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Comparison of Wet Wipe vs Micro-Vacuum Sampling Techniques for Determining Concentrations of Asbestos in Surface Dust

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COMPARISON OF WET WIPE VS MICRO-VACUUM SAMPLING TECHNIQUES FOR DETERMINING CONCENTRATIONS OF ASBESTOS IN SURFACE DUST

by

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Abstract

The objective of the study was to evaluate the detection efficiency of micro-vacuum surface sampling and surface wet wipe sampling in homes that had been identified with vermiculite attic insulation and/or other asbestos containing materials. Surface samples were collected pre and post weatherization activities and analyzed by transmission electron microscopy. Baseline sampling revealed that wet wipe sampling was more likely to detect surface asbestos contamination than micro-vacuum sampling; 55% of surface wet wipe samples revealed detectable asbestos compared to 17% of micro-vacuum samples. In addition, 16% of the surface wet wipe samples revealed asbestos concentrations above the established background level of 10,000 s/cm² compared with 3% of micro-vacuum samples. Results of this study suggest that surface wet wipe sampling, in accordance with other sampling methods, is recommended for baseline testing to assess potential living space asbestos contamination.

Keywords: asbestos, wet wipe sampling, micro-vacuum sampling

Dedication

I want to thank Mom, Dad, and Thomas for all your support. My professors at Montana Tech for their support and guidance throughout this project, I would have never finished!

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Table of Contents

List of Tables

List of Figures

Abbreviations

ACM	Asbestos Containing Material
AHERA	Asbestos Hazard Emergency Response Act
AIHA	American Industrial Hygiene Association
AS	Analytical Sensitivity
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
EPA	Environmental Protection Agency
HEPA	High Efficiency Particulate Air
LAAC	Licensed Asbestos Abatement Contractor
NIOSH	National Institute for Occupational Safety and Health
NMAM	NIOSH Manual of Analytical Methods
NVLAP	National Voluntary Laboratory Accreditation Program
OSHA	Occupational Safety and Health Administration
PCM	Phase Contrast Microscopy
PLM	Polarized Light Microscopy
PPE	Personal Protective Equipment
REACH	Residential Energy Assistance Challenge Program
s/cm²	Structures (asbestos) per square centimeter surface area
SD	Standard Deviation
TEM	Transmission Electron Microscopy
VAI	Vermiculite Attic Insulation

1. Introduction

Public and occupational contaminant exposures are most commonly assessed through air sampling techniques. Air sampling results are then compared to applicable exposure limits.

The National Institute for Occupational Safety and Health (NIOSH) was largely responsible for the development and evaluation of sampling and analytical methods for workplace compliance, with joint efforts from the Occupational Safety and Health Administration (OSHA). These methods provide specific guidelines to follow when sampling for contaminates, which include analysis and sampling procedures. The analysis procedure identifies the most appropriate analytical technique, calibration standards for equipment, and conditions under which a sample is collected. The sampling procedure states the proper selection of equipment and media based on the physical state of the analyte (Kennedy et al., 1995).

In addition to air sampling, surface sampling may be used to assess contamination in public and/or occupational settings. Some materials have the ability to remain airborne for extended periods of time, while others are heavy and settle on to surfaces at a higher rate. Surface sampling is important for determining potential exposure from settled contaminates. Settled contaminates possess a potential exposure risk to individuals when the material is disturbed and dispersed into the air.

Air monitoring was primarily developed in 1974 (Kennedy et al., 1995). The air sampling and analytical methods created by NIOSH provide guidance and procedures to estimate the precision, bias, and accuracy of a sampling and analytical method performance within +/- 25% of the true concentration 95% of the time (Kennedy et al., 1995). When conducting air monitoring, area and personal breathing zone data may be collected. Area sampling involves

strategically placing sampling media and the pump in a fixed location. Area samples are used to evaluate background concentrations, locate sources of exposure, and to evaluate the effectiveness of control measures. Personal breathing zone samples are worn by the affected personnel and placed as close as possible to breathing zone.

Testing for surface contamination varies depending on the material to be sampled and the characteristics of the surface to be sampled. Surface wet wipe sampling techniques may include colorimetric measures, such as direct-reading swabs or wipes that provide non-quantitative immediate indication of contaminant presence; or integrated methods, such as micro-vacuum or wet wipe. Surface wet wipe sampling is commonly used for heavy metal and dust sampling. American Society for Testing Materials (ASTM) recommends for the collection of settled dust samples be collected from hard, relatively smooth, nonporous surfaces. This practice is less effective for collecting settled dust samples from surfaces with substantial texture such as rough concrete, brickwork, textured ceilings, and soft fibrous surfaces such as upholstery and carpeting (ASTM, 2013).

Mirco-vacuum sampling is an alternate surface sampling technique that is typically used on soft, porous surfaces such as carpet or upholstery, but may also be used to collect samples from hard, rough surfaces and/or areas that cannot be easily sampled by other methods.

2. Objective

There are options available to sample for asbestos in surface dust; these include wipe techniques, micro-vacuum protocols, adhesive tape methods and removal of swatches of material from exposed surfaces, etc. The primary objective of this study was to evaluate the detection efficiency of the most common techniques for assessing asbestos concentrations in surface dust, wet wipe and micro-vacuum sampling. Sampling was conducted in homes with confirmed vermiculite attic insulation (VAI) or other asbestos containing materials (ACM). The homes utilized in this study were selected based on criteria for a larger study evaluating the impact of weatherization activities in homes with VAI and/or ACM (Spear et al., 2012). Ideally, this study would establish a relationship between wet wipe samples and micro-vacuum samples to predict correlation through a regression value plot.

Surface sampling was conducted during two phases of the weatherization study; baseline assessment and weatherization. During the baseline phase, surface samples were taken randomly throughout homes based on surface characteristics. Wet wipe samples were collected on hard, smooth surfaces and micro-vacuum samples were collected on porous surfaces.

