The Occurrence of Pneumoconiosis in a Talc Mining Population Exposed to Non-asbestos Elongate Mineral Particulate

John W. Kelse,*, John F. Gamble, and Brian A. Boehlecke

Vanderbilt Minerals LLC, Lawrence County, New York, USA

Division of Pulmonary and Critical Care Medicine, University of North Carolina at Chapel Hill School of Medicine, North Carolina, USA

Received Date: April 12, 2017, Accepted Date: June 16, 2017, Published Date: June 26, 2017.

*Corresponding author: John W. Kelse, 152 Pulaski Highway, Ansonia, Connecticut 06401, USA, E-mail: jkelz45@gmail.com.

Abstract

Background: The pulmonary toxicity of non-asbestos elongate mineral particulate (EMP) is of ongoing interest due, in part, to the known pulmonary risk of exposure to asbestos fiber. The purpose of this study is to provide new data relevant to the assessment of risk from exposure to non-asbestos EMP. One non-asbestos EMP exposure often addressed involves an industrial talc once mined in upstate New York. The mixed mineral blend found in this talc has enjoyed extensive mineral characterization, been the focus of human, animal and cellular studies principally addressing pulmonary cancer and is highly relevant to EMP risk issues in general. This review addresses the nature and level of the EMP exposure and the pneumoconiosis experience of workers exposed to it over a span of several decades. This experience is contrasted to that of persons without occupational exposure to mineral dust, to that of other talc workers not exposed to the EMP found in the New York talc and to that of workers exposed to asbestos.

Methods: Available dust exposure records covering a span of 60 years were tabulated chronologically by sample type (total dust, respirable dust, EMP counts). The study population consisted of all male workers with at least one chest radiograph and actively employed at the subject mine for any period of time from 1978 to 2008 with periodic follow-up during employment. The International Labor Organization (ILO) classification of Radiographs of the Pneumoconiosis system was used to classify parenchymal abnormalities by type, size, degree of profusion and progression. Pleural abnormalities were addressed as well. Studies of platy talc, amphibole asbestos workers and populations not exposed to occupational dusts that included ILO chest radiograph interpretations and dust exposure were used as comparative groups.

Results: The findings do not support the hypothesis that the EMP found in New York talc poses a risk of pneumoconiosis similar to that of asbestos even though some of the EMP found in this talc is similar in type and magnitude to that of amphibole asbestos and is present at exposure levels viewed as risk significant for asbestos. The pneumoconiosis risk was found to be similar to that for platy talc workers and for populations not exposed to occupational mineral particulate.

Conclusion: These data indicate that in addition to particle dimension, bio-durability and particle form, mineral type is an important determinant of the risk of pneumoconiosis associated with exposure to EMP. Therefore, accurate characterization of EMP is important in risk assessment.

Keywords: Talcosis; Asbestosis; Elongate mineral particulate; Asbestiform; Non-asbestiform

Abbreviations

EMP: Elongate Mineral Particulate; RTV: R. T. Vanderbilt Company, Inc; NIOSH: National Institute for Occupational Safety and Health; TF: Talc Fiber; ILO: International Labor Organization (with ref. to the classification of radiographs of the pneumoconiosis system); NMRRD: Non-Malignant Respiratory Disease; Mppcf: Million Particles Per Cubic Foot; PEL: Permissible Exposure Limit; MSHA: Mine Safety and Health Administration; OSHA: Occupational Safety and Health Administration; SMR: Standardized Mortality Rate.

Background

The pulmonary risk of asbestos fibers and other respirable-sized, bio-durable, elongate mineral particulate has been studied for decades [1–11]. One elongate, bio-durable mineral dust periodically addressed involves industrial grade talc mined and milled in the Gouverneur/Balmat talc mining region in northwestern New York State by R. T. Vanderbilt Company, Inc. (RTV) from 1948 until talc mining was terminated in 2008 [12–21]. Based on the levels and duration of exposure recorded, this mining population may have been the most exposed worker cohort to non-asbestos EMP in the world.

RTV talc consists of an uncommon blend of minerals and particle forms (morphologies). An easily observable portion of the particulate found in this talc satisfies the common definition of an elongate mineral particulate or EMP. The most commonly applied definition of an EMP is a particle that is at least three times longer than it is wide and ≥ 5 micrometers in length [12,13,22,23]. This is the definition of an EMP used in this paper.

The EMP found in RTV talc has been the subject of debate for four decades with respect to whether some of this particulate is (or should be viewed as) asbestos and/or whether it poses a risk similar in type and magnitude to that of asbestos [13,17,24]. This paper presents new data and discussion that addresses whether the EMP found in RTV talc poses a pneumoconiosis risk similar to that of asbestos.

One general area of debate involves how rigorously EMP exposures should be characterized with respect to pulmonary risk [15,25-33]. As described in a National Institute for Occupational Safety and Health (NIOSH) report entitled “Asbestos Fibers and Other Elongated Mineral Particles: State of the Science and Roadmap for Research”, uncertainty most often involves which EMP features (singularly or combined) are most pertinent to risk assessment [13]. These features commonly include particle length, width, bio-durability and the physiochemical properties of different mineral types and forms. Health studies involving RTV talc are informative with respect to this broader question.

The Composition of RTV talc

Most mineralogical investigations report the absence of asbestos in RTV talc [26,34-49] although a few have reported its presence [12,50,51]. Mineral scientists have explained this discrepancy as involving the incorrect identification of two EMPs commonly found in RTV talc as asbestos. The first, and most prevalent, are non-asbestiform elongate amphibole cleavage fragments which share the same chemistry as some forms of amphibole asbestos but not...
the same fibrous form. The second is the mineral talc found in a fibrous form that is similar to asbestos in form but differs chemically from asbestos [36,38,39,44,49,52,53].

Table 1 lists the mineral composition of RTV talc by weight percent range reported by the company (Safety Data Sheets). These ranges are inclusive of all the talc grades historically produced by RTV. Independent analysis confirms this content [27,36,38,39].

Table 2 is a breakdown of the typical EMP fraction found in bulk RTV talc product grades (i.e. Nytal 300 or 100) and on air sampling filters by mineral type and prevalence expressed as a percent of all EMP. For air samples, differences in specific gravity, particle size, air currents and the manner of dust generation influence particle settling time and accounts for the difference in mineral EMP content seen between the bulk samples and air samples. Talc fiber (TF), for example, typically represents < 1% by weight in the total product grades [47] but represents a significant proportion of the EMP count found in air samples.

