sites at which asbestos is naturally occurring and sites at which the source of asbestos is debris from asbestos-containing construction materials.

That the above contrasts sharply with what is observed for the El Dorado County Study (i.e. that risks estimated using the Berman and Crump protocol are substantially lower than those estimated using IRIS) reinforces the notion that something may be radically different about the nature of exposures in the *specific* locations in which this study was conducted than for the exposures characterized at most other asbestos sites. This and related considerations are addressed further in Section 4.3, below.

The information provided in the lower portion of Table 6 reinforces the findings obtained from the middle portion. It also suggests that use of the AHERA benchmark to

---

[14] Note that in all cases here, estimated risks were derived assuming lifetime-continuous exposure, which may or may not be appropriate for specific situations. Thus, such considerations need to be more carefully explored before drawing definitive conclusions.

delineate potentially hazardous exposures to asbestos may not be particularly health protective. As can be seen in the second to last row of the table, the risk equivalent to the AHERA benchmark (using IRIS) is near or at the upper end of the range of risks potentially considered acceptable by EPA (i.e. $1x10^{-6}$ to $1x10^{-4}$) for both the Libby and the World Trade Center sites. Moreover, based on the characteristics of the exposures at Libby, the risk equivalent to the AHERA benchmark estimated using the Berman and Crump approach is substantially above the range of risks potentially considered acceptable by EPA.

Unfortunately, the available data were not sufficient to estimate a risk equivalent to the AHERA benchmark using the Berman and Crump protocol at the World Trade Center site. If it is true, however, that virtually all of the asbestos observed is chrysotile (and that is not entirely clear), then the Berman and Crump protocol would not necessarily be expected to produce a risk estimate that is substantially higher.

4.2.2 A comparison of the status of review of the proposed approach with the Berman and Crump approach

Table 7 is a side-by-side comparison of the steps required to assess asbestos-related risk using, respectively, the approach proposed by EPA for El Dorado County and the Berman and Crump protocol. It also indicates what appears to be the current (review) status of each of the steps, based on a brief review of relevant documents.

In Table 7, the first column lists the major phases required for assessing risk (from acquisition of data through applying a risk factor to exposures estimated using a particular metric). Obviously, the steps of these phases had to be streamlined for brevity, although an effort was made to capture all steps in which distinctions are potentially important.

The remaining columns of Table 7 respectively indicate:

- the steps employed by EPA to develop the current risk factor for asbestos (IRIS Current) and to apply it using the approach proposed for El Dorado County;
- comments highlighting important considerations for some of these steps;
- the steps employed to develop the risk factors proposed by Berman and Crump (2001, 2003) and to apply it to El Dorado County; and
- comments highlighting important considerations for some of these steps.

As can be seen in Table 7, the Berman and Crump approach has substantially benefitted from the advantage of 14 additional years of research over development of the risk factor currently listed in IRIS. Among other things, this means that control environments potentially relevant to environments in which asbestos is naturally

occurring (and may therefore coexist with substantial contributions from massive forms of the same mineral) were considered.

It is also acknowledged in the table that the current IRIS risk factor enjoys the precedent of having been subjected to the entire, formal EPA review process needed for establishing such values. In contrast, the Berman and Crump protocol has only been subjected to an initial peer-review consultation (by a panel of 11 experts) heretofore. At the same time, even EPA staff acknowledge that the IRIS risk factor is out of date and needs to be revised (Fed Reg 2006).

What may be more important to the issues at hand, however, is the status of the steps listed in Table 7 that are subsequent to the establishment of risk factors. As can be seen in the table, because one is applying "apples directly to apples," and because the exposure metric recommended in the Berman and Crump protocol has already been converted to a TEM-dependent exposure metric (during development of the risk factor itself), no further assumptions are required (or need review) when applying the factor to assess risks at particular sites.

In contrast, as has been shown in previous sections of this report, determination of PCMe-based concentrations may not have been conducted entirely consistently heretofore. Moreover, the manner in which PCMe relates to risk in an environment such as observed in El Dorado County are entirely different than the kinds of environments studied by epidemiologists in the control studies used to derive the current risk factor in IRIS. In addition, it does not appear that either of these critical considerations have been subjected to any kind of formal agency review at this point in time.

The comment from the Peer Review Committee concerning the idea that the minimum diameter of the size range for protocol structures needs to be increased to 1.5 µm also needs to be addressed. It is important to understand that, currently, this is only a recommendation from the group of reviewers. It is *not* a finding from a formal analysis of any kind. This contrasts with the current size range limit, which has been formally evaluated as part of a meta analysis of the human epidemiology studies and extrapolated from a formal analysis of animal inhalation studies. Moreover, it is unlikely that members of the peer-review committee would suggest that such a change should be applied for exposure determination without first defining an appropriately matching risk factor (which would require that a formal meta analysis be completed using appropriate exposure data)[15].

---

[15] Unfortunately, the database of existing size distributions is not sufficiently rich to adequately evaluate the effects of length or width further than what has already been done (Berman and Crump 2003). It is important to remember, for example, that the effects of length and width are confounded so that the unfortunate length truncation of the existing database (i.e. that no information is available for the distribution of lengths beyond 10 µm) prevents more detailed consideration of either width or length using the

In fact, it is not even known whether such a change would result in risk estimates increasing or decreasing in specific environments. This is because the result of the meta analysis (which would need to be conducted to develop properly matched risk factors) would be to spread the "fixed" risk from the mortality observed in the epidemiology studies across a larger number of structures than is the case for the exposure metric currently recommended by Berman and Crump. The relative magnitude of the risk estimated using the new, thicker structures (versus current protocol structures) would then depend on the relative ratios of the two sets of structures in control studies vs. site studies.

To illustrate the above consideration, if the ratio of the new exposure metric (incorporating the thicker structures) to protocol structures is greater in the control environments (studied by epidemiologists) than in environments of interest at specific sites (where risks are assessed), then risks estimated using the new metric will be lower than risks estimated using the current (Berman and Crump) metric. Thus, it is possible that even this approach could potentially be "less health protective," although an appropriate meta analysis might (or might not) show that it is more reliable.

4.3 Considering Health Protectiveness

It is instructive to evaluate the relative degree of health protectiveness potentially afforded by the various approaches for assessing asbestos-related risk that are considered in this report. The information provided in the middle and lower sections of Table 6 can be used for this purpose.

Based on the factors presented in the row of Table 6 labeled: "Berman and Crump (2001)" and confirmed in the row labeled: "Risk Driver," it appears that the Berman and Crump protocol provides a more sensitive measure of asbestos-related risk than the approach using IRIS. Moreover, for sites in which asbestiform amphiboles are the primary contributors to exposure, risks estimated using the Berman and Crump protocol tend to be an order of magnitude or more greater than those estimated using IRIS. Such observations are further confirmed by studies at other sites (including sites at which amphibole asbestos is naturally occurring and sites at which it is derived from manufactured asbestos product debris). At virtually all such sites in which data are available for comparing the two approaches for assessing risk, the Berman and Crump protocol yields risk estimates that are substantially higher than those estimated using IRIS.

---

human epidemiology data.

It should also be noted that the results reported by NIOSH at a recent conference (Kuempel et al. 2006) tend to support the direction of the Berman and Crump work (i.e. toward very long and very thin fibers as the cause of disease), it is also important to recognize that the single environment available to the authors in this analysis is not sufficiently robust to adequately examine these kinds of questions.

The information in Table 6 also highlights the fact that the set of sites exhibiting elevated risks and the rank order of such risks varies as a consequence of the choice of the exposure metric used to assess risk. This helps to inform the question of which approaches, if applied consistently, are likely to best reflect what is known about the incidence of asbestos-related disease.

Use of the Berman and Crump protocol focuses attention on sites where long, thin, asbestiform amphiboles contribute substantially to exposure. These include (for example) sites such as Libby, where asbestos-related diseases have actually been observed among the exposed population.

