Clinical Presentation of Asbestosis with Intractable Pleural Pain in the Adult Child of a Taconite Miner and Radiographic Demonstration of the Probable Pathology Causing the Pain

MICHAEL R. HARBUT, CARMEN ENDRESS, JOHN J. GRAFF, CHRISTOPHER WEIS, HARVEY PASS

Taconite, although not classified by the United States Government as asbestos or asbestiform material, has been associated with asbestos-related diseases. The mineral is used in the production of steel and as a road-patch material and is mined in Michigan and Minnesota. This report describes the case of a middle-aged Caucasian woman with exposure to taconite mining dust from her miner father's clothing in childhood with a resultant presentation consistent with asbestosis and intractable pleural pain. Intractable pleural pain has been described in asbestos-exposed patients with theorized etiologies. However, no *in vivo* reported mechanism has demonstrated a plausible, anatomically apparent mechanism for the pain. We utilize an application of the Vitrea® software for enhancement of high-resolution computerized tomography which demonstrates at least one likely mechanism for intractable pleural pain.
Key words: taconite; pleuritic pain; asbestosis; asbestos-related disease; image processing, computer-assisted

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CASE PRESENTATION

A Caucasian female, 48 years of age, 65 inches tall, 231 pounds, was referred to the National Center for Vermiculite and Asbestos-Related Cancers (NCVAC) at the Karmanos Cancer Institute in Detroit, Michigan. The patient presented with pain at the inferior right lateral chest wall, extending to the region of the right upper lobe. A similar nidus of discomfort was emerging at the left midaxillary line at the region of rib 8.

Received from: Karmanos Cancer Institute, Wayne State University School of Medicine, Detroit, MI (MH, CE, JG); United States Environmental Protection Agency National Enforcement Investigations Center, Denver, CO (CW); Department of Thoracic Surgery, New York University, New York, NY (HP). Send correspondence to: Dr. John J. Graff, Karmanos Cancer Institute, Wayne State University School of Medicine, 110 E. Warren Avenue, Detroit, MI 48201; email: <graffj@karmanos.org>.

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The right-sided pain had been gradually increasing in intensity over the patient's previous 31 years. The nature of the pain was described at first as being soreness, ultimately progressing to a knife-like sensation at the time of presentation. The patient required narcotics to control the pain beginning three years prior to presentation at our institution.

The patient also complained of coughing four to six times per day for at least four days per week. The cough had been present for at least five years and was essentially dry with occasional mucus production. The patient stated her chest occasionally sounded wheezy or whistling, apart from colds, for at least five years. The patient stated she became dyspneic on exertion and, in comparison to her contemporaries, she walked at a slower pace on the level. This dyspnea had been occurring for at least five years.

At the time of her initial presentation, the patient had achieved some degree of pain control through the use of fluoxetine, venlafaxine hydrochloride, butalbital, acetaminophen, and nonsteroidal anti-inflammatories. She had also been prescribed medication for hypothyroidism, long-acting beta agonists, inhaled steroids, montelukast, and a rescue inhaler. There has been minimal relief of the dyspnea.

At physical examination we found a patient of very pleasant demeanor. Blood pressure was 118/86 and temperature 97.9°F. There was no edema at the extremities. There were bilateral dry rales at lung exam, with a possible friction rub at the right posterior lateral line and reduced air movement to the right lung. The patient was evaluated by Thoracic Surgery Service, Cardiology, Clinical Oncology, Physical Medicine and Rehabilitation, Endocrinology, and Gastroenterology at the Karmanos Cancer Institute and other medical institutions. Other causes of pain and shortness of breath were ruled out.

Pulmonary function studies were performed serially (Table 1), demonstrating a persistently reduced diffusion capacity consistent with asbestosis.[1]

The patient has over a four-year period undergone annual high-resolution computerized tomography (HRCT) scanning (Table 2). Plane chest x-rays with B readings are not routinely performed at our institution owing to their lack of sensitivity and specificity. All