The weatherization phase of the project assessed the impact of weatherization measures on homes that contain vermiculite insulation or other ACM. Prior to weatherization activities, a 20 x 20 cm piece of 0.3 mil plastic was secured with painters tape to a minimum of five horizontal surfaces throughout the home. Once secure, a 10 x 10 cm disposable manila template was positioned and attached to the plastic. The plastic templates were placed approximately in the same locations as the baseline surface samples collected. At the conclusion of all weatherization tasks, surface samples were collected from the template locations and sent to an accredited laboratory for analysis. These surface wet wipe samples were compared to the high

volume air sampling that was collected during weatherization activities. Mid-way through the weatherization phase, side-by-side wet wipe and micro-vacuum samples were collected to assess the potential correlation between the sampling methods. The baseline sampling results led the research team to investigate the two methods.

3. Hypotheses

Hypothesis 1: There will be a greater number of detectable asbestos samples collected via surface wet wipe versus micro-vacuum techniques during baseline sampling.

Null 1: There will not be a greater number of detectable asbestos samples collected via surface wet wipe versus micro-vacuum techniques during baseline sampling.

Hypothesis 2: There will be a greater number of detectable asbestos samples collected via side-by-side surface wet wipe versus micro-vacuum techniques collected during weatherization.

Null 2: There will not be a greater number of detectable asbestos samples collected via side-by-side surface wet wipe versus micro-vacuum techniques collected during weatherization.

Hypothesis 3: There will be measurable concentrations of asbestos in surface dust post-weatherization activities.

Null 3: There will not be measurable concentrations of asbestos in surface dust post-weatherization activities.

4. Background of Asbestos

4.1. History

Asbestos is a naturally occurring highly fibrous mineral with separable, long, and thin fibers. These fibers are heat, chemical, and electrical resistant. Asbestos has a high tensile strength and is very flexible. It is one of the best known insulators. These characteristics have made asbestos very useful for many industrial purposes. Asbestos has been in commercial use since the early 1900s.

There are two primary families of asbestos, amphibole and serpentine. There are many forms of asbestos minerals within these families, but the United States Environmental Protection Agency (EPA) and OSHA only regulate six asbestos minerals (ATSDR, 2008). The amphibole group consists of five regulated minerals including amosite, crocidolite, tremolite, actinolite, and anthophyllite. The serpentine family only has one regulated mineral, chrysotile. Chrysotile, or white asbestos, is the predominant commercial form of asbestos. Chrysotile is characterized by long, flexible crystalline fibers, while amphibole minerals are typically more brittle and rod or needle shaped (ATSDR, 2001). All forms of asbestos are hazardous, but amphibole forms are considered to be slightly more hazardous to health than chrysotile.

Asbestos commercial use peaked during the period from World War II into the 1970s. Asbestos containing products may vary in amount ranging from 1 percent to nearly 100 percent. The EPA began regulating asbestos-containing material under the Clean Air Act of 1970, defining materials to be ACM that are more than 1 percent asbestos by weight. The Occupational Safety and Health Administration specifies labeling any materials containing 0.1% or more asbestos (OSHA, 1994). In the mid-1970s, the EPA began banning several major kinds

of asbestos materials due to the increased concerns regarding health effects associated with material exposures but was overturned in 1991 by the U.S. Court of Appeals. Although, specific asbestos-containing products continued to remain banned including: spray applied fireproofing, thermal systems insolation, decorative textures, flooring felt, roll board, and corrugated commercial or specialty paper (USEPA, 1989).

Asbestos containing materials that remain in good condition are not likely to release asbestos fibers into the air. However, once ACM's become damaged, disturbed, or deteriorated, they are likely to release fibers into the air, resulting in a potential for airborne exposure. Once released into the air, asbestos fibers can remain suspended in air for extended periods of time. At this point, asbestos fibers may be inhaled and serious health hazards may occur.

4.2. Libby Vermiculite

Vermiculite is a group of minerals with a flaky, mica-like structure. It has been mined for its uses in insulation. When heated, vermiculite exfoliates, forming lightweight packets of air that make the mineral ideal for packing, insulation, and as a soil additive. Most vermiculite is not contaminated with asbestos. However, the Zonolite Mountain mine near Libby, Montana was contaminated with asbestiform amphibole minerals, including the regulated form tremolite asbestos. Zonolite Mountain supplied over 70% of the world's vermiculite from the 1920s to 1990 for commercial use (USEPA, 2014). The mineralogy of Libby amphibole asbestos is very unique both chemically and structurally and presents several unique analytical challenges. Meeker found that Libby amphiboles are morphologically variable, ranging from blocky crystals to acicular, non-flexible cleavage fragments to long flexible fiber bundles. There are no distinct morphological boundaries by which to categorize the amphiboles. These fibers may also vary in specific chemical composition between fibers or even along the same fiber (Meeker, et al.,

2003). Other non-regulated forms of amphibole asbestos contained in the Zonolite Mountain vermiculite include winchite, richterite, and ferro-edenite. Research has linked all of these forms to asbestos-related diseases (ATSDR, 2008).

Vermiculite ore retrieved from the Zonolite Mountain mine contained up to 26 percent amphibole minerals before it was concentrated and milled in Libby. The various grades of milled vermiculite shipped from Libby contained asbestos at concentrations ranging from 0.3 percent to 7.0 percent (Atkinson et al, 1982). Once the mineral was mined, it was transferred by trains or trucks to expansion facilities. These expansion facilities heated vermiculite to approximately 600 degrees Fahrenheit to expand the concentrate. The EPA has identified 245 expansion sites within the United States that may have received shipments of asbestos-containing vermiculite from the Zonolite Mine (ATSDR, 2008b). A review of company records from 1964-1990 indicated that approximately 6,109,000 tons of vermiculite concentration was shipped to these expansion facilities (ATSDR, 2008b). The precise number of U.S. homes insulated with Zonolite brand (from the Libby mine) vermiculite attic insulation (VAI) is unknown (Gunter et al., 2005; Zalac, 2003); however, vermiculite was widely distributed via processing plants throughout the country and may be present in millions of homes nationwide, including thousands of homes in Montana (USEPA, 2014).