In contrast, the approach proposed by EPA for use in El Dorado County (i.e. estimating exposure using the PCMe metric and combining such results with the IRIS risk factor) tends to focus attention on sites where local soils and rock contain high concentrations of non-asbestiform amphiboles (or serpentinite). Thus, locations such as the specific areas of El Dorado County studied by Ladd are emphasized. However, given that surface soils and rock over approximately 30% of the nation apparently contain substantial concentrations of non-asbestiform amphiboles with no current evidence of elevated disease in these areas, it is not clear how helpful such emphasis may be.

At the same time, the approach proposed by EPA may “miss” elevated risks at sites in which asbestiform amphiboles are present at low concentrations, but the host rock does not otherwise contain substantial concentrations of other (non-asbestiform) amphiboles. Thus, there may be situations in which “diluted” versions of Libby may be missed by this approach. Given such possibilities, it appears that the proposed EPA approach, if applied consistently, may miss potentially risky situations in various parts of the nation or even other parts of El Dorado County.

It should also be emphasized that, based on the information provided in the last two rows of Table 6, use of the AHERA benchmark as a screen for distinguishing potentially risky situations from those that are relatively safe, may not be as effective as desired (see Section 4.2.1).

One final note is also relevant here. As further work will inevitably be conducted to refine exposure metrics for assessing asbestos-related risk, it is important to debunk one widely held misconception. As it is a requirement of sound science for assessing risk, exposure concentrations estimated using any particular exposure metric should only be combined with risk factors that are properly matched to that particular exposure metric. Assuming this is the case, it is *not* true that an exposure metric resulting in greater numbers of structures being counted to determine concentration will necessarily result in greater estimates of risk than those derived using other exposure metrics.

To derive a risk factor matched to a particular exposure metric, it is first necessary to convert estimates of exposures relevant to the control studies (epidemiology studies) to the particular exposure metric. The manner in which this is accomplished is described

in detail in Berman and Crump (2003). However, the consequence of this step is that the risk factor derived from control studies will decrease as the number of structures included in exposure concentration estimates increase in these studies.

Given the above, whether risk estimated using a particular exposure metric will increase or decrease relative to a baseline case is a function of the ratio of the concentrations estimated for the particular exposure metric at the study site to the concentrations estimated at sites evaluated in the control studies. If more of the particular kinds of structures (defined by the exposure metric) are present in control study exposures than observed at a study site (relative to the baseline case), the risk estimated using the particular exposure metric will be *lower* than the baseline case for the study site in question.

5 CONCLUSIONS

Based on the evaluation presented above, it appears that the approach proposed by EPA to assess risk in El Dorado County satisfies neither of two criteria that are critical for assuring that risk assessments are reliable. First, due to substantial differences in character, exposure concentrations determined in terms of the PCMe metric in El Dorado County (Ladd 2005) are not directly comparable to the PCM-based exposures evaluated in the epidemiology studies used to derive the risk factor in IRIS (Current). Second, the PCMe exposure metric itself has been shown not to remain reasonably proportional to risk across exposure environments.

Given these findings, applying the IRIS risk factor to the exposures measured by Ladd will not provide a reliable estimate of risk. In contrast, use of the protocol structure metric combined with the appropriately matched risk factors recommended by Berman and Crump (2001)[16] can potentially provide a reliable estimate of risk for the locations studied by Ladd, subject to the additional considerations discussed below.

The Ladd (2005) study appears to suffer from quality control (QC) problems that will need to be resolved before any attempt is made to interpret the data. Even after the QC issues are resolved, however, it may prove difficult to extrapolate findings that may be gleaned from the study more broadly than to the specific locations at which airborne measurements were collected. This is because no relationship between bulk concentrations and airborne exposure measurements was established in the Ladd study.

---

[16] The analyses conducted to generate the data reported in Ladd (2005) were not explicitly designed to determine concentrations of long structures (longer than 10 µm) with sufficient sensitivity and precision to support risk assessment exclusively using these longer structures. Therefore, if there is ultimately a desire to apply the Berman and Crump protocol to these data, the 2001 version of the protocol should be applied rather than the 2003 version.

Until the quality control issues are resolved and an appropriate statistical analysis of the data is conducted, a proper assessment of risk cannot be completed from the Ladd (2005) data. Thus, it is not possible to tell at this time whether risks estimated using either protocol structures or PCMe structures will prove to be acceptable for the areas represented by the Ladd study environment. However, assuming that the ratios of concentrations are approximately correct, it appears that the IRIS approach for assessing risk yields a higher risk estimate than the Berman and Crump approach for the specific locations that were studied.

As the above observation (should it hold up) is highly unusual, compared to findings based on broad experience at other sites, it reinforces the finding that conditions at these specific locations in El Dorado County are very different from conditions found at most sites where asbestos is a hazard (potentially including other parts of El Dorado County).

If applied uniformly at sites across the nation, the approach proposed for assessing risk in El Dorado County will be less health protective than if such risks are assessed using the approach proposed by Berman and Crump. This is based on a growing body of experience at multiple, varied sites.

Whatever the relative risks that might be estimated for El Dorado County based, respectively, on the approach proposed by EPA and the approach recommended by Berman and Crump (2001), it appears that the proposed EPA approach is no better supported by precedent.

Given that (based on discussions with multiple geologists) about 30% of the soil and near-surface rock in the nation may contain amphibole, if the agency intends to apply their asbestos regulations consistently to all areas where amphibole may be present, then it is in everyone's interest to employ an approach that will adequately distinguish situations that are potentially risky from those that are not. Otherwise, there is a potential either to miss those sites in which true risks exist or, conversely, to *unnecessarily* wreak economic havoc. Neither result is in the public interest, although the first kind of error is clearly the more important to avoid.

6 REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR). *Toxicological Profile for Asbestos.* U.S. Department of Health and Human Services. September, 2001.

Amandus, H.E., Wheeler, R., Jankovic, J., Tucker, J., "The Morbidity and Mortality of Vermiculite Miners and Millers Exposed to Tremolite-Actinolite: Part I. Exposure Estimates." American Journal of Industrial Medicine, Vol. 11, pp. 1-14, 1987.

American Thoracic Society (ATS). "Health Effects of Tremolite." *Amer Rev Respr Disease* 142:6:pp 1453-1458. December, 1990.

Berman, D.W. *Analysis and Interpretation of Measurements for the Determination of Asbestos in Core Samples Collected at the Southdown Quarry in Sparta, New Jersey.* Prepared for the U.S. Environmental Protection Agency, Region 2 and the New Jersey Department of Environmental Protection. November 12, 2003.

Berman, D.W. and Crump, K.S. *Final Draft: Technical Support Document for a Protocol to Assess Asbestos-Related Risk*. Prepared for Mark Follensbee, Syracuse Research Corporation, Syracuse, New York and the Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C. 2003. Limited revision draft.

Berman, D.W. and Crump, K.S.; *Technical Support Document for a Protocol to Assess Asbestos-Related Risk*. Prepared for Mark Raney, Volpe Center, U.S. Department of Transportation, 55 Broadway, Kendall Square, Cambridge, MA 02142. 2001. Peer-reviewed draft.

Berman, D.W. "Asbestos Measurement in Soils and Bulk Materials: Sensitivity, Precision, and Interpretation -- You *Can* Have It All." in *Advances in Environmental Measurement Methods for Asbestos, ASTM STP 1342,* M.E. Beard, H.L. Rook, Eds., American Society for Testing and Materials. Pp. 70-89. 2000.

Berman, D.W.; Crump, K.S.; Chatfield, E.J.; Davis, J.M.G.; and Jones, A. "The Sizes, Shapes, and Mineralogy of Asbestos Structures that Induce Lung Tumors or Mesothelioma in AF/HAN Rats Following Inhalation." Risk Analysis. 15:2:181-195, 1995.

Berman, D.W. and Chatfield, E.J. "Interim Superfund Method for the Determination of Asbestos in Ambient Environments, Part 2: Technical Background Document." U.S. Environmental Protection Agency publication: 540/2-90/005b, May 1990.

Berry G; Newhouse ML. Mortality of Workers Manufacturing Friction Materials Using Asbestos. *British Journal of Industrial Medicine*. 40:1–7. 1983.