TABLE 1 Serial Pulmonary Function Testing Results

Date	FVC[a] % Pred[f]	Actual (liters)	FEV$_1$[b] % Pred	Actual (liters)	FEV$_1$[b]/FVC Actual %	FEF[c] 25–75% % Pred	Actual (liters/sec)	TLC by Pleth[d] % Pred	Actual (liters)	DLCO[e] Corrected % Pred	Actual (ml/min/mmHg)
7/1/2004	109	3.72	117	3.04	82	82	3.18	121	6.27	64	17.74
7/22/2005	105	3.57	116	3.00	84	100	3.86	112	5.85	59	16.40
9/28/2006	108	3.64	122	3.11	86	100	3.83	119	6.18	65	18.01
7/6/2007	107	3.58	122	3.08	86	111	4.22	124	6.46	68	18.57
7/25/2008	115	3.84	119	2.98	78	67	2.53	118	6.14	68	17.70

[a]Forced vital capacity
[b]Forced expiratory volume in one second
[c]Forced expiratory flow
[d]Total lung capacity by plethysmography
[e]Lung diffusion capacity
[f]Percent predicted

HRCT examinations were performed in the 64-multi detector row scanner (Somaton Sensation 64 Siemens Medical Solutions) during single breath hold. A high-frequency algorithm, 768 × 768 matrix, and a 325 mm field of view, with a rotation time of approximate 500-msec, were used. Bilateral calcified, partially calcified, and noncalcified pleural plaques; diaphragmatic plaques; pericardial plaques and pulmonary fibrosis consistent with asbestosis were reported. These findings have demonstrated progression, also consistent with asbestosis.[1]

The standard 64-slice HRCT images were then digitally enhanced via the use of the Vital Images Vitrea® software program, an advanced visualization software that allows for two and three-dimensional images of computed tomography data. Vitrea® is an image enhanc-

TABLE 2 High Resolution Computed Tomography (HRCT) Report Findings

Date	Interpreting Radiologist	Reported Findings
7/2/2004	Academic, Board-certified Radiologist	Calcified pleural plaques anterolaterally, bilaterally, and postero-medially bilaterally; calcified pleural plaques along the diaphragm posteriorly and along left heart border; linear interstitial opacities in lower lobe posteriorly, which may represent mild fibrosis vs. dependent atelectasis; peripheral minimal interstitial infiltrated in right middle lobe and lingula anteriorly.
7/22/2005	Academic, Board-certified Radiologist	Stable multiple bilateral pleural plaques; calcified pleural plaques noted along pericardium on left and along diaphragm bilaterally; mild stable subpleural basilar fibrosis; slight interval increase in fibrosis in right middle lobe and lingula.
3/28/2006	Academic, Board-certified Radiologist, B-Reader	Extensive calcified, partially calcified, and noncalcified pleural plaques throughout thorax; evidence of left pericardial and diaphragmatic plaques; no significant change in size and configuration of the pleural, pericardial, or diaphragmatic plaques since 7/2/04; unchanged bilateral curvilinear subpleural lines running parallel to pleural surface; increasing interstitial fibrosis and bronchiolectasis since 7/2/04.
9/28/2006	Academic, Board-certified Radiologist, B-Reader	Calcified and noncalcified pleural plaques noted in upper, mid, and lower lung zones; there are diaphragmatic and pericardial plaques; interstitial pulmonary fibrosis with pleural bands demonstrated in bilateral lower lobes and along inferior aspect of right middle lobe near the anterior aspect of the lung base; interstitial fibrosis is progressing since 7/2/04 film; pleural plaques have remained unchanged.
7/6/2007	Academic, Board-certified Radiologist, B-Reader	Interstitial fibrosis, pleural, diaphragmatic, and pericardial plaques demonstrate no significant appreciable change since 9/28/06; some of the pericardial, pleural, and diaphragmatic plaques are partially calcified.
7/25/2008	Academic, Board-certified Radiologist, B-Reader	Calcifications along the anterior right pleural plaques are increasing as well as the thickness of the pleural plaques; peripheral interstitial pulmonary fibrosis has remained essentially unchanged; fibrosis predominates along the mid and lower lung zones; pericardial thickening and partially calcified plaques are identified along the anterior left lateral aspect of the heart.

ing tool that enables visualization of 2D and 3D images of human anatomy from computed tomography data. This tool enables the physician to navigate between and within the images to better understand pathology and anatomy. The Vitrea® analysis of patients with asbestos-related disease includes the ability to analyze pleural plaques and gives semi-automatic contouring detection of plaques and lung volume. Through color segmentation, the physician can use Vitrea® to assign different colors to different density ranges in Hounsfield units allowing differentiation between normal tissue and fibrosis. Enhanced visualization of calcified pleural plaques and non-calcified pleural plaques is readily obtained, and plaques are easily visually distinguished from the adjacent lung and chest wall. Density ranges within mixed pleural plaques can also be calculated.