4.3. Asbestos Containing Materials

In addition to vermiculite insulation, many homes (especially those constructed from 1930 to 1970) contain serpentine asbestos in commercial products, as asbestos has been found to be present in 3000-4000 commercial products including thermal insulation, floor tiles, roofing tiles or shingles, gaskets, ceiling texture materials, and siding (Dodson & Hammar, 2006).

4.4. Asbestos Regulations

Currently, OSHA has set the 8-hour Permissible Exposure Limit (PEL) for asbestos at 0.1 fiber per ml for fibers > 5 μm long, with as aspect ratio greater than or equal to 3:1, as determined by phase contrast microscopy. The 10-hour time-weighted average as defined by National Institute for Occupational Safety and Health (NIOSH) is the same. The OSHA PEL also includes an excursion limit of 1.0 fiber per ml averaged over a sampling period of 30 minutes (OSHA, 1994).

The EPA defines asbestos-containing material as any material containing one percent asbestos by weight. Following this definition, the EPA restricts the use of products and materials with detectable amounts of asbestos and is designed to mimic the potential for asbestos fibers to become airborne. NIOSH does considers asbestos to be a potential occupational carcinogen and recommends that exposures be reduced to the lowest feasible concentration. EPA states that vermiculite should not be disturbed even though popped, or exfoliated, vermiculite frequently contains < 1% asbestos.

The National Emission Standards for Hazardous Air Pollutant (NESHAP), regulates air pollution under the EPA and the Clean Air Act. The NESHAP regulation restricts the release of asbestos fibers during the processing and handling of ACM and prohibits or restricts the use of ACM in several industries (USEPA, 2000).

While there are several regulatory and best practices for air sampling asbestos exposure levels, currently there are no national regulatory standards that define asbestos contamination in surface dust. In addition, there is little scientific research available to quantify the background asbestos surface levels. When analyzing surface asbestos contamination, literature suggests that a surface may be considered ‘clean’ when the asbestos concentrations is below 1,000 structures

per square centimeter (s/cm²) and a surface is considered contaminated when the asbestos concentration is greater than 100,000 s/cm² (Millette, 1994).

4.5. Predicting the K Factor

Several researchers have attempted to predict potential airborne asbestos concentrations that may be obtained when surface asbestos dust is disturbed. This resuspension factor is also known as the K factor (Millette, 1994). K factors are experimentally determined ratios of surface dust to air levels in correlation with amount of human activity in the designated space. Specifically in the nuclear industry, K factors have been established and are an acceptable means of monitoring radioactive contamination. K factors would be beneficial to estimating air concentrations and risk from settled asbestos dust when air concentrations are unknown or when available air testing is not sensitive enough.

Many studies have been completed in attempt to determine a K factor for asbestos. To estimate the airborne concentration, the surface concentration (s/cm²) is multiplied by the K factor given for that specific activity. Currently it is suggested that low levels of asbestos in the settled dust, in the range of 1,000 s/cm², does not give rise to elevated levels of airborne asbestos when dust is disturbed during normal activities (Millette, 1994). It is typical for consultants to use simple K factor calculations in attempt to predict airborne asbestos fiber concentrations, these attempts assume there is no direct asbestos surface dust disturbance, but use the K factor associated with sweeping to predict the airborne concentration (Fowler, 1997).

In a study completed by Fowler and Chatfield where inhalation of particles is the primary hazard, measurements of loose surface contamination have been used to monitor or predict the airborne contamination when the material has been disturbed. The K factor will vary depending on the type of disturbance, the type of surface, and air movement in the affected space.

Predictions based on K factors for asbestos may error drastically if the nature of the settled dust changes in any way, including particle size distribution or if other types of dust are added or become associated with the measured particle species. When using ASTM D5755-95 and published K factor values for other materials, the airborne concentrations yielded may be much higher for asbestos then concentration actually observed under normal occupancy (Fowler, 1997).

According to the EPA (2003), "establishing action levels based upon indoor dust levels is not straightforward. There are two primary reasons for this. First, unlike air samples, there are no established regulatory or health-based standards to guide the determination of acceptable concentrations of asbestos in indoor dust. Second, the relationship between the concentration of asbestos in dust and the resultant concentration in the air is highly variable. This is because the relationship depends on a long list of different factors, most important of which is the nature and frequency of dust disturbance. This makes it difficult to calculate a value in surface dust that corresponds to acceptable levels in air, and it is even harder to try to select a level in dust based on site-specific measurements."

4.6. Asbestos Related Diseases

The EPA does not find any exposure to asbestos to be acceptable, and EPA states there is no safe exposure to asbestos:

“Available evidence supports the conclusion that there is no safe level of exposure to asbestos. This conclusion is consistent with present theory of cancer etiology and is further supported by the many documented cases where low or short term exposure has been shown to cause asbestos-related disease.

Most occupational studies have been conducted on populations exposed to high airborne concentrations of asbestos for long periods of time. However, short term occupational exposures have also been shown to increase the risk of lung cancer and mesothelioma. In addition, there are many documented cases of mesothelioma linked to extremely brief exposures to high concentrations or long-term exposure to low concentrations" (USEPA, 2002).

Epidemiology studies have shown that chronic inhalation of all types of asbestos fibers is associated with asbestosis, pleural abnormalities, mesothelioma, and lung cancer (Bull, 2007).

Asbestosis is a disease that involves scarring of lung tissue as a result of breathing in asbestos fibers at high level exposures. The increased collagen interferes with alveolar gas exchange which results in impaired breathing due to scar tissue which does not expand (Mossman et al., 1990). Asbestosis is a progressive disease that worsens over time. The latency period to develop an asbestos-induced respiratory disease can range from 10 to 20 years after initial exposure (ATSDR, 2001).