California Air Resources Board. *Staff Report: Initial Statement of Reasons for Proposed Rulemaking. Public Hearing to Consider the Adoption of a Regulatory Amendment Identifying Asbestos as a Toxic Air Contaminant.* February 10, 1986.

California Air Resources Board. *Method 427: Determination of Asbestos Emissions from Stationary Sources.* March 27, 1988.

California Office of Environmental Health Hazard Assessment. *Chemicals Listed Effective February 3, 2006 as Known to the State of California to Cause Cancer.* Required as part of the Safe Drinking Water and Toxic Enforcement Act of 1986 (California Proposition 65). 2006.

Cherrie, J; Addison, J; and Dodgson, J. “Comparative Studies of Airborne Asbestos in Occupational and Non-occupational Environments Using Optical and Electron Microscope Techniques.” *IARC Sci Publ* (90). pp 304-9. ISSN 0300-5038. 1989.

Chesson, J; Rench, JD; Schultz, BD; and Milne,KL. “Interpretation of Airborne Asbesos Measurements.” *Risk Analysis.* 10(3):437-47. 1990.

Davis, JMG; Addison, J; McIntosh, C; Miller, BG; Niven, K; “Variations in the Carcinogenicity of Tremolite Dust Samples of Differing Morphology.” *Annals New York Academy of Sciences.* pp. 473-490. 1991.

de Klerk NH; Musk AW; Armstrong BK; Hobbs MST. Diseases in Miners and Millers of Crocidolite from Wittenoom, Western Australia: A Further Followup to December 1986. *Annals of Occupational Hygiene*. 38(Suppl 1):647–655. 1994.

Dement JM; Harris RL; Symons MJ; Shy CM. Exposures and Mortality Among Chrysotile Workers. Part I: Exposure Estimates. *American Journal of Industrial Medicine*. 4:399–419. 1983a.

Dement JM; Harris RL; Symons MJ; Shy CM. Exposures and Mortality Among Chrysotile Workers. Part II: Mortality. *American Journal of Industrial Medicine*. 4:421–433. 1983b.

EPA (see, U.S. Environmental Protection Agency).

Eastern Research Group, Inc. (ERG). *Report on the Peer Consultation Workshop to Discuss a Proposed Protocol to Assess Asbestos-Related Risk*. Prepared for the Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C. 20460. Final Report, May 30, 2003.

Federal Register 71/36/pp. 9333-9336. February 23, 2006.

Finkelstein MM. Mortality Among Long-Term Employees of an Ontario Asbestos-Cement Factory. *British Journal of Industrial Medicine*. 40:138–144. 1983.

Henderson VL; Enterline PE. Asbestos Exposure: Factors Associated with Excess Cancer and Respiratory Disease Mortality. *Annals New York Academy of Sciences*. 330:117–126. 1979.

ICF Technology, *Evaluation of Risks Posed by Residents of Diamond XX Who Are Exposed to Airborne Asbestos Derived from Serpentine Covered Roadways. Final.* Prepared for: The U.S. Environmental Protection Agency, Region 9. June 9, 1994.

Ilgren, E.B. “The Biology of Cleavage Fragments: A Brief Synthesis and Analysis of Current Knowledge.” *Indoor Built Environ* 13:pp 1-14. 2004.

International Agency for Research on Cancer (IARC). Monographs on the Evaluation of Carcinogenic Risks to Man. Volume 14. IARC Scientific Publications. Lyon, France. 1977.

Integrated Risk Information System (IRIS). Toxicological Review of Asbestos. U.S. Environmental Protection Agency. Office of Research and Development, National Center for Environmental Assessment. Washington, D.C. http://www.epa.gov/iris/subst/0371.htm. Current.

International Organization for Standardization. *Ambient Air-Determination of asbestos fibers - Direct-transfer transmission electron microscopy method.* ISO 10312. 1995.

Kenny, L.C.; Rood, A.P.; and Blight, B.J.N. "A Direct Measurement of the Visibility of Amosite Asbestos Fibers by Phase Contrast Optical Microscopy." *Annals of Occupational Hygiene,* 31/pp. 211-214. 1987.

Kuempel, E.D.; Stayner, L.T.; Dement, J.D.; Gilbert, S.J.; and Hein, M.J. "Fiber Size-Specific Exposure Estimates and Updated Mortality Analysis of Chrysotile Asbestos Textile Workers." Presented at the Society of Toxicology Meeting. March 6, 2006.

La Ville de Thetford Mines. *Thetford Mines a ciel ouvert: Histoire d'une ville miniere 1892-1992.* La Ville de Thetford Mines. 144 Notre-Dame Sud, Thetford Mines, Quebec, Canada G6G 5T3. 1994.

Ladd, K (Ecology and Environment, Inc.). *El Dorado Hills Naturally Occurring Asbestos Multimedia Exposure Assessment El Dorado Hills, California: Preliminary Assessment and Site Inspection Report, Interim Final.* Prepared for The U.S. Environmental Protection Agency, Region 9 under Contract No. 68-W-01-012, Work Assign. No. 001275.0440.01. May, 2005.

Liddell FDK; McDonald AD; McDonald JC. The 1891–1920 Birth Cohort of Quebec Chrysotile Miners and Millers: Development From 1904 and Mortality to 1992. *Annals of Occupational Hygiene*. 41:13–36. 1997.

Lynch JR; Ayer HE; Johnson DJ. The Interrelationships of Selected Asbestos Exposure Indices. *American Industrial Hygiene Association Journal*. 31(5):598–604. 1970.

McDonald JC; Gibbs GW; Liddell FDK. Chrysotile Fibre Concentration and Lung Cancer Mortality: A Preliminary Report. In *Biological Effects of Mineral Fibres*. Wagner JC (ed). IARC Scientific Publications. pp. 811–817. 1980a.

McDonald JC; Liddell FDK; Gibbs GW; Eyssen GE; McDonald AD. Dust Exposure and Mortality in Chrysotile Mining, 1910–1975. *British Journal of Industrial Medicine*. 37:11–24. 1980b.

McDonald AD; Fry JS; Wooley AJ; McDonald JC. Dust Exposure and Mortality in an American Chrysotile Textile Plant. *British Journal of Industrial Medicine*. 39:361–367. 1983a.

McDonald AD; Fry JS; Woolley AJ; McDonald JC. Dust Exposure and Mortality in an American Factory Using Chrysotile, Amosite, and Crocidolite in Mainly Textile Manufacture. *British Journal of Industrial Medicine.* 40:368–374. 1983b.

McDonald AD; Fry JS; Woolley AJ; McDonald JC. Dust Exposure and Mortality in an American Chrysotile Asbestos Friction Products Plant. *British Journal of Industrial Medicine*. 41:151–157. 1984.

The National Center for Environmental Assessment (NCEA). *Exposure and Human Health Evaluation of Airborne Pollution from the World Trade Center Disaster.* Office of Research and Development, U.S. Environmental Protection Agency. October, 2002.

Nicholson WJ; Selikoff IJ; Seidman H; Lilis R; Formby P. Long-Term Mortality Experience of Chrysotile Miners and Millers in Thetford Mines, Quebec. *Annals New York Academy of Sciences*. 330:11–21. 1979.

National Institute for Occupational Safety and Health (NIOSH). Method for Determination of Asbestos in Air Using Positive Phase Contrast Microscopy. NIOSH Method 7400. NIOSH, Cincinnati, Ohio, U.S.A. 1985. Current revision: 1994.

National Institute for Occupational Safety and Health (NIOSH). Method for Determination of Asbestos in Air Using Transmission Electron Microscopy. NIOSH Method 7402. NIOSH, Cincinnati, Ohio, U.S.A. 1986. Current Revision: 1994.

The Occupational Safety and Health Administration (OSHA) “Final Rule: Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite,” *Federal Register* 57:110:pp 24310-24331. 1992.

Peto J. Lung Cancer Mortality in Relation to Measured Dust Levels in an Asbestos Textile Factory. In *Biological Effects of Mineral Fibres*. Wagner JC (ed.). IARC Scientific Publications. pp. 829–836. 1980a.