With the use of the Vitrea®-enhanced HRCT images, we found evidence of progressive erosion of the ribs, corresponding to the area of intractable pain at the patient's right hemithorax, as well as the emerging contralateral pain. While many HRCT readers claim they can see this type of progression on the unenhanced HRCT alone, such readings are not always reproducible. Vitrea® enhancement will hopefully help address the problem of inter-reader variability. We are currently refining the software and its uses in order to do a reliability (inter-reader comparison) study.

The enhanced HRCT images in Figures 1a through c display the pleural plaque progression over the three year period 2005–2008. Figure 1a is the coronal volume rendered HRCT of the chest, showing progressive erosions in the right and left ribs, corresponding to the region of discomfort. Figure 1b shows progression of the volume and surface area of the right side pleural plaques. The pleural plaque volume on the right hemithorax increased from 116.9 cm^3 to 160.6 cm^3 from July 2005 to July 2008. The pleural plaque surface area increased from 490.3 cm^2 to 767.6 cm^2, with a total peripheral right lung surface area of 1342.7 cm^2. Figure 1c displays the progression of the left-side pleural plaque from 314.8 cm^2 surface area to 486.2 cm^2, with a total left thorax peripheral surface area of 1322.2 cm^2. Over the three year period 2005–2008, there was a substantial increase in plaque-to-lung surface area: 37% to 57% on the right side and 24% to 37% on the left side. These findings are consistent with a friction coefficient generated by the plaques, which apparently exerts pressure on the parietal pleura, periosteum, and/or neurovascular bundle, resulting in bony erosion and pain.

Pain receptors are located in the parietal pleura[2], the periosteum and bone.[3] The location of the plaques and their increasing volume and juxtaposition to the eroded periosteum is consistent with an identification of the plaques as the cause of pain.

We also obtained nuclear bone scans four years apart and found no evidence of a metastatic or similarly isotope-avid process.

POSSIBLE SOURCES OF EXPOSURE

The patient is currently employed as a librarian for a school district in the taconite mining region of Michigan's Upper Peninsula. She also worked from 1982 to 1994 in an asbestos-containing local high school building . She attended high school from 1968 to 1972 in the same building. Mossman and others have shown that there is an extremely low likelihood of developing asbestos-related diseases from such exposures.[4–6]

The patient's father was employed as a taconite miner in the Tilden II mine at L'Anse, Michigan from 1962 to 1969. He lived with the patient and had daily contact with her. He neither showered nor changed clothing before coming home from work. He later worked in a tile factory, but there is no known further occupational asbestos, asbesiform, or fibrogenic dust exposures. The patient's father by report has interstitial lung disease at this time and requires supplemental oxygen.

DISCUSSION

Chronic pleuritic pain among patients exposed to asbestos has been reported by Miller.[7] Mukherjee et al. noted 43% of patients enrolled in an asbestos surveillance program complained of chest pain.[8] This patient presents with pleuritic pain, pulmonary function findings, radiographic findings, physical exam findings, and symptomology consistent with asbestosis whose reported exposure is taconite mining dust.

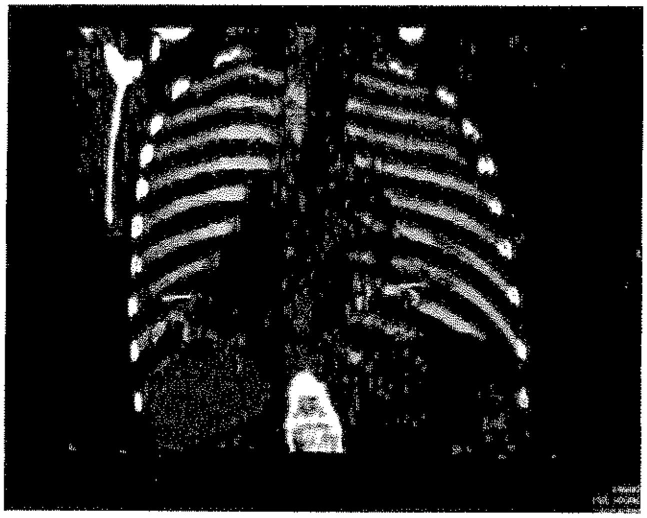
Taconite is an iron-bearing Precambrian rock, rich in silica, and found throughout the Mesabi Iron Range of northern Minnesota and the Negaunee Range in the upper peninsula of Michigan. Iron in these formations is present in the form of magnetite which is finely dispersed through the ore at concentrations up to 30%.