Lung cancer resulting from asbestos exposure usually occurs in the epithelial linings of the air passages or in the terminal bronchioles. The latency period of lung cancer ranges from 10 to 40 years after initial exposure (ATSDR, 2001). The potential of developing lung cancer greatly increases with using tobacco products due to having a higher underlying risk of susceptibility to lung cancer and the synergism between tobacco products and asbestos fibers (ATSDR, 2001). Cigarette smoke and asbestos together significantly increases the likelihood of developing lung cancer by 50 to 84 times (ATSDR, 2006).

Mesothelioma is a rare malignant tumor of the tissue that lines the lungs, stomach, heart, and other organs. There is a chance that mesothelioma may be developed in the abdominal regions and the symptoms include: abdominal pain, blood clotting abnormalities, bowel

obstruction, anemia and fever (Kurunthachalam, 2013). Mesothelioma is primarily caused by chronic asbestos exposure (USEPA, 2013) and commonly occurs 35 to 45 years following exposure, but may appear up to 60 years after exposure. Various studies have found that amphiboles are twice as likely to cause mesothelioma as serpentine fibers (USEPA, 2013); (Hodgson, 2000); (Mossman et al., 1990). Fiber length may also contribute to developing mesothelioma. Longer fibers (> 8μm) are more difficult to remove from the pleural and peritoneal spaces, though the fiber diameter is also a factor. Larger fibers prohibit their removal through lymphatic channels (Mossman et al., 1990).

The 1991 report from Health Effects Institute – Asbestos Research (HEI-AR, 1991), states that while the differential responses to fibers of different lengths cannot yet be specified precisely, data suggest that the risks of lung cancer and mesothelioma increase with increasing fiber length. In particular, experimental evidence suggests that the rates of induction of tumors, fibrosis, and transformation of cells in vitro, increase as fiber length increases above 5 μm in animals. Thus, the conventional definition of an asbestos fiber used for industrial hygiene purposes is fibers longer than 5 μm with an aspect ratio of 3:1 and greater continues to be a practical index for risk assessment. Whether there is any length threshold below which there is no carcinogenic effect in humans is not known; animal data suggests that very short fibers have much less carcinogenic activity than longer fibers and may even be relatively inactive (HEI-AR, 1991).

Pleural plaques are the most common indication of significant exposure to asbestos. These plaques are characterized by areas of fibrous thickening on the lining of the lungs or diaphragm and typically appear 20-30 years post exposure. Pleural plaques develop from fibers reaching the pleural space via the lymphatic system. These plaques develop slowly over time

and grow as fibrotic scar tissue accumulates. Pleural plaques are benign and cannot become cancerous over time.

In general, asbestos is not considered acutely toxic. However, high exposures for short time periods may increase the potential to develop an asbestos related disorder later in life. Chronic exposure to asbestos, even at low concentration levels, increases the possibility of developing pleural disorders, mesothelioma, or lung cancer. Chronic high dose exposure may lead to developing asbestosis many years after exposure. Asbestos has been classified as a known human carcinogen by the U.S. Department of Health and Human Services, the EPA, and the International Agency for Research on Cancer (National Cancer Institute, 2009).

Everyone is exposed to asbestos at some time during their life due to asbestos being present in air, water, and soil at low levels (National Cancer Institute, 2009). The chemical make-up of fibers, size, shape, and personal risk factors such as smoking and/or pre-existing lung diseases are additional risk factors that may contribute to developing asbestos related disorders.

4.7. Asbestos Toxicology

Asbestos, known for its indestructibility, is especially resistant to the internal defenses of the human body. Once fibers are lodged inside the lungs, most fibers will not break up or dissolve, and cannot be neutralized or removed as other non-fibrous chemicals.

The size, shape, concentration, and type of asbestos fibers play a major role in the toxicity (ATSDR, 2008b). The primary route of asbestos exposure occurs through inhalation of fibers, with the lungs as the target organ. Most short-thick fibers (>3.0 μm) that are deposited in the upper respiratory tract are cleared by mucociliary action. Longer-thin fibers may be carried into the alveolar (deep lung) region and can only be cleared after fragmentation, splitting, or dissolution. Asbestos fibers that are at least 5 μm long, with a width of greater than 0.25 μm,

and an aspect ratio greater than or equal to 3 to1 have thepotential to be extremely hazardous. These fibers are small enough to be inhaled into the deep lungs, known as respirable size, but are large enough to be retained. Contributors to the severity of asbestos related disorders are long, thin, durable fibers (tremolite and other amphiboles). This is due to the fact that these fibers are expected to reach the lower respiratory system including the alveolar regions of the lung and pleura. Once reaching the deep lung, the fibers are retained longer and are therefore more toxic than the short and wide fibers. Amphibole fibers have a higher chance of reaching the lower respiratory system and retaining there than chrysotile fibers that are similar in dimension. Generally, the longer the fiber length and smaller fiber diameter, the greater will be the carcinogenic potential of an asbestos fiber (Besson et al., 1999).

A common toxicological justification for the counting rule is that short fibers are cleared more readily from the lungs (Dodson et al., 2003) and that longer fibers impair the phagocytic process (Stanton et al., 1981). Longer fibers have a greater potential than short fibers to generate an inflammatory response and stimulate release of Il-1B from macrophages (Kane, 1992; Donaldson et al., 2010; Palomaki et al., 2011). However, as in any toxicological assessment, the dose and dosing frequency are critical factors to consider in the long versus short fiber toxicity discussion (Kane et al., 1992; Castranova et al., 2000; Dodson et al., 2003).

Finkelstein and Dufresne analyzed clearance of short asbestos fiber to long fibers. Based on analysis of lung fiber concentration in 72 chrysotile miners and miller, years of exposure, and time since last exposure, the long term clearance half-times were estimated to be about 4 and 8 years for chrysotile. While amphibole half-time clearance levels were estimated at 8 and 16 years (ATSDR, 2001).