Peto J. The Incidence of Pleural Mesothelioma in Chrysotile Asbestos Textile Workers. In *Biological Effects of Mineral Fibres*. Wagner JC (ed.). IARC Scientific Publications. pp. 703–711. 1980b.

Peto J; Seidman H; Selikoff IJ. Mesothelioma Mortality in Asbestos Workers: Implications for Models of Carcinogenesis and Risk Assessment. *British Journal of Cancer*. 45:124–135. 1982.

RJ Lee (R.J. Lee Group, Inc.). *Final: Evaluation of EPA's Analytical Data from the El Dorado Hills Asbestos Evaluation Project*. Prepared for the National Stone, Sand, and Gravel Association, Alexandria, Virginia. Project No. LSH306975. November, 2005.

Sebastien P; Plourde M; Robb R; Ross M. Ambient Air Asbestos Survey in Quebec Mining Towns - Part 1, Methodological Study. Environmental Protection Service, Quebec Region, 3/AP/RQ/1E. pp. 1–41. 1984.

Seidman H; Selikoff IJ; Hammond EC. Short-Term Asbestos Work Exposure and Long-Term Observation. *Annals New York Academy of Sciences*. 330:61–89. 1979.

Seidman H. Short-Term Asbestos Work Exposure and Long-Term Observation -- July 1984 Update. Department of Epidemiology, American Cancer Society. 1984.

Selikoff IJ; Hammond EC; Seidman H. Mortality Experience of Insulation Workers in the United States and Canada 1943–1976. *Annals New York Academy of Sciences*. 330:91–116. 1979.

Smith, G.W. *The Thetford Mines. 1878-1967.* Copyright: George Washington Smith, Bell Asbestos Mines Ltd. 1968.

Steel, E.B., Small, J.A., "Accuracy of Transmission Electron Microscopy for the Analysis of Asbestos in Ambient Environments." Analytical Chemistry, Vol. 57, pp. 209-213, 1985.

Turner, S. And Steel, E.B. *Airborne Asbestos Method: Standard Test Method for Verified Analysis of Asbestos by Transmission Electron Microscopy.* Version 2.0. National Institute of Standards and Technology. U.S. Department of Commerce. 1994.

Turner. S. And Steel, E.B. "Accuracy of Transmission Electron Microscopy Analysis of Asbestos in Filters: Interlaboratory Study." *Analytical Chemistry* 63(9)pp. 868-872. 1991.

U.S. Environmental Protection Agency. *Libby Asbestos Site Residential/Commercial Cleanup Action Level and Clearance Criteria. Technical Memorandum. Draft Final.* U.S. Environmental Protection Agency, Region 8. December 15, 2003.

U.S. Environmental Protection Agency. Asbestos-containing Materials in Schools; Final Rule and Notice. 40 CFR Part 763. Federal Register, Vol 52 (210): 41826-41905. October 30, 1987.

U.S. Environmental Protection Agency. Airborne Asbestos Health Assessment Update. Report 600/8-84-003F, U.S. Environmental Protection Agency. 1986.

Walton WH. The Nature, Hazards, and Assessment of Occupational Exposure to Airborne Asbestos Dust: A Review. *Annals of Occupational Hygiene*. 25:117–247. 1982.

Weill H; Hughes J; Waggenspack C. Influence of Dose and Fibre Type on Respiratory Malignancy Risk in Asbestos Cement Manufacturing. *American Review of Respiratory Disease*. 120:345–354. 1979.

Wylie AG; Bailey KF; Kelse JW; Lee RJ. The Importance of Width in Asbestos Fiber Carcinogenicity and its Implications for Public Policy. *American Industrial Hygiene Association Journal*. 54:239–252. 1993.

TABLES AND FIGURES

TABLE 1:
DEFINITIONS FOR PCM EQUIVALENT FROM VARIOUS SOURCES[a]

Source:	IRIS	NIOSH 7402[b]	ISO 10312	CARB Staff Report	CARB Method 427	CA Proposition 65	ATSDR
Year:							
Referenced	Current	1994	1995	1986	1988	2002	2001
Original	1988	1989	1995	1986	1988	1987	2001
TEM Criteria:							
Min Length (µm)	5	5	5	ND	5	ND	5
Min Width (µm):	0.4	0.25	0.2	ND	0.2 *or* 0.3	ND	0.3
Max Width (µm):	ND	ND	3	ND	ND	ND	3
AR:	≥3	≥3	≥3	≥3	≥3	≥3	≥3
Comments:	Indicates that correlation between TEM and PCM fiber counts are "very uncertain."	Count those structures that "would have been counted by PCM"		Defined as total TEM structures (no minimum length or width defined) divided by either 100 or 1000.		Defined as total TEM structures (no minimum length or width defined) divided by either 100 or 1000.	Defined as total TEM structures longer than 0.5 µm divided by 60
		Indicates that potential interferences include non-asbestos amphibole particles with AR ≥ 3:1 and some non amphiboles with similar diffraction patterns to amphiboles	Indicates that the method cannot distinguish between the asbestiform varieties of amphibole minerals and their non-asbestos analogs.				

NOTES:

ND means: "not defined in the method"

[a] To the extent possible, the most recent version of each of the above documents are presented, based on the results of a search of the appropriate agency websites. If there are newer versions, they are not easily located.

[b] This method was not designed to provide concentrations of asbestos fibers directly. Rather, it was designed to provide a factor that would be used to "adjust" a concentration measurement derived by PCM.