Included in the category of talc fiber, is a small subset of fibers described as mixed talc/amphibole particulate. These mixed mineral EMP’s are predominantly the mineral talc geologically being altered from an amphibole mineral to the mineral talc in a fibrous form [36,38,44,49,54,55]. In the case of RTV talc the originating amphibole mineral is anthophyllite in a non-fibrous/massive form [36,38,44,49,54,55]. In the case of RTV talc the originating amphibole mineral is anthophyllite in a non-fibrous/massive form according to McNamee et al [56]. The more common pure talc fiber often visually resembles asbestos fiber and is therefore correctly described as asbestiform in appearance while the mixed evolving fiber is typically rod like in appearance.

Table 1: Mineral composition of RTV talc grades by weight %

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>% Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talc</td>
<td>20 – 40%</td>
</tr>
<tr>
<td>Tremolite (nonasbestiform)</td>
<td>40 – 60%</td>
</tr>
<tr>
<td>Anthophyllite (nonasbestiform)</td>
<td>&lt;1 - 5%</td>
</tr>
<tr>
<td>Serpentine (antigorite)</td>
<td>10 – 20%</td>
</tr>
<tr>
<td>Quartz</td>
<td>&lt;1% when detected at all</td>
</tr>
</tbody>
</table>

Table 2: Typical EMP (All elongate mineral particulate having a length to width ratio of 3 to 1 or more & length 5 micrometers or longer. The serpentine component rarely achieves EMP dimensions) Content by Count % in RTV talc bulk grades and air samples.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%EMP</td>
<td>%EMP</td>
<td>%EMP</td>
<td>%EMP</td>
</tr>
<tr>
<td>Tremolite</td>
<td>75.8 %</td>
<td>80.0 %</td>
<td>51.0 %</td>
<td>36.0 %</td>
</tr>
<tr>
<td>Anthophyllite</td>
<td>0.1 %</td>
<td>0.4 %</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mixed EMP</td>
<td>5.7 %</td>
<td>8.6 %</td>
<td>Combined with TF</td>
<td>1.0 %</td>
</tr>
<tr>
<td>Talc Fiber (TF)</td>
<td>18.4 %</td>
<td>11.0 %</td>
<td>49.0 %</td>
<td>63.0 %</td>
</tr>
</tbody>
</table>

Figure 1a shows the diverse EMP content of RTV talc. The prominent fiber in the center of the photomicrograph labeled “TF” is a typical asbestiform talc fiber. Tremolite (T) and anthophyllite (A) appear as non-asbestiform blocky/massive particulate with some fragments fitting the dimensions of an EMP. Figure 1b is a typical mixed particle with little or no obvious talc fiber separations which is a key asbestiform growth or formation characteristic.

Table 3 shows the typical dimensions of the amphibole and talc fiber EMP found in RTV talc compared to other amphibole non-asbestos fragments and amphibole asbestos fibers reported in the literature. It is important to note that only the EMP component in RTV talc is being addressed in Tables 2 and 3. EMP represents a smaller particle sub-population in bulk RTV talc (5–10%) but a larger component in air samples (15–25%).

The tremolite and anthophyllite found in RTV talc are consistent with the dimensions of common elongate amphibole cleavage fragments formed by mechanical breakage and are not commonly described as fibrous (very long and thin) while talc fiber exhibits fiber bundling and dimensions closer to those of amphibole asbestos [10,26,27,29,30,35,57,59–63]. As such, talc fiber can optically resemble asbestos fiber and therefore be correctly described as asbestiform. In a cell study involving a talc fiber concentrate from RTV talc, talc fiber was shown to overlap the dimensions found in a crocidolite sample (amphibole asbestos) tested in the same study [15].

The non-asbestos and talc mineral components found in RTV talc contain very little iron. Both have long lung retention time comparable to that of amphibole asbestos [64]. Talc fiber exhibits the same physio-chemical properties as platy talc including the lowest hardness of any mineral. A complete breakdown of all physio-chemical properties associated with the mineral particulate found in RTV talc is currently not available although additional information can be found in several of the cited references [37,54,55].

The importance of non-asbestiform amphiboles as a risk factor is a topic of current discussions. It is important to note that all amphibole non-asbestos EMP found in RTV talc compared to other amphibole non-asbestos fragments and amphibole asbestos fibers reported in the literature. It is important to note that only the EMP component in RTV talc is being addressed in Tables 2 and 3. EMP represents a smaller particle sub-population in bulk RTV talc (5–10%) but a larger component in air samples (15–25%).

The tremolite and anthophyllite found in RTV talc are consistent with the dimensions of common elongate amphibole cleavage fragments formed by mechanical breakage and are not commonly described as fibrous (very long and thin) while talc fiber exhibits fiber bundling and dimensions closer to those of amphibole asbestos [10,26,27,29,30,35,57,59–63]. As such, talc fiber can optically resemble asbestos fiber and therefore be correctly described as asbestiform. In a cell study involving a talc fiber concentrate from RTV talc, talc fiber was shown to overlap the dimensions found in a crocidolite sample (amphibole asbestos) tested in the same study [15].

The non-asbestos and talc mineral components found in RTV talc contain very little iron. Both have long lung retention time comparable to that of amphibole asbestos [64]. Talc fiber exhibits the same physio-chemical properties as platy talc including the lowest hardness of any mineral. A complete breakdown of all physio-chemical properties associated with the mineral particulate found in RTV talc is currently not available although additional information can be found in several of the cited references [37,54,55].

The importance of non-asbestiform amphiboles as a risk factor is a topic of current discussions. It is important to note that all amphibole non-asbestos EMP found in RTV talc compared to other amphibole non-asbestos fragments and amphibole asbestos fibers reported in the literature. It is important to note that only the EMP component in RTV talc is being addressed in Tables 2 and 3. EMP represents a smaller particle sub-population in bulk RTV talc (5–10%) but a larger component in air samples (15–25%).

The tremolite and anthophyllite found in RTV talc are consistent with the dimensions of common elongate amphibole cleavage fragments formed by mechanical breakage and are not commonly described as fibrous (very long and thin) while talc fiber exhibits fiber bundling and dimensions closer to those of amphibole asbestos [10,26,27,29,30,35,57,59–63]. As such, talc fiber can optically resemble asbestos fiber and therefore be correctly described as asbestiform. In a cell study involving a talc fiber concentrate from RTV talc, talc fiber was shown to overlap the dimensions found in a crocidolite sample (amphibole asbestos) tested in the same study [15].
consideration is that they are common rock and soil producing minerals found throughout the soils of the continental United States [35,59]. Moreover, exposures to long/thin (often asbestiform) talc fiber, provides an opportunity to explore the pulmonary risk of a non-asbestos EMP that shares some, but not all, of the features of an asbestos EMP.

### Health Studies and RTV talc

Health investigations specifically addressing RTV talc include cohort mortality and morbidity studies [13,16,18,19,21,65–68], animal studies [7,31], in-vitro cell research [15] and case studies [20,69]. Here have also been reviews and critiques of these studies [16,17]. The majority of this work addresses pulmonary cancer (bronchogenic carcinoma in the mortality studies and pleural mesothelioma in the animal and cell research) and does not find a causal link between pulmonary cancer and exposure to RTV talc.