In the Dodson et al. (2003) review of fiber length and pathogenicity, the conclusions drawn from Castranova et al. (2000), of "constant infusions of short fibers and a resultant eventual dust overload, can greatly compromise clearance" was cited as the main reason to underscore the short fiber clearance reasoning. A similar hypothesis regarding particle overload and the potential for short crocidolite asbestos fibers to generate substantial inflammatory responses was discussed by Kane (1992). Dodson et al. (2003) further emphasized that when appropriate techniques are used to analyze asbestos fiber tissue burden, in most tissues, a substantial majority of asbestos fibers are less than 5 μm in length. These observations may be due to increased deposition of shorter fibers and/or breaking of longer fibers over time.

Once asbestos enters the lungs and accumulates through inhalation, the lungs begin to experience irritation, scarring and/or inflammation. Currently no studies have confirmed an acute or intermediate-duration exposure to asbestos results in lethality in humans or animals. Inhalation of asbestos fibers may lead to death or a shortened lifespan (ATSDR, 2001).

Ingestion of asbestos is another possible route of exposure, though it is not considered a major route of exposure. The ingestion of asbestos usually accompanies the inhalation of fibers that are cleared from the respiratory tract and then swallowed. Asbestos contaminated drinking water is another form of potential ingestion. Most ingested fibers will be removed by excretion, while few fibers penetrate through the gastrointestinal tract wall and reach blood, lymph, urine, and other tissues (Bull, 2007). Currently, epidemiologic studies cannot consistently support a relationship between non-respiratory cancers and asbestos exposure. Although mortality studies reveal small increases in the incidence of death from cancer at one or more sites other than the lung, the pleura, or the peritoneum.

Also, dermal health effects have been reported from contact with asbestos and the development of small "warts" or corns. Although these lesions have been reported and penetration of fibers appears to be the causation, there is no quantitative data to support a dose-response curve and therefore dermal exposure is not a pathological concern (ATSDR, 2001).

For many years the term asbestos has referred to all types of asbestiforms and has provided little quantitative scientific basis for distinguishing between the effects of chrysotile and amphibole asbestos (Bernstein et al., 2013).

Amphibole fibers do not appear to undergo any major changes while retained in the lungs. However, chrysotile fibers do appear to undergo a type of breakdown or alteration in the lungs. The conclusion is based on measurements of asbestos levels in the lung as a function of exposure duration. A study was completed on animals in which a continued exposure to both types of asbestos fibers, amphibole levels tend to rise, while chrysotile levels reach a steady state (ATSDR, 2001). It is believed that the loss of chrysotile fibers may be related to a slow dissolution of fibers in tissue fluids or in macrophages, or the separation of the fibers into finer components (ATSDR, 2001).

Amphibole asbestos structures are very strong and durable, resulting in difficulty breaking down due to the insolubility at any pH level. There are five asbestiform varieties of amphiboles. One of the varieties, tremolite, is not used commercially but has been found as a contaminant in other industrial minerals including chrysotile (Bernstein et al., 2013).

Tremolite, which is classified as amphibole, asbestos exposure has been associated with an increased incidence of disease in vermiculite miners and millers from Libby, Montana. Although Libby amphibole was originally mischaracterized as tremolite, it only contains 6% tremolite (Meeker et al., 2003). The evidence is supported by reports of increased incidences of

nonmalignant respiratory diseases, lung cancer, and mesothelioma in various regions of the world that have traditionally used tremolite asbestos in homes or have high surface deposits of tremolite asbestos. Amphibole fibers maintain their structure while retained in the human body, which allows the long amphibole fibers to be quickly translocated to the pleural cavity and result in fibrosis and pleural inflammation.

In contrast, chrysotile fibers are rapidly attacked by the acidic environment of the macrophage and fall apart in the lung into short fibers and particles. Studies of the toxicity of chrysotile have determined at non-lung overload conditions, the long chrysotile fibers (>20 μm) are rapidly cleared from the lung and are not translocated to the pleural cavity (Bernstein et al., 2013). Chrysotile is distinguished by its behavior to decompose by contact with acid and is one of three different polymorphs of serpentine.

Recent studies conducted by Bernstein on serpentine chrysotile asbestos have shown that it is not very biopersistent in the lung and is more soluble than amphibole asbestos (Bernstein et al., 2013). Chrysotile has a relatively short biopersistence and does not result in pathological response through 90 days of exposure, whereas amphibole asbestos is highly persistent in the lung and resulted in a fibrotic response even after 5 days of exposure (Bernstein et al., 2013). Following such exposures, chrysotile asbestos produces neither a pathological response in the lung nor in the pleural cavity at doses up to 5,000 times the US threshold limit value (TLV) for chrysotile. In the 90 day exposure study, at an exposure concentration more than 14 ,000 times the TLV, slight fibrosis was observed. In addition, the chrysotile fibers clear rapidly from the lung and are not observed at the visceral pleural surface, neither in the pleura nor on the parietal pleural surface.

The amphibole asbestos fibers tremolite and amosite have thus far been evaluated. In the lung, immediately following a 5 day exposure, the amphibole fibers have been shown to produce extensive inflammation with granuloma formation. With 28 days after cessation of exposure, interstitial fibrosis was observed with both tremolite and amosite. Both of these fibers were poorly cleared from the lung with the fibers longer than 20 μm persisting through the end of the study (365 day post exposure) (Bernstein et al., 2013).

A mortality review was conducted by the Agency for Toxic Substances and Disease Registry (ATSDR) which compared the death rates for those of the Libby areas in Montana and with those of the United State for asbestos related diseases associated to asbestos exposure from 1979-1998. The recently published study reported that asbestosis mortality among groups of 1,672 Libby vermiculite workers was 166 times higher than expected when compared to other white males of the same age in the United States; nearly 2 times more likely than expected to die from lung cancer; 23 times more likely than expected to die from cancer of the pleura; and 15 times more likely than expected to die from mesothelioma (Sullivan, 2007). The study completed by Sullivan, also revealed the chance of dying from asbestos related diseases or lung cancer increased with more years on the job and with increasing cumulative workplace exposure to fibers from vermiculite (Sullivan, 2007). This study also documented 15 mesothelioma deaths for this occupational group.