D. Wayne Berman, Aeolus, Inc.

TABLE 2:
COMPARISON OF STATUS OF VARIOUS EXPOSURE METRICS FOR EVALUATING ASBESTOS RISKS

	EXPOSURE METRIC						
	Total Respirable Particles	**PCM**	**PCMe**	**Total Protocol Structures**	**Long Protocol Structures**	**Long Protocol Structures Further Optimized**	**Long Protocol Structures Extended to Address Mouth Breathing**
Dimensions	AED < 10 µm	Length > 5 µm Width > ~0.25 µm Aspect Ratio ≥ 3	Length > 5 µm Width > ~0.25 µm Aspect Ratio ≥ 3	Length > 5 µm 0.5 µm > Width	Length > 10 µm 0.4 µm > Width	Dimensional criteria would be optimized based on new meta analysis	Length > 5 µm 1.5 µm > Width
Sampling and Analysis	Midget Impinger with Analysis by Optical Microscopy[a]	Membrane Filter with Analysis by Optical Microscopy[b]	Membrane Filter with Tandem Analysis by both Optical and Transmission Electron Microscope[c]	Membrane Filter with Analysis by Transmission Electron Microscopy[d]	Membrane Filter with Analysis by Transmission Electron Microscopy[d]	Membrane Filter with Analysis by Transmission Electron Microscopy[d]	Membrane Filter with Analysis by Transmission Electron Microscopy[d]
Magnification	~400	~400	500-1,000	10,000	10,000	10,000	10,000
Origin		Asbestos Research Council (ARC)[e]	NIOSH[c]	Berman and Crump[f]	Berman and Crump[g]	Hypothesis proposed by Berman[h]	Peer Review Committee[i]
Year		1958	1989	2001	2003	2001	2003
Theoretical Basis for Linking to Risk	**None.** In common use for particulate matter at the time.[e]	**Ad hoc.**[e] Developed primarily for analytical convenience with general recognition of need to distinguish fibers from particles.[e]	Based informally on presumption that measuring same size range as PCM (but adding mineral confirmation) would allow link to epidemiology study results.	Size rationally extrapolated from findings in Berman et al. 1995 with a modification required by the published size data available for application to the epidemiology studies.[f,g]	Modified from 2001 protocol based on *formal hypothesis test* of effect of length on ability to reduce variability across existing epidemiology studies.[g] Width interval reduced to match that indicated in Berman et al. (1995) per recommendation of the peer review committee.[g,i]	Proposed for testing based on implications from the literature that even longer structures are the major contributors to risk. Would also have optimized width dimensions based on a new analysis using new data	Proposed for consideration based on general idea that this range of structures includes all structures that potentially contribute to risk. Importantly, this metric may not automatically prove more health protective than others.[j]
Other Evidence	Recognized as inadequate for asbestos when extrapolating across environments[e]	(1) Recognized as inadequate for asbestos when extrapolating across environments.[e,f,g] (2) Shown not to adequately predict risk in animal inhalation studies.[k]	As PCM has not been shown to reasonably predict risk, utility for extrapolating across exposure environments is questionable.	In a formal meta analysis, shown to substantially reduce variability across existing epidemiology studies compared to use of PCMe.[f]	Shown to provide some improvement over 2001 protocol, based on limited hypothesis testing involving effects of length.[g]	Proposed for testing by completing a new meta analysis as soon as data from now cancelled study would have become available.[h]	The peer review committee proposed this metric for consideration as part of further meta-analysis, which is required to define matching dose-response factors for the metric.[j]
Intent	Designed originally for general application to toxins inhaled as particulate matter.[e]	Designed originally for evaluating exposure to commercial asbestos. NOT initially designed for application to other environments.[e]	Based on interferences listed in the method, it appears to have been designed originally for evaluating exposure to commercial asbestos.[c]	Designed originally for general application to asbestos in any environment.[f]	Designed originally for general application to asbestos in any environment.[g]	Proposed for consideration for application to asbestos in any environment.	Proposed for consideration for application to asbestos in any environment.
Pre-requisites for Implementation for Linking to Risk	No Longer Applied	None for most environments involving exposure to commercial asbestos, although direct link to risk is questionable.[e,g,k] Shown to be **NOT** applicable in natural environments due to presence of extensive interfering materials.[e,l,m]	NONE for environments involving exposure to commercial asbestos (but subject to some of the same limitations as PCM).[e,g,k] Applicability to natural environments still not demonstrated (and this is the current controversy).	NONE Already shown to provide substantial improvement over PCMe.[f]	NONE Already shown to provide some improvement over Total Protocol Structures.[g] ***Can be further optimized with data from now-cancelled study***	Need to evaluate in a formal meta-analysis both: (1) to develop appropriately matched dose-response factors and (2) to compare against the performance of Long Protocol Structures.	Need to evaluate in a formal meta-analysis both: (1) to develop appropriately matched dose-response factors and (2) to compare against the performance of Long Protocol Structures.
Strength of Evidence for Supporting Extrapolation to Natural Environments	No longer Applied and clearly not applicable	Shown not to be applicable in natural environments.[e,l,m]	Applicability to natural environments still not demonstrated (and this is the current controversy).[n]	Based on a growing track record, expected not to under-estimate asbestos risk relative to PCMe.	Expected not to under-estimate asbestos risk relative to PCMe.	Unknown. Will require validation with a meta analysis incorporating appropriately relevant control environments.	Unknown. Will require validation with a meta analysis incorporating appropriately relevant control environments.[o]

TABLE 2 (cont.):
COMPARISON OF STATUS OF VARIOUS EXPOSURE METRICS USED FOR EVALUATING ASBESTOS RISKS

Notes: AED means aerodynamic equivalent diameter.

[a] TBP

[b] NIOSH Method 7400 (1989). The history of the development of precursor methods predating the NIOSH Method is provided in Walton (1982).

[c] NIOSH Method 7402 (1994).

[d] ISO Method 10312 (1995), with modifications incorporated to focus on the indicated size range of structures. Note that complex structures (bundles, clusters, and matrices) are also incorporated into the counting rules.

[e] Walton (1982).

[f] Berman and Crump (2001).

[g] Berman and Crump (2003).

[h] Until February of this year, I was conducting a study to generate improved characterizations of the historical exposures relevant to critical epidemiology studies, which would have been used to support a revised meta analysis. The study was terminated.

[i] ERM (2003)

[j] As noted in the table, the potency assigned to structures representing any particular exposure metric needs to be determined by a formal meta analysis. If the concentrations of structures representing a particular exposure metric are more plentiful in the exposure environments of the original epidemiology studies (i.e. the control environments) than in the test environments (e.g. El Dorado County), than risks estimated in such environments will be lower than if such risks are estimated using an exposure metric in which such a difference is not as extreme (or the ratios are even reversed).

[k] Berman et al. (1995).

[l] Cherrie et al. (1989).

[m] Berman (no date) Unpublished data from the Oakland Hills Fire Project.

[n] At a minimum, an appropriately matching slope factor should be redeveloped for this exposure metric from a meta analysis that appropriately incorporates considerations of environments in which cleavage fragments predominate such as the Homestake Mine in South Dakota and the Taconite Mines in Minnesota. The slope factor currently being employed with this metric was derived from an analysis in which cleavage fragments were at most a miniscule component of the dusts in the environments studied (see text).

[o] The existing database of size distributions is not sufficiently rich to evaluate effects of diameter among the human epidemiology data with adequate statistical power. Among other things, for example, the existing database is truncated for length so that, due to the confounding effects of length and width, hypothesis testing using this truncated data set may not provide reliable determinations beyond what has already been reported by Berman and Crump. The study described in Footnote h was designed to provide the needed, additional data.

TABLE 3:
CHARACTER OF EXPOSURES IN ENVIRONMENTS INCLUDED IN THE 1986 HEALTH EFFECTS ASSESSMENT UPDATE REVIEW OF ASBESTOS EPIDEMIOLOGY STUDIES AND REPORTED IN IRIS 1988 AS THE BASIS FOR ESTABLISHING THE CURRENT UNIT RISK FACTOR

Fiber Type	Operation	Cohort	Lung Cancer K_L x 100	Mesothelioma K_M x 100	Exposure Metric[a]	Reference	Comments
							All samples contain asbestiform fiber. The indicated samples contain fiber with:
Chrysotile	Mining and Milling	Quebec mines and mills	***Not Used*** [b]		MI	(1)	serpentinite and trace amphibole cleavage fragments[b]
			Not Used [b]		MI	(2)	serpentinite and trace amphibole cleavage fragments[b]
	Friction Products	Connecticut plant	0.01		MI*	(3)	*at most* , small amounts of serpentinite cleavage fragments[c]
	Textiles	South Carolina plant	2.8		PCM	(4)	*at most* , trace serpentinite cleavage fragments
			2.5		PCM	(5)	*at most* , trace serpentinite cleavage fragments
Amosite	Insulation Manufacture	Patterson, NJ factory	4.3		PCM**	(6)	*at most* , trace amphibole cleavage fragments[d]
				1.00E-06		(7)	
Mixed	Friction Products	British factory	0.058		PCM	(8)	*at most* , trace amphibole cleavage fragments[c,d]
	Cement Manufacture	Ontario factory	6.7	1.20E-05	MI*	(9)	*at most* , trace serpentinite and amphibole cleavage fragments[e]
		New Orleans plants	0.53		MI	(10)	*at most* , trace serpentinite and amphibole cleavage fragments[e]
	Factory workers	U.S. retirees	0.49		MI*	(11)	*at most* , trace serpentinite and amphibole cleavage fragments
	Insulation Application	U.S. insulation workers	0.75	1.50E-06	NS	(12), (13)	*at most* , trace serpentinite and amphibole cleavage fragments[d]
	Textiles	Pennsylvania plant	1.4		MI*	(14)	*at most* , trace serpentinite and amphibole cleavage fragments
		Rochedale plant	1.1	3.20E-06	TP*	(15), (16)	*at most* , trace serpentinite and amphibole cleavage fragments

NOTES:

[a] Symbols in this column indicate the primary metric by which exposure was monitored in the indicated study. "MI" means midget impinger with a study specific factor applied to convert to PCM. "MI*" means midget impinger with a non-study specific conversion factor. "PCM" means phase contrast microscopy. "PCM**" means PCM, but with measurements determined at a different plant from the one where mortality was monitored. "TP*" means that the initial measurements were collected by thermal precipitator and a non study specific conversion factor was applied. "NS" means non-specific; exposures were estimated for the Selikoff et al. (1979) simply as the average concentration reported for the overall insulation industry.