Electron microscope and X-ray diffraction studies of taconite processing facilities in the Mesabi Iron Range of northern Minnesota have been conducted by the US Environmental Protection Agency. These studies identified the presence of fibrous amphibole in stack emissions and fugitive dusts from processing facilities in Silver Bay, Minnesota.[9]

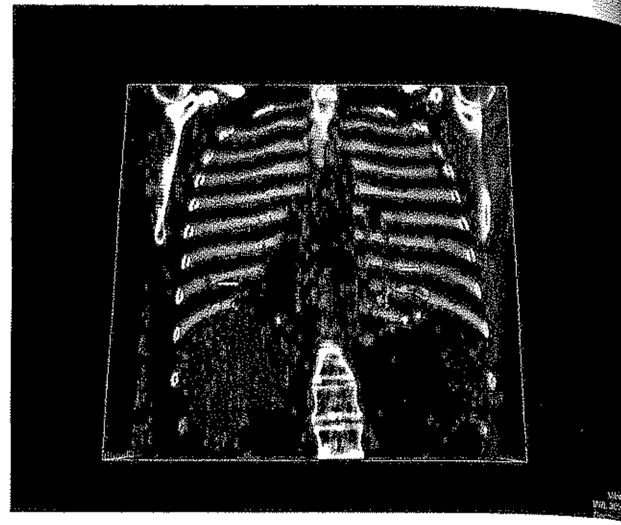
The Negaunee Iron Formation of northern Michigan is similarly permissive for the formation of fibrous amphibole including grunerite, tremolite and minnesotaite.[10] Variability in the mineralogical nature of the Minnesota Iron Range and the Negaunee Iron Formation is, however, likely.

In commercial processing, ores are finely ground and the iron is magnetically extracted , then mixed with clay and limestone to make pellets used in the manufacturing of steel. Inhalation of dusts from this process have been associated with a variety of lung diseases in both humans and animals.

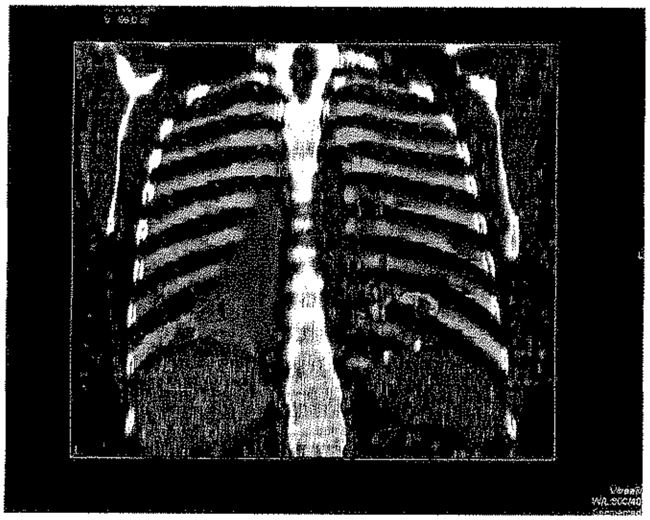
Biological effects of dosing materials prepared from loose-surface iron-formation rocks have caused neo-