Nearly 18 percent of over 7,300 people who participated in a community-based medical screening program and underwent chest radiographs from Libby had radiographic pleural abnormalities consistent with asbestos exposure (Peipins et al., 2003). Pleural abnormalities were noted in 51 percent of the 365 study participants who were workers in the mine and associated facilities. A mortality review for the Libby community revealed significantly elevated

standardized mortality rates for asbestosis were 40 percent to 80 percent higher than expected; and lung cancer were 20 percent to 30 percent higher than expected (ATSDR, 2008b). Mesothelioma mortality rate was also elevated during the 20 year study, but only a small number of individuals were identified during this time period (ATSDR, 2008b).

5. Measurement and Analytical Techniques for Asbestos in Surface

5.1. Dust

Currently, there are several recognized methods for determining levels of asbestos concentrations in surface dust. The four most common methods for determining asbestos in surface dust include micro-vacuum, surface wet wipe, adhesive tape and ultrasonic techniques.

5.1.1. Micro-Vacuum Sampling Method

Micro-vacuum sampling may be completed using one of two methods: American Society for Testing and Materials (ASTM) method D5755, Test Method for Micro-vacuum Sampling and Indirect Analysis of Dust by Transmission Electron Microscopy for Asbestos Structure Number Surface Loading or D5756, Test Method for Micro-vacuum Sampling and Indirect Analysis of Dust by Transmission Electron Microscopy for Asbestos Mass Surface Loading.

Micro-vacuum sampling for this project was conducted using the ASTM method D5755-02 (ASTM, 2007). Samples were collected using a disposable 10x10-centimeter manila template placed on a porous surface. A sample probe was then moved over the surface for two minutes. The sample probe consisted of a 3/4 inch long section of Tygon tubing attached to a 25-mm asbestos sampling cassette, using a 0.8 μm MCE filter. An SKC Aircheck sampling pump was attached to the cassette. The pump was pre- and post-calibrated at two liters per minute with a Bois Defender 510 Dry Cal primary flow calibrator. Samples were then capped and sent to an accredited laboratory.

Micro-vacuum sampling is preferred for soft or rough, porous surfaces and is typically the first line test for carpets and fabrics to determine if there is an asbestos contamination. Micro-vacuums are not strong enough to remove all embedded fibers from the contaminated

porous surface, even with steam or water. Roughly only 60% of the fibers will be removed (USEPA, 2002). It is stated in sub-section 1.2.1 of the ASTM Standard D 5755-95 that "The collection efficiency of this techniques in unknown and will vary among substrates. Properties influencing collection efficiency include surface texture, adhesiveness, electrostatic properties and other factors." This technique should be regarded as a measurement tool for determining the presence, type of asbestos on surfaces, and quantifies asbestos structures.

Currently neither the EPA regulations under the Asbestos Hazard Emergency Response Act (AHERA) nor the Clean Air Act (CAA) asbestos National Emission Standards for Hazardous Air Pollutants (NESHAP) specifically require the removal of asbestos-contaminated carpet (USEPA, 2002). The only requirement is to clean surfaces until background levels are reached. The EPA is requiring that all contaminated residences in Libby, MT receive new carpet and upholstered furniture at no expense due to the heavy contamination (USEPA, 2002).

5.1.2. Wet Wipe Sampling Method

Wet wipe sampling is preferred for settled dust on non-porous, hard surfaces including floors, counters, and appliances. Although, wet wipe sampling is not recognized by the EPA.

Surface wet wipe samples are collected using the ASTM D 6480-05 method, Wipe Sampling for Settled Asbestos (ASTM, 2006). Surface wipe method sampling schemes, as displayed in Figure 1, demonstrate "s-strokes" in a.) and b.); while c.) uses concentric squares. Sample collection is typically performed while applying firm pressure on the wipe and using "s-strokes" or concentric squares and progressing toward the center making squares of decreasing size, and repeating the procedure three times, each time refolding the wipe and changing the wipe orientation by 90^{o} (NIOSH, 1994). Sample are collected using a 10x10-centimeter disposable manila template place at desired locations and using a SKC Ghost Wipe that was pre-

moistened with deionized water. Wet wipe samples were collected using "s-stroke" scheme. Samples were placed in a sealable freezer bag and sent to the laboratory.

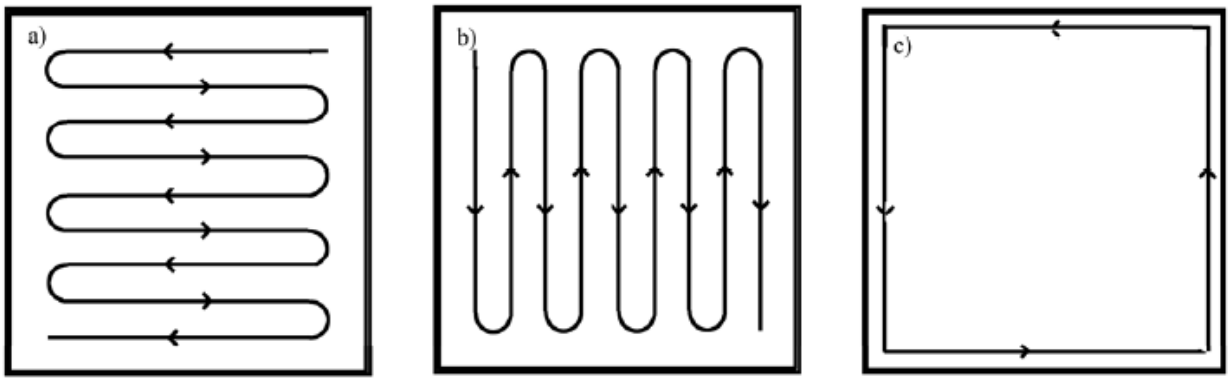

Figure 1: Surface Wipe Sampling Schemes (ASTM, 2013)