[b] Although these are the only environments in which serpentinite or amphibole cleavage fragments might be present at greater than very small amounts (due to the presence of the parent rock in which the asbestos is embedded), these studies were excluded from the EPA analysis used to derive the EPA recommended unit risk factor for asbestos.

[c] Although cleavage fragments are potentially present (at most in small amounts) in friction product environments (because the lowest grade asbestos fiber used to manufacture these materials may not have been as well purified as higher grade fiber (Walton 1982), these environments also exhibit among the lowest dose-response factors.

[d] In these environments, it is possible that particles composed of organic materials or other non-serpentinite and non-amphibole inorganic materials may be present (which are distinct from serpentinite or amphibole cleavage fragments). However, it is not clear whether any of these materials have been shown to cause cancer in other environments where asbestos was not used. Certainly, up to this point, EPA has not applied the asbestos regulations to environments where particles of these other materials might be present without asbestos also being present.

[e] In these environments, particles composed of the cementitious binders and fillers used in cement manufacture may be present (which are distinct from serpentinite or amphibole cleavage fragments). However, whether any of these materials have been found to be carcinogenic in other environments in the absence of asbestos is not relevant here. Certainly, up to this point, EPA has not applied the asbestos regulations to environments where these types of cementitious binders and fillers are present without asbestos

D. Wayne Berman, Aeolus, Inc.

TABLE 3 (cont.)

CHARACTER OF EXPOSURES IN ENVIRONMENTS INCLUDED IN THE 1986 HEALTH EFFECTS ASSESSMENT UPDATE REVIEW OF ASBESTOS EPIDEMIOLOGY STUDIES AND REPORTED IN IRIS 1988 AS THE BASIS FOR ESTABLISHING THE CURRENT UNIT RISK FACTOR

REFERENCES

(1) McDonald et al., (1980)
(2) Nicholson et al., (1979)
(3) McDonald et al., (1984)
(4) Dement et al., (1983)
(5) McDonald et al., (1983a)
(6) Seidman (1984)
(7) Seidman (1979)
(8) Berry and Newhouse (1983)
(9) Finkelstein (1983)
(10) Weill et al., (1979)
(11) Henderson and Enterline (1979)
(12) Selikoff et al., (1979)
(13) Peto et al. (1982)
(14) McDonald et al., (1983b)
(15) Peto (1980)
(16) Peto et al. (1982)

TABLE 4:
COMPARISON OF REPORTED NUMBERS OF STRUCTURES BY DIFFERENT ANALYSTS IN COMMON GRID OPENINGS

Sample Identification	Number of Analyses	Analysis Identification	Number of Grid Openings Compared	Number of Differences in Counts	Total Error Rate	Consistent?[a]
SRA-R05-110604	3	Original	15	6	40%	**NO**
		QC Analysis 1	15	4	27%	**NO**
		QC Analysis 2	15	5	33%	**NO**
SRA-R02-100604	2		14	7	50%	**NO**
NRA-02-101104	3	Original	17	2	12%	YES
		QC Analysis 1	17	1	6%	YES
		QC Analysis 2	17	2	12%	YES
NRA-R03-101104	2		16	9	56%	**NO**
SFBC-H2-1FD-10064	2		22	8	36%	**NO**

NOTES:

[a] Analyses were considered consistent if the total error rate was less than 20% (see text).

TABLE 5:
COMPARISON OF REPLICATE EXAMINATIONS OF THE SAME GRID OPENINGS ACROSS GRID SPECIMENS PREPARED FROM SAMPLE SRA-R05-110604

Original Analysis									
Gr	No	Loc.	ID	Prim	Tot	Class	Len	Wid	Asp
A	1	A2		NSD					
A	1	A2							
A	2	A20		NSD					
A	3	B11	AZQ	1	1	B	13	0.7	19
A	3	B11							
A	3	B11							
A	3	B11							
A	3	B11							
A	3	B11							
A	3	B11							
A	3	B11							
A	3	B11							
A	3	B11							
A	3	B11							
A	3	B11							
A	3	B11							
A	4	B23	AQ	2	2	F	12	1	12
A	4	B23							
A	4	B23							
A	4	B23							
A	4	B23							
A	5	C12	AQ	3	3	F	1.7	0.5	3.4
A	5	C12	AQ	4	4	F	7	0.5	14
A	6	C31		NSD					
A	6	C31							
A	7	D21	AQ	5	5	F	8	1.2	6.7
B	8	D2		NSD					
B	9	A11	AQ	6		MD2-1	25	22	1.1
B	9	A11	AQ		6	MF	22	0.7	31
B	9	A11	AQ		7	MF	4.8	0.3	16
B	9	A11							
B	9	A11							
B	9	A11							
B	9	A11							
B	9	A11							
B	10	A30		NSD					
B	11	B23	AQ	7	8	***B***	3	0.8	3.8
B	11	B23							
B	11	B23							
B	12	C1		NSD					
B	13	C32	AQ	8	9	F	2.5	0.3	8.3
B	13	C32	AQ	9	10	F	4.9	0.7	7
B	13	C32							
B	13	C32							
B	13	C32							
B	13	C32							
B	13	C32							
B	14	D40		NSD					
B	14	D40							
B	14	D40							
B	14	D40							
B	14	D40							
B	14	D40							
B	15	D11	AQ	10	11	B	11	1.3	8.5
B	15	D11	AQ	11	12	F	5.3	1	5.3

QA Analysis #1									
Gr	No	Loc.	ID	Prim	Tot	Class	Len	Wid	Asp
A	1	A2		NSD					
A	1	A2							
A	2	A20	AQ	1	1	F	12	2	6
A	3	B11	AQ	2	2	B	12.5	1	12
A	3	B11	AQ	3	3	F	13	2.5	5
A	3	B11	AQ	4		MD1-1	12	10	1
A	3	B11	AQ		4	MF	12	1.5	8
A	4	B23	AQ	5	5	F	12	0.9	13
A	5	C12							
A	5	C12	AQ	6	6	F	7	0.5	14
A	6	C31	AQ	7		MD	15	15	1
A	6	C31	AQ		7	MF	8	0.5	16
A	7	D21	AQ	8	8	F	8.3	1.1	8
A	8	D2		NSD					
B	9	A11							
B	9	A11							
B	9	A11							
B	9	A11	AQ	9	9	F	3	0.3	10
B	9	A11	AQ	10		MD1-1	20	10	2
B	9	A11	AQ		10	MF	15	0.8	19
B	9	A11							
B	9	A11							
B	10	A30		NSD					
B	11	B23		NSD					
B	11	B23							
B	11	B23							
B	12	C1		NSD					
B	13	C32							
B	13	C32							
B	13	C32	AQ	11		***MD1-1***	11	4	3
B	13	C32	AQ		11	MF	11	1	11
B	13	C32							
B	13	C32							
B	13	C32							
B	14	D40	AQ	12	12	***F***	5.1	0.4	13
B	14	D40	AQ	13	13	***F***	9	1.5	6
B	14	D40							
B	14	D40							
B	14	D40							
B	14	D40							
B	15	D11	AQ	14	14	B	11	1.3	9
B	15	D11							