In more recent years it has been suggested that RTV talc may be causally linked to mesothelioma based on case study reports [20,69]. These reports have been critiqued for failure to adequately address competing risk, latency, diagnostic reliability, data interpretation and inconsistency with the existing science base [17,70–74]. They do, however, sustain debate over the possible “asbestos like” pulmonary risk of EMPs found in RTV talc, including pneumoconiosis.

The occurrence of pneumoconiosis among employed RTV talc workers has not been studied since the mid 1970’s [12,66] and efforts to contrast this occurrence with the pneumoconiosis experience of other talc workers and asbestos workers are limited [19,66]. It has been established that excessive exposure to RTV talc can cause nonmalignant pulmonary effects [18,21,66,68,75] as can talc dust in general (takosis) [76–78].

The nonmalignant pulmonary effects caused by elevated exposure to talc and other mineral dusts can be indistinguishable from those caused by asbestos [77–80]. Shared radiographic features include linear and irregular parenchymal changes beginning as fine shadows (small opacities) resulting from fibrosis in the lower and mid lobe area of the lung. Localized pleural plaques, often regarded as “sign posts” of asbestos exposure, have also been reported among RTV talc workers as well as some platy talc workers and others with non-asbestos exposures [75,81]. Shortness of breath and cough, symptoms often reported by asbestos-exposed workers, can be caused or aggravated by a variety of particulate exposures, including talc and by smoking.

### Methods

Vanderbilt Minerals, LLC authorized access to all RTV talc dust exposure and pulmonary records retained by the company. Dust records available from any source were identified and tabulated chronologically by sample type (total dust, respirable dust and both total and EMP particle counts). Pulmonary evaluations of RTV talc workers included chest radiograph interpretations and pulmonary function data. The study population comprises all male workers with at least one chest radiograph and actively employed at the RTV mine and mill for any period of time from 1978 to 2008. Follow-up chest radiographs were subsequently obtained through a company medical surveillance program applied during employment.

The International Labor Organization (ILO) classification of Radiographs of the Pneumoconiosis system was used to classify radiographic parenchymal abnormalities by type, size and degree of profusion. A detailed description of the application of this system and its revisions can be found in the literature [82–86]. Irregular small opacities meeting or exceeding an ILO profusion classification of ≥ 1/0 were considered to be likely dust linked nonmalignant respiratory disease (i.e. consistent with pneumoconiosis). Pleural abnormalities (i.e. plaques) were recorded using this system but are independent of the ILO profusion classification for pneumoconiosis.

The chest radiograph review includes a study undertaken in the 1970’s by NIOSH of employed RTV talc workers that used three readers proficient in the ILO system (B readers) and followed a consensus protocol [12,66]. Another consensus reading by three different B readers was conducted in 1982–1984 of workers 40 years or older with follow-up review by a 4th B reader (BB) [87]. Readings were subsequently obtained through the company’s medical surveillance program and continued, uninterrupted, until closure of the plant in 2008. This program included serial posterior-anterior chest radiographs (4” by 7”) for all RTV talc workers every two years which were classified according to the ILO guidelines in effect at the time of the examination. Pulmonary function testing was also conducted serially as part of the program.

The chest radiographs obtained though the company’s surveillance system were read by local hospital radiologists for abnormalities of clinical significance and were then independently read by a pulmonary specialist proficient in the use of the ILO system. Consensus was sought when interpretative variation occurred. Chest radiographs obtained at the time of mine closure in 2008 were independently read by an additional pulmonary specialist current for certification by NIOSH as proficient in the ILO system and who had no knowledge of prior radiograph interpretations or employment histories [88]. A consensus protocol was applied in this final reading.

In 2016 chest radiographs of 20 RTV talc workers who were employed at the end of talc production in 2008 and who had no further talc exposure were read by one B reader who had also read the films of these same workers in 2008 [89]. A mortality study
contrasting nonmalignant respiratory disease (NMRD) linked deaths for all RTV and Vermont talc workers with at least one year of employment provided supplemental information with respect to post exposure and NMRD [19].

The serial radiograph data are presented as cross-sectional studies and reflect the prevalence of pneumoconiosis for all tested workers employed at the time (year) tested. Some subpopulation reviews are similarly addressed (such as those over a certain age, or with and without prior mining exposures). Results for the entire study population are addressed by aggregating findings over the full study period (1978 – 2008) and recording each workers last ILO category prior to termination.

For employed workers not tested in a given testing cycle (out on disability or declined test) or when poor quality films were encountered, prior and/or subsequent chest radiographs were reviewed to assess status. Workers who did not have recognizable pneumoconiosis on their first radiograph were followed through the duration of their RTV employment to detect its occurrence as a measure of incidence. A check of pneumoconiosis progression for cases as a measure of risk was applied as well. Workers without radiograph review within four years of termination of RTV employment were classed as “unaccounted for” with respect to their pulmonary status at termination.

Published morbidity and mortality studies of platy talc and amphibole asbestos exposed work populations that included ILO chest radiograph interpretations, dust exposure levels, duration of exposure and some control of competing risks (i.e. crystalline silica) were identified and used as comparative work groups. These include all studies identified through a search of the PubMed database for papers published through December of 2014. ILO chest radiograph studies involving populations with no reported occupational dust exposure were similarly identified and used as a measure of background. Amphibole asbestos studies were selected because the predominant EMP found in RTV talc is tremolite – an amphibole mineral that can be found in either an asbestos or non-asbestos form.

**Results**

**RTV Talc Dust Exposure**

Table 4 shows the range and average airborne dust levels recorded for RTV talc by different dust measures, the span of time in which these levels were recorded and a permissible exposure limit (PEL) commonly applied for each of these dust measures. Supplemental file S-1 provides a more detailed breakdown of historical dust sampling results.

<table>
<thead>
<tr>
<th>Dust Categories: Limits applied</th>
<th>Mppcf: 20</th>
<th>Total Dust: 10 mg/m²</th>
<th>Respirable Dust: 2 mg/m³ for talc</th>
<th>EMP Fibers/cc: 0.1 for asbestos</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1948 - 1969</td>
<td>18.8 (2-70 range, 58 samples)</td>
<td>Not available</td>
<td>Not available</td>
<td>Not available</td>
<td>[11, 89]</td>
</tr>
<tr>
<td>1970 - 1990</td>
<td>8.0 (0.2-62 range, 78 samples)</td>
<td>3.5 (0.4-11.4 range, 59 samples)</td>
<td>0.79 (0.06-3.4 range, 120 samples)</td>
<td>5.7 (0.1-33 range, 347 samples)</td>
<td>[11], MSHA, RTV testing &amp; insurance data.</td>
</tr>
<tr>
<td>1991 - 2007</td>
<td>5.4 (1 - 10 range, 4 samples)</td>
<td>1.83 (0.2-31 range, 113 samples)</td>
<td>0.54 (0.05-4.4 range, 135 samples)</td>
<td>1.9 (0.04-4.5 range, 45 samples)</td>
<td>[20], MSHA, RTV testing &amp; insurance data.</td>
</tr>
</tbody>
</table>

Table 4: Average period RTV talc dust category exposures and permissible dust limits commonly applied to each category.