5.1.3. Adhesive Tape Sampling Method

Adhesive tape sampling method follows the ASTM E1216-11, Standard Practice for Sampling for Particulate Contamination by Tape Lift method. This practice consists of the application of a pressure-sensitive tape to the surface followed by removal of particulate contamination with the removal of the tape. The tape is then mounted on counting slides. This method determines the presence of particulate contamination of 5 μm and larger and reported in SI units. The counting and measuring of particles is completed by standard techniques (ASTM, 2011). The sampling method provides three methods to evaluate the adhesive tape lifts. Practice A uses light transmitted through the tape and tape adhesive to detect particles that adhere to it. Practice B use light transmitted through the tape adhesive after bonding to a base microscope slide, dissolving the tape backing, and cover slide. The particles are embedded in the adhesive, and air bubbles are eliminated with acrylic mounting media. Practice C use light reflected off the tape adhesive to detect particles that adhere to it (ASTM, 2011).

The adhesive tape method has become a common method to sample for surface contamination of asbestos. An advantage of adhesive tape sampling in comparison to wipe

sampling is that the original position of the fibers are maintained when removed from the surface which allows the sample to be analyzed with a method similar to air sampling and resulting is a more quantitative sample. A disadvantage of tape sampling is that is has not been validate in literature and/or research.

5.1.4. Ultrasonication Sampling Method

The EPA recognizes a method known as ultrasonication test method. This method is used to test for asbestos contamination in carpets and woven fabrics. Results of the ultrasonication test method are given in structures per square centimeter. These units allow the results to be compared to background and safety levels. An advantage of this method is that no consultant or industrial hygienist is needed to take the samples. The only fee is the laboratory expense. The disadvantage is that the method requires a 16 square inch piece of material be sent to the laboratory.

The method number is EPA 600/J-93/167, the Millette ultrasonication carpet method. The carpet and fabric samples should be enclosed in double Ziplock sealed baggies. Once at the laboratory, the carpet sample is cut into 5 centimeter by 5 centimeter squares and placed side down in 1,000 milliliter beaker containing 100 milliliters a specified solution. The beaker is placed in an ultrasonic bath for 30 minutes. Once time is reached, the carpet piece is removed and rinsed into the beaker with 100 milliliters of particle-free water. The entire suspension is shaken vigorously by hand to disperse the particles and left to settle for two minutes. Once the particles are separated, three measured aliquots of different volumes are extracted with disposable graduated pipettes. The aliquot is then mixed with particle-free water to make 50 milliliters and filtered through a mixed cellulose ester (MCE) filter. The filters are dried and prepared according to the direct filter preparation procedures. At least two TEM grids from

different areas of the filter are prepared for each aliquot. After the three filtrations are complete, the remaining suspension is transferred to a graduated cylinder and the volume recorded and added to the volumes of the measured aliquots for the sample volume (Millette, 1994).

This method was specifically developed for carpeting and upholstered materials by the EPA Risk Reduction Laboratory. The ultrasonication method captures over 100 times the amount of asbestos present in the carpet and/or upholstery when compared to the ASTM micro-vacuum method (USEPA, 2002).

Studies completed by the EPA have demonstrated that carpets cannot be fully decontaminated using a HEPA (high-efficiency particulate air) filter micro-vacuum.

The ultrasonication method may be used to identify the presence of asbestos and/or to verify that decontamination of asbestos was successful upon abatement procedures. The ultrasonic method is the official EPA method specific to carpet, and is preferred (USEPA, 2002).

5.1.5. Assessing Asbestos Surface Concentration – Previous Studies

There have been limited peer-reviewed studies evaluating the collection efficiency of these surface sampling techniques for asbestos dust. A two year study was completed to assess the capability of adhesive tape sampling (Ryan et al, 1997). The study was designed to compare surface asbestos concentrations measured directly from contaminated surface asbestos collected by adhesive tape sampling. The tape samples were analyzed by scanning electron microscopy (SEM) and polarized light microscopy (PLM). Two lengths were used for fiber counting, 3 μm and 5 μm. The study collected three types of samples to compare: tape-SEM, tape-PLM, and drywall-SEM.

Based on the 3 μm criteria, all three samples were significantly different. Based on the 5 μm criteria, the tape-SEM and tape-PLM were not significantly different from one another ($p \geq$

0.10) but they were significantly less than the dry-wall-SEM ($p = 0.05$). Multiple regression analyses were completed with none of them producing a statistically significant correlation of tape concentration to drywall concentrations.

The adhesive tape method is still considered to be a qualitative test. The inability to produce a uniform surface concentration may affect the capability to produce a significant correlation. Once a strategy is developed on how to uniformly produce surface contamination, the method may become quantitative.

Wipe sampling has gained a broader application when micro-vacuum sampling is not feasible. Wipe sampling is preferred for maximum collection efficiency of metals, excluding bulk samples (Ashley et al, 2011) Asbestos surface wipe sampling follows the lead surface sampling method. Table 1 summarizes the standard surface sampling methods.

Table I: Standardized Surface Sampling Methods (Ashley, 2006)

Method	**Media/Device**	**Types of Surface(s)**
OSHA ID-125G & ID-206	Wet or dry filter or wipe	Smooth / Hard; Dermal
NIOSH 9100 & 9102	Wet Wipe	Smooth; Dermal
ASTM D 6966	Wet Wipe	Smooth surfaces
ASTM E 1216	Adhesive Tape	Smooth surfaces
OSHA Technical Manual	Patch or hand rinsates	Dermal samples
NIOSH 2600, 3601, 9202, & 9205	Patch or hand rinsates	Dermal Samples
ASTM D 7296	Dry wipe (Beryllium only)	Special substrates
ASTM D 5438	Vacuum sampler	Carpets
ASTM D 7144	Micro-Vacuum	Rough, porous, or fragile surfaces

5.1.6. Surface Sampling Techniques for Contaminants other than Asbestos

The application of surface sampling techniques is not unique to asbestos. There have been many standardized wipe sampling methods developed for environmental surface contamination of metals, such as lead and beryllium. Lead surface sampling stemmed from an increase in lead poisoning reports from children in government subsidized housing. This lead to the Residential Lead-Based Paint Hazard Reduction Act, which is enforced by U.S. Department of Housing and Urban Development (HUD) (Kerr, 2004). The EPA reviewed multiple surface sampling methods for HUD. These methods included the Vostal Method, Farfel Method, 1990 HUD method, Rabinowitz Method, the OSHA method, and the Lioy-Weisel-Wainman (LWW) Wipe method.