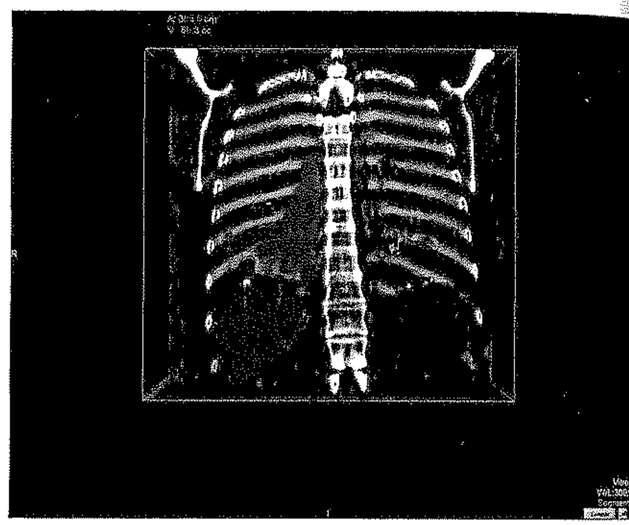
a) July 2005



July 2008



b) July 2005



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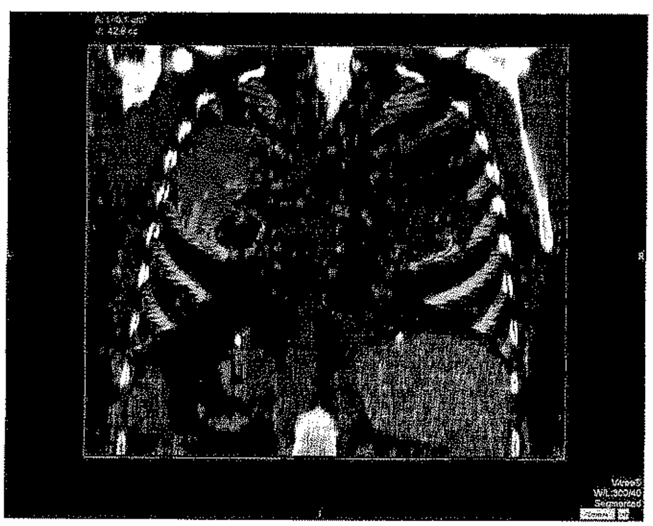

c) July 2005

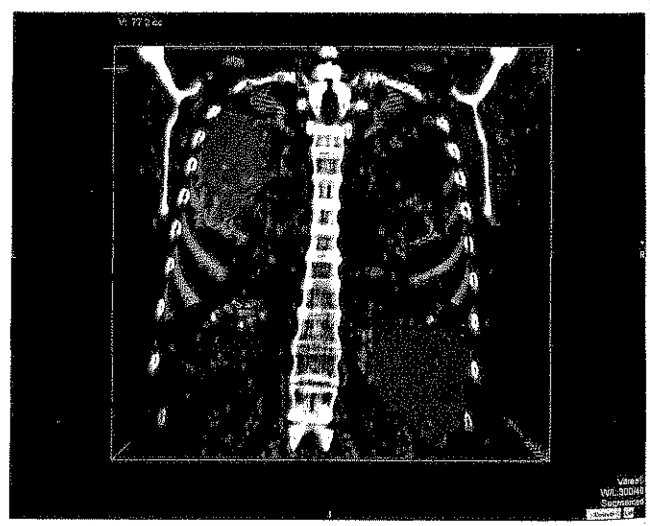

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Figure 1—High Resolution Computed Tomography (HRCT) Images, Enhanced Using Vitrea® Software

plastic lesions in male Fischer 344 rats dosed by intratracheal instillation and intrapleural injection.[11] The Minnesota Department of Health is presently conducting investigations into the cause of more than 48 cases of mesothelioma associated with mining in northeastern Minnesota.

Engineering emissions test reports provided by the Tilden Mine Company in the Negaunee/Ishpeming area of Michigan's Upper Peninsula do not report the presence of asbestiform fibers from various sources.[12,13] This information contrasts with mineralogical investigations of the Negaunee Iron Formations in the Marquette district conducted by researchers from the Oak Ridge National Laboratory.[10] Geological and mineralogical evaluations of the Negaunee formation indicate the presence of ultramaphic sills containing fibrous forms of minnesotaite and grunerite. Grunerite is of the general formula $Fe_7Si_8O_{22}(OH)_2$ and is known to be associated with cancer, mesothelioma, and pleural disease.[14] Large areas of the Marquette Iron Range have been mined for the production of taconite, creating direct and indirect exposure pathways for workers and family members.

From a medical perspective, this case exceeds the level of evidence required in previously published reports of second-hand exposure to asbestos as a cause of asbestos-related pulmonary disease.[15] This patient has most likely developed asbestosis, pleural plaques, and intractable pleural pain from inhalation exposure to the taconite-mining dusts unknowingly carried to her childhood home by her taconite miner father.

The radiographic demonstration of a mechanism which is scientifically plausible and biologically consistent with the causation of intractable pleural pain has also been presented here. There may be other mechanisms as well, but through this description clinical steps may be taken to help relieve the pain.