Average dust levels (mppcf, total and respirable dust) fall below commonly applied PELs while EMP counts exceeded the limit applied to asbestos fibers. By this measure, average airborne RTV talc EMP levels typically exceeded the asbestos PEL of 0.1 fibers/cc by a factor of 15 to 20.

Table 5 compares the percent elongate amphibole cleavage fragments to talc fiber reported in mill airborne dust characterization studies [46]. Importantly, each EMP component in these samples exceeds the PEL for asbestos by 7 to 10 fold. NIOSH recorded total fiber/cc levels in the mid 1970’s in the 2 to 8 fiber/cc range with an average of 4.2 in both the mine and mill [12]. The higher EMP NIOSH data are not included in Table 5 because they do not provide adequate amphibole to talc fiber differentiation.

Applying the most conservative fiber/cc level and tenure averages for RTV talc workers (1.0 fiber/cc for 15 years = 15 fiber/cc years), the average cumulative exposure is 3 times greater than the cumulative exposure to asbestos that OSHA feels does not eliminate the risk of asbestos over a working lifetime (0.1 fiber/cc for 45 years = 4.5 fiber years) [90]. Importantly, cumulative exposure to each EMP component in RTV talc (elongate amphibole cleavage fragments and talc fiber) is approximately 1.5 to 4 times greater than the OSHA asbestos cumulative exposure standard since each EMP represents approximately ½ the total EMP found on air sampling filters.

Twenty percent of the talc fiber in these air samples were below 1 micrometer in width and 10 micrometers or more in length [45] (see S-1). In contrast, only 1.3 % of the amphibole EMP (cleavage fragments) in RTV talc satisfied these width/length parameters [46,91]. As seen in Table 3 these EMP dimensions are consistent with the asbestiform nature of talc fibers and the non-asbestiform nature of deavage fragments.

In the early years of RTV talc mining (1950’s – 1970’s) 20-30% of RTV talc workers had worked in other area talc mines and exposed to the same or similar talc ore [12]. On average non-RTV dust levels have been reported as 10 to 30 times greater than levels recorded in the RTV talc mines and mill [21,89]. The reduced dust levels at the RTV operation are principally attributed to improved mill ventilation systems and to wet drilling in the mine.

**Prevalence of Pneumoconiosis among RTV Talc Workers**

Table 6 shows the prevalence of ≥ 1/0 pneumoconiosis for employed RTV talc workers recorded over a period of 30 years, compares workers with and without other area mining exposure and reflects the range of years exposed to RTV talc. A more detailed
Table 6: Breakdown of ILO roentgenographic interpretation of > 1/0 pneumoconiosis among all RTV talc workers from 1978 to 2008. (1) Each worker during the study period is counted only once. (2) Seven workers worked 40 years or more. RTV exposed only cases divided by 191. Seven total cases divided by 289 (5 of whom had prior area talc mining exposure).

<table>
<thead>
<tr>
<th>Case #</th>
<th>First RTV Year Reported as ≥ 1/0</th>
<th>Hire Year</th>
<th>RTV Years Worked</th>
<th>Years Prior Mining</th>
<th>Last Radiograph Year – Progression from 1/0 (if any) – Time Period from 1st yr. 1/0 Recorded to Last Radiograph at RTV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1978 (1)</td>
<td>1948</td>
<td>30</td>
<td>12-14</td>
<td>1978 - n/a – recorded on last X-ray</td>
</tr>
<tr>
<td>3</td>
<td>1978 (1)</td>
<td>1974</td>
<td>10</td>
<td>10</td>
<td>1984 - no progression - 6 yrs.</td>
</tr>
<tr>
<td>4</td>
<td>1978 (1)</td>
<td>1974</td>
<td>10</td>
<td>19</td>
<td>1984 - 1/1 from 1/0 - 6 yrs.</td>
</tr>
<tr>
<td>6</td>
<td>1994</td>
<td>1974</td>
<td>31</td>
<td>0</td>
<td>2005 - 1/1 from 1/0 - 11 yrs.</td>
</tr>
<tr>
<td>7</td>
<td>1998</td>
<td>1974</td>
<td>34</td>
<td>5</td>
<td>2008 - 1/2 from 1/0 - 10 yrs.</td>
</tr>
</tbody>
</table>

Table 7: Chest Radiograph Cases ILO Class ≥ 1/0 Progression to Last Radiograph at RTV. (1) Year first reported in 1978 may not be the same as first year reached.

<table>
<thead>
<tr>
<th>Worker #</th>
<th>Radiographic Abnormality</th>
<th>Years of Talc Exposure Prior to Hire at RTV</th>
<th>Years from Hire to First Evidence of Pleural (not parenchymal) Abnormality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Parenchymal &amp; pleural</td>
<td>11</td>
<td>0 – 3*</td>
</tr>
<tr>
<td>2</td>
<td>Parenchymal &amp; pleural</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Parenchymal &amp; pleural</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Pleural only</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Pleural only</td>
<td>none</td>
<td>unclear</td>
</tr>
<tr>
<td>6</td>
<td>Pleural only</td>
<td>none</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>Pleural only</td>
<td>none</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>Pleural only</td>
<td>none</td>
<td>12</td>
</tr>
<tr>
<td>9</td>
<td>Pleural only</td>
<td>none</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>Pleural only</td>
<td>none</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 8: Workers with abnormalities consistent with pneumoconiosis and pleural plaque in a 1982/84 review of 203 chest radiographs contrasted to first evidence of pleural plaque after RTV hire. (1) First available chest radiograph was 3 years after hire. [65].

The contribution of prior area talc mining exposures to RTV pneumoconiosis experience appears high (5 of the 7 cases) and has previously been observed [19,21,66]. 20 to 30% of employed RTV workers in 1978 had exposure in other area talc mines. This exposure data was not complete enough to reliably include in the total exposure time so average years worked reflects RTV exposure only and therefore a minimum. The earliest pneumoconiosis cases were not developed because a causal link between New York talc and pneumoconiosis has previously been established [12,21]. The latency for cases 1-4 can also not be positively ascertained because pneumoconiosis may have been present prior to 1978. The long tenure of the cases recorded coupled with the known elevated talc exposures in other area talc mines are consistent with the exposure-response trend reported in the earlier epidemiological studies.