QA Analysis #2									
Gr	No.	Loc.	ID	Prim	Tot	Class	Len	Wid	Asp
A	1	A2	AQ	1		MD1-1	20	15	1.3
A	1	A2	AQ		1	MF	5.5	0.55	10
A	2	A20	AQ	2	2	F	12	2	6
A	3	B11							
A	3	B11							
A	3	B11							
A	3	B11							
A	3	B11	AQ	3		MD2-2	15	15	1
A	3	B11	AQ		3	MF	15	1.2	12
A	3	B11	AQ		4	MF	13	2.5	5.2
A	3	B11	AQ	4		MD1-1	7.5	6	1.2
A	3	B11	AQ		5	MF	6	0.75	8
A	3	B11	AQ	5	6	F	1.5	0.25	6
A	3	B11	AQ	6		MD1-1	20	12	1.7
A	3	B11	AQ		7	MF	12	2.5	4.8
A	3	B11	AQ	7		MD1-0	2.5	2	1.2
A	3	B11	AQ		8	MF	2.5	0.2	12
A	4	B23							
A	4	B23	AD	8		MD1-0	10	7.5	1.3
A	4	B23	AD		9	MF	5	1	5
A	4	B23	AD	9		MD1-1	17	10	1.7
A	4	B23	AD		10	MF	12	1	12
A	5	C12							
A	5	C12	AQ	10	11	F	6	0.3	20
A	6	C31		NSD					
A	6	C31							
A	7	D21	AQ	11	12	F	7.5	1.2	6.2
A	8	D2	AQ	12	13	F	30	5	6
B	9	A11							
B	9	A11							
B	9	A11							
B	9	A11							
B	9	A11							
B	9	A11							
B	9	A11	AQ	13		MD1-0	25	25	1
B	9	A11	AQ		14	MF	***4***	***0.6***	6.7
B	10	A30	AQ	14	15	F	2.5	0.25	10
B	11	B23							
B	11	B23	AQ	15		MD1-0	5	3	1.7
B	11	B23	AQ		16	***MF***	2.85	0.75	3.8
B	12	C1		NSD					
B	13	C32							
B	13	C32							
B	13	C32							
B	13	C32							
B	13	C32	AQ	16		***MD2-0***	7.5	7.5	1
B	13	C32	AQ		17	MF	5	1.1	4.5
B	13	C32	AQ		18	MF	2.5	0.6	4.2
B	13	C32							
B	13	C32							
B	14	D40	AQ	17		MD1-0	5	5	1
B	14	D40	AQ		19	***MF***	4.5	0.35	13
B	14	D40	AQ	18		MD1-1	7.5	7.5	1
B	14	D40	AQ		20	***MF***	7.5	1.5	5
B	15	D11	AQ	19	21	**F**	11	1.2	9.2
B	15	D11							

D. Wayne Berman, Aeolus, Inc.

Key:

Structure Missed on this G.O.

Phantom Structure on this G.O.

Disagreement in Structure Dimensions Between Analysts on this G.O.

Findings:

Original Analysis
of 11 structures observed, 4 are unconfirmed and 2 are disputed. Also, there are 6 missing

QC Analysis #1
of 14 structures observed, 3 are unconfirmed and 7 are disputed. Also there is 1 missing

QC Analysis #2
of 19 structures observed: 12 are unconfirmed and 3 are disputed. Also, 2 are missing.

NOTES:
Comparisons were performed using rules that are most favorable to finding agreement among the analysts.
The colors in the table highlight the descrepencies noted.

TABLE 6:
COMPARISON OF APPROACHES FOR EVALUATING ASBESTOS-RELATED RISKS APPLIED AT SELECTED GOVERNMENT-LEAD SITES

	Diamond XX [a]	World Trade Center[b]	Southdown[c]	Libby[d]	El Dorado[e]
Year of Study	1994	2002	2003	2003	2005
Source of Asbestos	Natural	Construction Products	Natural	Natural	Natural
Surrounding Matrix	Serpentinite road aggregate	Varied construction materials	Marble with massive amphibole	Soil with vermiculite and massive amphibole	Serpentinite soil with massive amphibole
Type of Asbestos	Chrysotile	Primarily Chrysotile	Amphibole Asbestos	Amphibole Asbestos	Chrysotile and Amphibole Asbestos
Type of structures	Chrysotile with serpentinite rock fragments	Pure, milled asbestos with fragments of other construction debris	Mixed massive and asbestiform amphibole with other rock fragments	Mixed massive and asbestiform amphibole with other rock fragments	Mixed massive and asbestiform serpentinite[f] and amphibole with other rock fragments
PCMe Definition[g]	(1) NIOSH; and (2) COEHHA	ATSDR	NIOSH	NIOSH	NIOSH
Analytical Method for PCMe Determination[h]	ISO (1993)	AHERA	ISO 10312	(1) ISO 10312; and (2) AHERA	ISO 10312
Risk Assessment Approach	(1) Combined $PCMe_{NIOSH}$ with IRIS URF (2) Early version of Berman and Crump Protocol	Used standards rather than risk analysis: (1) PCM < 0.1 f/ml for workers (2) $PCMe_{ATSDR}$ < 0.0003 f/ml (converted from 70 s/mm^2) for residents	(1) Combined $PCMe_{NIOSH}$ with IRIS URF (2) Berman and Crump Protocol In both cases, separately evaluated "total structures" and the asbestiform component	Combined $PCMe_{NIOSH}$ with IRIS URF	Not Yet Completed: Requires attention to QC issues
Relative Risk[i] (Relative to IRIS)					
Observed or Estimated[i]	Observed	Estimated	Observed	Estimated	Estimated
IRIS (Current)	1[j]	1[j]	1[j]	1[j]	(1[j])[k]
COEHHA PCMe (1986)	0.3x - 2x	NA [l]	NA [l]	NA [l]	NA [l]
Berman and Crump (2001)	1.2x[m]	DNA[n]	15x - 90x	5.9x - 7.5x	(0.04)[k]
Risk Driver[o]	Berman and Crump Protocol	DNA[n]	Berman and Crump Protocol	Berman and Crump Protocol	IRIS
Risk Equivalent for AHERA Benchmark[p]					
Compared to IRIS	NA [l]	8.E-05	NA [l]	1.E-04	NA [l]
Compared to B and C protocol	NA [l]	DNA[n]	NA [l]	6.E-04	NA [l]

TABLE 6 (cont.)
COMPARISON OF APPROACHES FOR EVALUATING ASBESTOS-RELATED RISKS APPLIED AT SELECTED EPA-LEAD SITES

NOTES:

[a] ICF Technology 1994

[b] NCEA 2002

[c] Berman, 2003

[d] EPA 2003

[e] Ladd 2005

[f] Asbesiform serpentinite is just a synonym for chrysotile.

[g] The PCMe definitions that are referenced in this table vary by the specific dimensions (primarily the minimum width) of the structures included when counting to determine PCMe concentrations. Thus, "NIOSH" means PCMe as defined in NIOSH 7402 (NIOSH 1994); COEHHA means PCMe as defined in COEHHA 2006; and ATSDR means PCMe as defined in ATSDR 2001. For further information about these various definitions, see Table 1.

[h] The specific analytical methods employed for determination of asbestos concentrations in each cited study (from which PCMe concentrations were estimated) are defined in this row. In this row, ISO (1993) is a draft version of ISO Method 10312 (ISO 1995) and that "AHERA" refers to the analytical method defined in the Asbestos Hazard Emergency Response Act (EPA 1987). Interestingly, for some studies, there is a mismatch in the size range defined for PCMe structures actually recorded in various studies (i.e. NIOSH) and the size range defined in the specific analytical method employed to determine PCMe concentrations (i.e. ISO 10312). For details, see Table 1.

[i] The ratios of the levels of risk estimated using the indicated approach for assessing risk to the risk estimated based on the approach recommended in IIRIS (Current) are provided in this section of the Table. When these ratios are listed as "observed" for a particular study, it means that risk estimates derived in the study itself were directly compared to derive the indicated ratios. When listed as "estimated" it means that the ratios were derived indirectly from information concerning the distribution of asbestos structure sizes reported for the site studied. Note that, when the ratios indicated for a particular approach are greater than one, it means that risks estimated using that approach would be *more* health protective than the approach recommended in IRIS *for the particular environment studied.*

[j] This footnote was added to the specific cases in which there is actually a mis-match in the size range of PCMe structures counted to determine exposure concentrations and the size range indicated in IRIS (Current). For details, see Table 1.

[k] The ratios estimated for the El Dorado County study are shown in parentheses because they are highly uncertain due to a combination of QC questions that remain to be addressed for this study and the fact that the analytical methods employed in the study may not have been optimized to adequately determine protocol structure concentrations.

[l] In this table, "NA" means not applied in the study indicated.