CONCLUSION

We report for the first time a patient who meets the criteria for a diagnosis of asbestosis and pleural plaques, as established by the American Thoracic Society, and whose most likely fibrogenic exposure was from dusts generated by taconite mining which were carried home on her father's clothing.

The patient is symptomatic, radiographic findings support asbestos-related disease, and she exhibits asbestosis-consistent abnormalities in pulmonary function. The patient also has physical exam abnormalities which support this diagnosis.

The Vitrea®-enhanced radiographic demonstration of the probable etiology of the plaque-associated pain offers important routes for therapeutic investigations. The rate and nature of the progression of the pleuritic pain and radiographic findings of asbestosis and plaque volume suggest additional pathways of inquiry in future epidemiological studies of pleural disease.

These findings also support earlier human and animal reports that dusts produced by taconite mining can evoke the same biological responses as do other fibers already defined as asbestos or asbestiform materials.

Finally, the identification of a material which has not been categorized as asbestos, but causes a disease consistent with asbestosis, requires a reevaluation of the definition of asbestos. This is especially important within the context of legislative efforts to prohibit the use of asbestos.

The question is logically asked, "What exactly is asbestos?" The most honest answer is, "A fiber which causes asbestosis."

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References

1. American Thoracic Society Documents. Diagnosis and initial management of nonmalignant diseases related to asbestos. American Journal of Respiratory and Critical Care Medicine. 2004;170:691-715.
2. Johnson D. Pleura, lungs, trachea and bronchi. In: Gray's Anatomy The Anatomical Basis of Clinical Practice. 39th ed. Elsevier Churchill Livingstone; 2005. p. 1063-1080.
3. Standring S. Functional anatomy of the musculoskeletal system. In: Gray's Anatomy The Anatomical Basis of Clinical Practice. 39th ed. Elsevier Churchill Livingstone; 2005. p. 83-136.
4. Mossman BT, Bignon J, Corn M, Seaton A, Gee JB. Asbestos: scientific developments and implications for public policy. Science. 1990;247:294-301.
5. Chesson J, Hatfield J, Schultz B, Dutrow E, Blake J. Airborne asbestos in public buildings. Environ Res. 1990;51(1):100-107.
6. Burdett GJ, Jaffrey SA. Airborne asbestos concentrations in buildings. Ann Occup Hyg. 1986;30(2):185-199.
7. Miller A. Chronic pleuritic pain in four patients with asbestos induced pleural fibrosis. British Journal of Industrial Medicine 1990;47(3):147-153.
8. Mukherhee S, deKlerk N, Palmer LJ, Olsen NJ, Pang SC, Musk AW. Chest pain in asbestos-exposed individuals with benign pleural and parenchymal disease. American Journal of Respiratory Critical Care Medicine. 2000;162(5):1807-1811.
9. Cook PM, Smith PL, Wilson DG. Amphibole fiber concentration determination for a series of community air samples: use of x-ray diffraction to supplement electron microscope analysis. In: Russel PA and Hutchings AE, editor. Electron Microscopy and X-Ray Applications to Environmental Health Analysis. Ann Arbor, MI: Ann Arbor Science Publishers, Inc. 1978. p. 107-119.
10. Haase D. Metamorphic petrology of the Negaunee Iron Formation, Marquette District, northern Michigan: mineralogy, metamorphic reactions, and phase equilibria. Econ Geol. 1982; 77:60-81.
11. Coffin DL, Palekar LD, Cook PM. Tumorigenesis by a ferroactinolite mineral. Toxicol Lett. 1982;13(3-4):143-149.
12. NCG, Engineering Emissions Test Report—Cliff's Mining, Ishpeming, Michigan (Project No.: M99-0353/Client No.: CLIFF 001). 1999. Nova Consulting Group, Inc.
13. NEI, Report of a Particulate and Metals Emission Study Performed for the Tilden Mining Company at the Tilden Mine, National Mine, Michigan (053.13). 2002. Network Environmental, Inc.
14. Ribak J, Ribak G. Human health effects associated with grunerite asbestos (amosite): Patterson, NJ; Tyler, TX; Uxbridge, UK. Regulatory Toxicology and Pharmacology. 2008;52(1 Supplement):S82-90.
15. Anderson HA, Lilis R, Daum SM, Fischbein AS, Selikoff IJ. Household-contact asbestos neoplastic risk. Annals New York Academy of Sciences. 1976;271:311-323.