There were three employees whose pulmonary status could not be adequately ascertained. These workers were hired in the mid to late 1970’s, had normal chest radiographs in the early 1990’s then terminated RTV employment prior to 2002 with no additional testing for at least four years prior to termination (out on disability or refused test). If all were cases it would raise the RTV pneumoconiosis occurrence level from 2.4% to 3.4% and not change the findings of this study.

Table 8 shows parenchymal and pleural abnormalities first recorded after hire in an early 1980’s radiological study. Pleural plaques are routinely observed among 5 to 12% of RTV talc workers during periodic (semi-annual) chest radiograph reviews. In this review a 5% prevalence was observed. A finding of localized pleural plaque among RTV talc workers had previously been reported [12,66,81].

In this 1982/84 prevalence check only those exposed in non-RTV mines had a parenchymal abnormality and showed pleural plaque at the time of RTV hire or within three years of hire. In contrast, pleural plaque (without parenchymal involvement) was observed among talc workers with no prior talc exposure and after 10 or more years RTV employment. This finding suggests that while New York talc can cause both pneumoconiosis and pleural plaque, pleural plaque occurs at lower dust levels than pneumoconiosis after an extended exposure period.

Table 9 shows the prevalence of pleural plaque, parenchymal
abnormality, pulmonary function status, smoking and years talc exposure for each pleural plaque case among 90 RTV talc workers employed at the time of mine closure in 2008 [88]. An 8.8% prevalence of localized pleural plaque was seen in this 2008 review. Among these workers, 55% were 50 years or older and 73% had worked 15 years or more. With one exception, no clinically significant lung function impairment was noted. This is consistent with the findings of other pleural plaque and pulmonary function studies [81,94–99]. The exception (case #4) is a smoker.

The prevalence of pleural plaque (referenced as pleural thickening) among plagioclase talc miners in Montana, Texas and North Carolina is similar to that found among RTV talc miners [80]. Other plagioclase talc studies, however, did not find pleural plaque or did not report this finding if observed [98–100]. While localized pleural plaque and diffuse pleural thickening are distinct abnormalities, these terms were often used interchangeably in the 1970’s and 80’s so studies reported in this period may not have differentiated these abnormalities. The same terminology, however, was used in comparing these three US talc cohorts to RTV talc miners [66,81].

Table 9: RTV workers with parenchymal and pleural plaque abnormalities and their pulmonary function test (PFT) status recorded in 2008 at mine closure.

<table>
<thead>
<tr>
<th>Worker #</th>
<th>Radiographic Abnormality</th>
<th>Years RTV Talc Exposure</th>
<th>Smoking History</th>
<th>PFT Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Parenchymal &amp; Pleural</td>
<td>34</td>
<td>no</td>
<td>mild restrictive</td>
</tr>
<tr>
<td>2</td>
<td>Pleural only</td>
<td>43</td>
<td>yes</td>
<td>mild obstructive &amp; restrictive</td>
</tr>
<tr>
<td>3</td>
<td>Pleural only</td>
<td>34</td>
<td>yes</td>
<td>mild obstructive</td>
</tr>
<tr>
<td>4</td>
<td>Pleural only</td>
<td>34</td>
<td>yes</td>
<td>moderate obstructive &amp; restrictive</td>
</tr>
<tr>
<td>5</td>
<td>pleural only</td>
<td>34</td>
<td>yes</td>
<td>within normal range</td>
</tr>
<tr>
<td>6</td>
<td>pleural only</td>
<td>38</td>
<td>no</td>
<td>within normal range</td>
</tr>
<tr>
<td>7</td>
<td>pleural only</td>
<td>34</td>
<td>no</td>
<td>within normal range</td>
</tr>
<tr>
<td>8</td>
<td>pleural only</td>
<td>30</td>
<td>yes</td>
<td>within normal range</td>
</tr>
</tbody>
</table>

The average years worked for all 60 in this subset of workers was close to 20 years and one case with a ≥ 1/0 ILO classification was recorded. The rate of pneumoconiosis among this subset is < 2% (1 case divided by 60 workers). This is a prevalence approximately the same as that seen among all employed RTV workers and suggest no disproportionate cases occur among RTV workers who leave RTV employment – a finding that does not support pneumoconiosis as a cause of termination.

A complete accounting of inactive RTV talc workers who might show the onset of pneumoconiosis post-employment could not be completed because post-employment chest radiographs were not routinely obtained. After the talc mine closed in 2008, however, Vanderbilt continued to operate a wollastonite mine in the region and staffed this operation with former talc workers. Table 11 shows the ILO profusion classification for former talc workers employed at the wollastonite mine and mill that had chest radiographs read in 2008 and in 2016 by the same B reader.

**Pneumoconiosis among RTV Talc Workers Contrast to Platy Talc and Amphibole Workers**

Figure 2 compares the prevalence of pneumoconiosis among RTV talc, platy talc, amphibole asbestos workers and non-occupationally dust exposed populations. Platy talc and amphibole studies included are those known to involve, or likely to have involved, a relatively pure platy talc with little or no EMP exposure and a significant amphibole asbestos exposure (respectively).

Prevalence of pneumoconiosis (≥ 1/0 ILO classification) was commonly > 40% among asbestos workers and generally

<table>
<thead>
<tr>
<th>Last chest X-ray Year</th>
<th># That Left Employment</th>
<th>Average Age at Termination</th>
<th>Average Yrs. worked &amp; % ≥ 15 Years</th>
<th># ILO Class &gt; 0/1 on Last X-ray</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>16</td>
<td>55</td>
<td>23 (81%)</td>
<td>0</td>
</tr>
<tr>
<td>1994</td>
<td>4</td>
<td>48</td>
<td>17 (57%)</td>
<td>0</td>
</tr>
<tr>
<td>1996</td>
<td>9</td>
<td>40</td>
<td>13 (55%)</td>
<td>0</td>
</tr>
<tr>
<td>1998</td>
<td>8</td>
<td>48</td>
<td>20 (100%)</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>5</td>
<td>50</td>
<td>22 (100%)</td>
<td>0</td>
</tr>
<tr>
<td>2002</td>
<td>3</td>
<td>50</td>
<td>16 (66%)</td>
<td>0</td>
</tr>
<tr>
<td>2004</td>
<td>4</td>
<td>51</td>
<td>23 (100%)</td>
<td>1</td>
</tr>
<tr>
<td>2006 to 2008</td>
<td>9</td>
<td>52</td>
<td>22 (78%)</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>60</td>
<td></td>
<td>19.8 (76%)</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 10: ILO pneumoconiosis status among RTV talc workers ending employment. (1 80% of workers had chest X-ray ≤ 2 yrs. prior to termination while remaining 20% ≤ 4 yrs. 2 76% of of workers at this average age were > 50 yrs. of age.)