[m] For this one study, an earlier draft of the Berman and Crump protocol was applied, as the study was conducted 7 years prior to completing the 2001 version of the protocol.

[n] In this table, "DNA" means dimensions not analyzed (or, at least, the data are not readily available).. Thus, it was not possible to estimate relative concentrations for the exposure metric indicated.

[o] The approach for risk assessment that produced the greatest risk estimate (between the Berman and Crump protocol and IRIS) is indicated in this row for each of the site studies presented in the table. This is based simply on whether the ratios of relative risks indicated in the previous row are less than or greater than 1.

[p] The level of risk that would be equivalent to the benchmark health criteria employed in each indicated study is presented in this portion of the table. In the row labeled, "compared to IRIS," the level of risk equivalent to the health criterion is determined based on the approach in IRIS. In the row labeled, "compared to B and C protocol," the level of risk equivalent to the health criterion is determined based on the Berman and Crump protocol.

TABLE 7:
COMPARISON OF STEPS USED TO ASSESS RISK BY THE BERMAN AND CRUMP PROTOCOL AND THE CURRENT IRIS APPROACH, RESPECTIVELY, ALONG WITH THEIR RELATIVE REVIEW STATUS

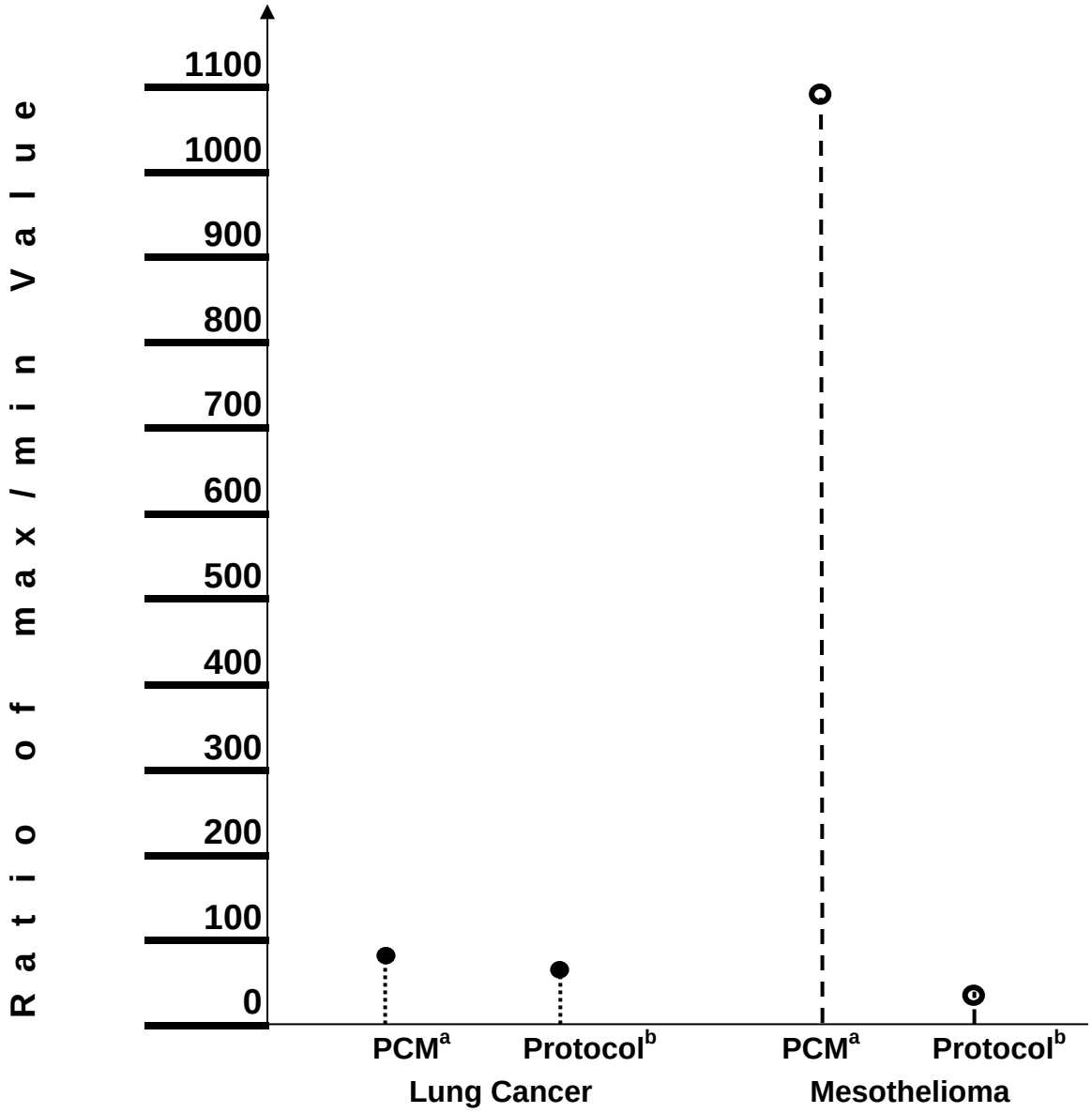
Steps in Assessing Risk Current IRIS Approach	Comments	Berman and Crump Approach	Comments
Assemble Database of Control Studies			
Used 1986 database of 13 studies, rejected two studies	The studies rejected were the two available mining studies: McDonald et al. (1980) and Nicholson et al. (1979).	Used 2000 database of 19 studies	
Contains no amphibole mining studies		Includes an amphibole mining study	de Klerk et al. (1994)
Contains no amphibole contaminated mining studies		Includes 2 amphibole contaminated mining studies	Liddell et al. (1997) and Amandus and Wheeler (1987).
Derivation of Risk Factors in Control Studies			
1 Mortality Evaluated		1 Mortality Evaluated	
2 Exposure Evaluated		2 Exposure Evaluated	
3 Exposure Converted to PCM		3 Exposure Converted to PCM	
		3a Exposure Converted to Protocol Structures based on published TEM size distributions matched to each respective control study.	
4 Informally "averaged" exposure/response factors generated for PCM metric from existing studies excluding mining studies.		4 Optimized risk factors across all studies by fitting data as part of a meta analysis.	Resulting agreement across control studies is substantially improved over agreement observed using the current EPA approach (see Figure 1)
Status of Review Process for Derivation of Risk Factors			
Completed full, formal EPA review process	EPA has recognized the need to update this document and is in the process of doing so. Also, see comment on Berman and Crump approach to the right.[a]	Completed initial peer-review consultation (by a panel of 11 experts)	Review comments suggesting changes to dimensions for protocol structures are not based on formal analysis and the comment would apply equally to IRIS approach in any case.
Derivation of Exposure Estimates from Site Studies			
Determine PCMe concentrations by direct measurement using TEM		Determine protocol structure concentrations by direct measurement using TEM	
Evaluate Site-Specific Risk			
Combine risk factors derived for PCM metric to exposure estimates derived in PCMe metric	Requires consistency in manner that PCMe is determined and equivalence in risk/PCMe relationship across environments. Evidence suggests neither. Process has not been subjected to formal agency review.	Combine risk factors matched to protocol structure metric with exposure estimates derived in matching metric	No assumptions required
Considerations for Application to Amphibole Contaminated Soil and Rock			
Risk factors not derived from potentially relevant control studies	Mining studies were excluded from the analysis used to derive the current IRIS risk factor.	Risk factors derived from potentially relevant control studies	The mining studies are most relevant to environments with naturally occurring asbestos

NOTES:

[a] Federal Register 2006

D. Wayne Berman, Aeolus, Inc.

FIGURE 1:
RELATIVE RANGE OF POTENCY ESTIMATES FOR LUNG CANCER AND MESOTHELIOMA BASED ON EXISTING MODELS



Notes: In all cases, ranges are evaluated using the studies available in 2000 with one negative study excluded.

[a] PCM with common potency for chrysotile and amphibole, as is current EPA policy.

[b] Long Protocol Structures with differing potency for chrysotile and amphibole, as in Berman and Crump (2003).

D. Wayne Berman, Aeolus, Inc.