Table 11: ILO class ≥ 0/1 for 20 former RTV talc workers after 8 years of no talc exposure while working at an RTV wollastonite mine and mill. (1 High dust jobs include: crushers, millers, packers, drillers. 2 All 20 received chest radiographs when the talc mine closed in 2008 and again in 2016 by the same B reader.)

<table>
<thead>
<tr>
<th>Years Talc Exposed</th>
<th># Workers Exposed</th>
<th># With High Dust jobs</th>
<th>2008 ILO Class ≥ 0/1</th>
<th>2016 ILO Class ≥ 0/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 14</td>
<td>7</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15 - 19</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20 - 24</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>25 - 29</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>30 - 33</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Figure 2: Percent ILO Classification ≥ 1/0 by talc and asbestos occupational groups and by non-dust exposed groups (background) with average exposure years and dust exposures when available.


Note: Some asbestos studies reporting asbestosis may not have applied the ILO system
less than 5% among platy talc workers, RTV talc workers and individuals with no reported occupational dust exposure (listed as “background” in Figure 2). Meyer et al. [104] reported background prevalence’s of 5.3% (95% CI 2.9 to 7.7) for small lung opacities grades > 1/0 among 9 unexposed dust populations in Europe and North America. Platy talc and RTV talc workers showed similar potentials for developing pneumoconiosis (talcosis) at similar dust exposure levels despite the presence of significant EMP in RTV talc not present in the platy talc exposures.

**RTV talc workers contrasted to platy talc workers:** Montana, Texas and North Carolina talc (Figure 2 - studies 1, 2 and 3) were reported as containing “no fibers” by light microscopy but in Texas and North Carolina a few were seen by transmission electron microscopy [75]. These elongate particles were not described as asbestos fibers but given their fine size may have been a talc plate observed on edge or the mineral talc in fibrous form. Crystalline silica levels were reported as below detection limit in Montana and 2.2% (in bulk material) in Texas. Respirable dust levels overlapped those during the mining of RTV talc except in the North Carolina cohort where dust levels appear to be lower and with no pneumoconiosis reported. Average years worked for these three cohorts (≤ 10 years) was less than that of RTV talc workers and overall rates of pneumoconiosis (talcosis) slightly less.

In the two rubber-workers studies platy talc is described as “non-fibrous talc” with no mention of an asbestos, crystalline silica or non-asbestos EMP exposure [100,101] (Figure 2 - studies 4 & 5). In these plants platy talc was used as a detackifier in molds and between sheets of uncured rubber to prevent them from sticking together. In Fine et al. [101] respirable dust levels (0.6 to 3.5 mg/m³) and average tenure (16 years) were similar to RTV talc workers while respirable dust levels in Neghab et al [102] (12-28 mg/m³) were higher but average years worked was not reported.

The French talc study (Figure 2 - study 6, [103]) did not record average dust exposure levels or average years worked but involved pure platy talc with no EMP reported. The pneumoconiosis cases described as “significant” numbered 10 out of 176 platy talc workers (6%) that were exposed to ≥ 15 mppcf for ≥ 50 years. Pneumoconiosis cases with only RTV talc exposure numbered 2 out of 289 (1.0%) exposed to a maximum average dust level of 18.8 mppcf with a maximum of 35 years worked (from Tables 4 and 8). The minimum cumulative dust level for the French talc cases falls in the 750 mppcf range while the maximum cumulative dust level for RTV talc exposed only cases falls in the 650 mppcf range and the prevalence is higher among the French talc workers (6% vs 1.0%).

One Italian platy talc study [105] was not included in the comparison because it involved relatively few workers (43 mill workers) and gave no information on average exposure duration and crystalline silica exposure for mine workers. Among the mill workers, an elevated particle count (mppcf) and pneumoconiosis rate (9%) was reported among those who worked 22 years or more. No profusion greater than 1/2 was reported among the French, Italian and RTV talc workers.

Mortality studies that address non-malignant respiratory disease (NMRED) provide another means of contrasting the prevalence of pneumoconiosis among RTV talc workers and platy talc workers. Figure 3 compares the standard mortality rate (SMR) for NMRED reported among RTV talc workers and platy talc workers in Vermont [12,19,106,107] studied by NIOSH during the same time period and with updated RTV talc worker data to 1989 [21].

The SMR for NMRED related deaths was two times higher among the Vermont workers than among RTV talc workers even though the population and overall dust levels were similar (Figure 3). Crystalline silica was reported as insignificant in both mining regions. The minor EMP level recorded for Vermont talc largely consisted of talc plates counted on end by optical microscopy [107].

Caution is advised in this comparison because NMRED includes pulmonary abnormalities besides pneumoconiosis and workers who die from other causes might not have pneumoconiosis listed.

---

**Figure 3:** Nonmalignant respiratory disease standardized mortality rate (SMR) excluding pneumonia and influenza for Vermont talc and RTV talc workers with ≥ 1 year’s exposure.
on the death certificate despite its presence. However, both the RTV and Vermont talc worker NMRD mortality rates would suffer from these same limitations. Mortality studies of Italian and Norwegian platy talc workers [105,108] reported other NMRD SMR’s in the 100 to 300 range. These studies are additionally limited by unclear exposure histories, the presence of elevated crystalline silica levels in the case of Italian miners and short tenure in the case of the Norwegian miners.

In the platy talc mines respirable dust predominantly (or exclusively) in dusts fine talc partculate absent the EMP component found in RTV talc. The similar occurrence of pneumoconiosis and pleural plaques in RTV and platy talc-exposed workers with similar respirable dust exposure suggest the mineral talc is the particulate component most associated with the occurrence of pneumoconiosis and not the EMP found in RTV talc.

**RTV talc workers contrasted to amphibole asbestos workers:** The most relevant mortality and morbidity studies of asbestos workers are the six amphibole asbestos studies in Figure 2. Sluis-Cremer et al. [109] of South African crocidolite and amosite miners (study 7) provides the best comparative data with respect to RTV talc workers because fiber/cc exposure is reported. Sluis-Cremer et al. [112] (study 8) uses determination of asbestosis at autopsy rather than radiographically. The Four remaining asbestos studies (studies 9[110], 10[4], 11[111] and 12[1]) include ILO radiograph data and likely involve significant amphibole asbestos exposures though these exposures are not reported.

Sluis-Cremer et al [109] reported a prevalence of 56% irregular opacities at category ≥ 1 (Figure 2, study 7) among 448 South African crocidolite and amosite miners with a cumulative exposure of ≤ 5 fiber/cc years and a normal radiograph at first evaluation. In the same review, 73% of 574 miners with less than 5 years of exposure showed progression from normal to a category ≥ 1 profusion (not included in Figure 2).

In an earlier study of 807 South African amphibole miners the same researchers (Figure 2, study 8) [112] reported a 42% prevalence of asbestosis identified at autopsy for miners with a 20–50 fiber/cc year cumulative exposure. It should be noted that the prevalence of pneumoconiosis is determined differently in this comparison (autopsy determination versus chest radiographs). The radiographic study of amphibole miners from the same mines [109] showed a prevalence similar to that in the autopsy study (56% vs. 42%).

The authors of these South African amphibole asbestos studies concluded from this work that asbestosis “occurs at an average fiber exposure of 1 or less or a cumulative exposure of > 2-5 fibers/ml years. Theoretically this implies that the disease will occur at exposures of > 0.1. -0.5 fibers/ml for 20 years.”[109,112]. Average EMP levels for RTV talc workers was in the 1.0 – 2.0 fibers/ml range with an average tenure of 17½ years or approximately 18 - 42 fibers/ml years. Thus cumulative RTV talc exposure is some 6 times greater than South African amphibole asbestos workers while the pneumoconiosis risk among RTV workers is approximately 20 times lower [109,112].

Studies 9 through 12 [1,14,110,111], in figure 2 involve amphibole exposures unlikely confounded by crystalline silica or non-asbestiform elongate mineral fragments because they involve processed asbestos applications (textiles and insulation). They also show asbestosis prevalence similar to that of the South African amphibole asbestos miners.

Two frequently cited amphibole asbestos radiographic reviews were not included in Figure 2 because mineral exposure/response attribution was likely compromised by inadquate exposure characterization as explained below. One involved a chest radiographic study of 184 Libby, Montana vermiculite workers [113] and the second 839 asbestos cement pipe workers in New Orleans, Louisiana [114].

Libby vermiculite workers were exposed to a mixed mineral dust that included asbestiform amphibole (mostly winchite, lesser richterite and minor tremolite asbestos) plus a high non-asbestiform elongate cleavage fragment content and some crystalline silica [115]. Importantly, non-asbestos elongate fragments were included in Libby “asbestos” fiber counts. This dilution adversely affects an accurate assessment of asbestos risk [30] and is further addressed in the discussion section of this paper. In one analytical study of Libby vermiculite 1,205 EMP were collected on air filters and over 90% were reported as non-asbestos [116].

The asbestos cement pipe workers [114] were exposed to an unspecified blend of chrysotile and crocidolite (serpentine and amphibole asbestos respectively). Exposure was expressed only as a total particle count (mppcf) in a mixed dust environment with no accounting of what portion of the particle exposure was asbestos.

Although the level of asbestos exposure in both of these studies is unclear, prevalence’s of ILO ≥ 1/0 are 4 times greater than the maximum reported among RTV talc workers (about 10% at Libby and asbestos-cement cohorts versus 2.4 % among all RTV workers and 1.0% among RTV only workers, Table 6). In addition, among Libby vermiculite workers, Amandus et al. [113] reported 38% of the mine workers showed an ILO profusion greater than 2/0 after a 22 year average exposure. No RTV talc worker showed a profusion greater than 1/2 despite an average exposure of 17½ years (1978-2008) or after 23 ½ years average exposure for those employed at mine closure in 2008 (see Table 6 and S-2).

Figure 4 shows the prevalence of pneumoconiosis among RTV talc workers compared to asbestos workers with greater than 20 and 30 years worked. Asbestos textile workers with ≥ 20 years had approximately 50 times higher prevalence of radiographic pneumoconiosis while those with ≥ 30 years had 40 to 90 times higher prevalence than RTV talc workers with similar years worked. Such differences are unlikely accounted for by EMP exposure level misclassification or incomplete ascertainment.

**Discussion**

Particular mischaracterization can prompt a presumption of risk where it does not exist or serve to obscure one that does. The impact of accurate EMP identification on risk assessment is of particular importance given the ubiquitous presence of EMP in many environments.

The EMP dimensional criteria used in this paper (aspect ratio 3 to 1 or greater, ≥ 5 um length) are the same or similar to those used for decades in a host of asbestos analytical protocols as a means to quantify asbestos fibers in air and bulk materials. While use of this EMP counting criteria is not detrimental in a known asbestos work environment, it introduces a potentially serious error source when applied in an unknown or mixed dust environment to identify asbestos fibers, a purpose for which it was never intended [30,53,117].

Another error source involves an understanding of the term “asbestiform”. Mineralogists use this term as a general description of fibers (EMP) that “look like” asbestos whether they are treated as asbestos or not [13,14,35,62]. Though relatively rare, some zeolites, certain amphibole minerals (i.e. winchite, richterite), talc in a fibrous form and well over a hundred other non-asbestos minerals can be found in an asbestiform habit or other highly fibrous form.
and are not viewed or regulated as asbestos [118]. In effect, while all asbestos is asbestiform not all minerals found in the asbestiform habit or in a highly fibrous form are asbestos. Figure 5 may aid in the understanding (visualization) of asbestiform and non-asbestiform mineral habit forms [23,53].

By the naked eye, an asbestos fiber is almost always observed as a bundle of extremely thin individual crystal fibers called fibrils. Fibrils fall in the 0.02 to 0.6 micrometer thickness range while a human hair typically falls in the 100 micrometer range [29]. This unusual bundle form is often described as the “hallmark” characteristic of asbestos [26,35,53,57,62]. When inhaled, asbestos fiber bundles disaggregate in the respiratory system yielding a large particle surface area and pose a challenge to pulmonary macrophage clearance systems [8,10,13,119].

Figure 6 show the macro and micro photographs of tremolite in the asbestiform habit and non-asbestiform habit. The non-asbestiform tremolite shown is from the RTV talc mine. With respect to amphiboles, both the asbestiform (rarely found) and the common non-asbestiform varieties share the same elemental composition, refractive indices, crystal structure and biologic persistence.

This investigation demonstrates that incorrect characterization of EMPs as asbestos can cause an under-estimate of asbestos risk.
when non-asbestos is mistakenly identified as asbestos (masking the actual, lower asbestos exposure by dilution). Asbestos studies most likely to show an exposure dilution bias (i.e. Libby vermiculite and asbestos cement studies) were not used in the asbestos to RTV talc comparison for this reason even though pneumoconiosis rates in these studies were also higher than RTV talc rates. Asbestos studies involving processed and mined amphibole asbestos were used in the comparisons to improve confidence that the asbestos exposure would not be unduly influenced (if at all) by non-asbestos EMP.

A detailed description of the definitional, mineralogical, and analytical issues associated with the proper identification of RTV talc and a host of other elongate mineral particulate is beyond the scope of this paper but is provided in cited references. In particular, readers may wish to consult early Bureau of Mines publications [26,35,47] and several more recent overviews [17,54,120].

Some additional factors beyond exposure characterization warrant expanded discussion with regard to the reliability and significance of this study's findings.

**Small Study Cohort Size**

The number of individual workers addressed in this study (289) is relatively small. All of the platy talc and most of the amphibole asbestos cohorts compared to RTV talc workers were also small (51 to 448 workers). Generally speaking, larger cohorts most often produce more reliable findings. However, limitations due to relatively small size of the cohort are off-set by consistent findings in the morbidity and mortality cohort comparisons, availability of talc dust exposure data over the entire time period of the study long tenure among many RTV talc workers, a standardized pneumoconiosis epidemiological status measurement tool (ILO system) applied to both RTV talc workers and the comparative cohorts, lack of confounding silica exposures and the existence of pneumoconiosis status data of RTV talc workers who left RTV employment. Prior studies of RTV talc (human, cell and animal research) provide additional support with respect to the toxicity of the EMP found in RTV talc.

**Pleural Plaque**

There is evidence that the mineral talc itself is capable of causing pleural plaque after long dust exposure [82]. In some mining populations where pleural plaques were observed, only a minority of workers had recognizable exposure to asbestos [121–123]. Pleural plaques are not uniformly associated with either pulmonary parenchymal fibrosis or reduced lung function nor are they premalignant lesions [95,97,124–131]. Localized pleural plaques are commonly regarded as “sign posts” of asbestos exposure although most of the studies cited did not report either the presence or absence of plaque. Therefore, unlike the ILO opacity profusion reporting, there is no feasible way to assess the occurrence or significance of plaques except for the NIOSH studies of Montana, Texas and North Carolina talc miners. The finding of pleural plaques among RTV talc workers and other U.S. talc workers, therefore, does not imply: 1. that an asbestos exposure exists; or 2. that a finding of pleural plaque by itself carries the same risk for other adverse health effects associated with exposure to asbestos.

**Limited Asbestos Exposure data**

A limitation in the RTV talc to asbestos comparison is the sparse fiber exposure information available in the amphibole asbestos studies. Comparisons with the South African asbestos studies, however, showed that a higher exposure to the non-asbestos EMP found in RTV talc was associated with a much lower prevalence and intensity of pneumoconiosis than that found among these asbestos miners. Further offsetting this limitation are the findings for comparisons not involving asbestos. These include the RTV talc comparison to platy talc where dust exposure levels can be more reliably contrasted, the comparison of RTV talc EMP airborne exposure to an asbestos safe exposure limit (PEL) and similarity of pneumoconiosis prevalence in talc and un-exposed background populations. Useful as well in addressing the “same as” asbestos hypothesis is the historical testing of RTV talc EMP in other pulmonary end point disease studies (lung cancer and mesothelioma).

**Cancer and Pneumoconiosis**

The prevalence of pneumoconiosis among RTV talc workers does not directly address the question of a cancer risk. The asbestos exposure level causally associated with lung cancer is generally viewed as lower than that for asbestosis and that for mesothelioma lower still [9].

However, pneumoconiosis is a very common finding in lung cancer cases caused by asbestos at EMP exposure levels similar or lower than those recorded for RTV talc [109,112,114]. The linkage between fibrosis and cancer of the lung has been debated for many years and remains unresolved [132] but there is little question that the majority of studies that address this linkage show a strong association between fibrosis in the lung and cancer of the lung [133, 134]. The literature reviewed does not provide similar information on the linkage between fibrosis and pleural mesothelioma.

In the asbestos cement worker study [112], for example, the authors report that among the lung cancer cases with 20 or more years of employment, 100% showed an ILO classification of ≥ 1/0. In the South African studies [110], the authors state that “slight asbestosis is important as it is strongly associated with a risk of bronchial cancer.” Moreover, if the mechanism of lung damage is similar for RTV talc and asbestos, the lack of significant pneumoconiosis among RTV talc workers despite high cumulative EMP exposures is inconsistent with an asbestos-like carcinogenic risk for RTV talc.

**Conclusions**

The radiographic occurrence of pneumoconiosis was less than 3%, among employed RTV talc workers and when detected showed little progression with only one case reaching a radiographic stage greater than 1/1 despite long exposures. This occurrence is similar to that recorded among platy talc workers not exposed to EMP [19,82,101–103] and the general unexposed population [102]. No evidence was found of an elevated pneumoconiosis rate among formerly employed RTV talc workers. This experience is in marked contrast to amphibole asbestos workers where the prevalence of pneumoconiosis ranged from 30 to > 75% and the severity of asbestosis included some category 2 or greater cases with evidence of an accelerated progression rate. These differences were found even though RTV talc EMP airborne exposures exceeded the asbestos permissible fiber exposure standard for both the elongate amphibole cleavage fragment and fibrous talc components found in the talc. Consideration of time/dose cumulative dust exposures also supports this contrast.

The similarity of results with those of other talc cohorts and an unexposed cohort does not support the hypothesis that the non-asbestos EMPs found in RTV talc produce the high prevalence’s and severity of pneumoconiosis observed in workers exposed to amphibole asbestos EMP (fibers). The lesser toxicity of RTV EMPs is also supported by the mortality, animal and cell studies of RTV talc. Moreover, the similar occurrence of pneumoconiosis and pleural plaques in RTV and platy talc-exposed workers with
similar respirable dust exposure suggest the mineral talc itself is the particulate component most associated with the occurrence of pneumoconiosis and not the EMP found in RTV talc.

This review points out the importance of reliable mineral identification when investigating EMP toxicity. Until the mechanisms of asbestos-related disease are more fully understood, assigning risk solely on the basis of particle dimension, biologic retention and mineral habit may be inadequate. The finding of lower than background prevalence of non-progressive interstitial markings associated with long exposure to asbestiform talc fiber, the EMP found in RTV talc that most resembles asbestos in dimension and mineral habit, further suggests that the mineral with all its attending physiochemical/elemental properties - matters.

Acknowledgement

The authors wish to thank Andrew Ghio, M.D. for his independent interpretations of the chest radiographs of 2008 RTV talc workers. Dr. Ghio received no reimbursement for this review.

References


89. BB/AG. Independent ILO Chest Radiographic Readings by Boehlecke B and Ghio A of the 2008 Chest Radiographs of RTV talc Workers. Submitted to Vanderbilt Minerals, LLC. 2013. A file was also later submitted to Vanderbilt Minerals, LLC by A. Ghio, M.D. of 2016 Chest Radiographs of RTV wollastonite workers who had prior RTV talc exposure. Contact: DBLebedin@vanderbiltglobalservices.com.


92. ETC. Analytical report to R. T. Vanderbilt Company, Inc. (RTV) on 37 fiber samples collected at the Gouverneur tacle mine - survey dates Sept. 16-18, 1998. Available at: Vanderbilt Global Services, LLC DBLebedin@vanderbiltglobalservices.com.