Beryllium is another contaminant that presents an exposure hazard through surface contamination; however, it does not have surface contamination limit values set by OSHA, NIOSH, or ACGIH. The Department of Energy (DOE) has set a limit value for surface contamination for equipment release of 0.2 µg/100 cm² and a surface contamination for housekeeping of 0.3 µg/100 cm² (Ashley, 2006). A specific surface sampling method for beryllium was not identified until September 2004, when the DOE decided to adopt ASTM D6966-03 as the standard wipe sampling method (Kerr, 2004).

Beryllium surface sampling can be collected via wet wipe or mirco-vacuum samples. The same methodology applies, using wet wipes for hard, smooth surfaces and micro-vacuum for soft, rough, or porous surfaces. Beryllium exposure is comparable to asbestos in a sense that exposed individuals tend to carry the contaminate home via clothing, hands, vehicles, etc.

Kerr (2004) researched three wipe sampling techniques that are currently used to test for beryllium contamination of room and equipment surfaces. Research was conducted at Department of Energy facilities. The three sampling techniques tested painted surfaces using a wipe without a wetting agent, a water-moistened wipe, and a methanol-moistened wipe (Kerr, 2004). Kerr's research demonstrated removal efficiencies of 9.33% for dry wipes, 22.97% for water-moistened wipes, and 50.62% for alcohol-moistened wipes (Kerr, 2004). A finding from Kerr's research was that moistened wipe methods removed significantly more surface contamination, but left behind varying amounts of beryllium in the moisture that remained on the sampled surface.

6. Analytical Methods

6.1. Phase Contrast Microscopy (PCM)

Phase contrast microscopy (PCM) is an optical microscopy analytical technique used to measure asbestos levels in air. Regulations issued by OSHA require the use of PCM to determine indoor asbestos levels in air for occupational settings to ensure a safe working environment. PCM uses a compound light microscope to illuminate the fibers with a hollow cone of light. The lens induces a phase shift of a wavelength of light that causes minute variations of the refractive index of the specimen. The magnification is 400 times. The change in the phase contrast allows fibers as thin as 0.25 μm in diameter to become visible but prevents fiber identification. Therefore, PCM is used to identify fibers but cannot distinguish between asbestos fibers and non-asbestos fibers. Only fibers that are greater than 5 μm in length and have an aspect ratio of 3:1 or greater are counted in this method (Dodson and Hammar, 2006).

The advantages of PCM method for determining asbestos in air is that it is inexpensive and analysis can be performed on site (DeMalo, 2004). This makes the testing convenient for assessing exposure in the workplace. Also, PCM has been used in historical epidemiological studies (OSHA, 1997), allowing the results from PCM analysis to be compared to health studies used to estimate the risk of acquiring as asbestos-related disease (Chesson et al, 1990; Verma and Clark, 1995).

PCM has a much lower resolution, with the smallest fiber diameter of 0.20 to 0.25 μm being visible, than TEM which may result in a significant underestimation of the asbestos fiber concentration in air.

6.2. Transmission Electron Microscopy (TEM)

Transmission electron microscopy (TEM) is an analytical technique used for air and surface sampling. This technique is recommended when fiber identification is required. The magnification of the sampling technique is 100,000 with a resolution greater than 10 μm. TEM is able to identify fibers as small as 0.02 μm in diameter and classifies fibers as non-asbestos or asbestos, fiber type, and reports the concentration of structures (Dodson & Hammar, 2006).

TEM technique relies on electron microscopy rather than optical microscopy. TEM uses electromagnetic coils as lenses to form magnified images from an electron beam to form images. To be considered a fiber, a grouping must have zero, one, or two definable intersections. To be an intersection is "a nonparallel touching or crossing of fibers" (USEPA, 1987). Air sample analytical techniques that utilize TEM methods include NIOSH 7402, asbestos by TEM and EPA AHERA (NIOSH, 1994B). Surface sample analytical techniques that utilize TEM analysis include ASTM D 6480-05 (ASTM, 2006) and ASTM D 5755-03 (ASTM, 2007) which were adopted for this study.

TEM is considered a superior technique to phase contrast microscopy (PCM), which is commonly used for air sampling, for several reasons. First, transmission electron microscopes have greater resolution and thus can better detect smaller fibers (Mossman, et al., 1990; Kauffer et al., 1996; Karaffa et al., 1987; GETF, 2003) and better examine a particulate's morphology. Secondly, TEM methods for analyzing airborne asbestos use energy dispersive x-ray analysis (EDXA) to determine the elemental makeup of a fiber, which enables this technique to be able to determine if a fiber possesses a chemical composition characteristic of asbestos or not (DeMalo, 2004) (USEPA, 1987).

6.3. Scanning Electron Microscopy (SEM)

Scanning electron microscopy method can be used to detect smaller fibers better than PCM and is primarily used in bulk sampling. Fiber type can also be identified, but fiber counting accuracy is very poor. SEM analysis usually images fibers that are more than 0.2 μm in diameter because of contrast limitations. SEM may also incorporate energy dispersive x-ray analysis devices (ATSDR, 2001).

SEM uses a beam of electrons from a filament in a vacuum and produces an image of the topography of the sample. The electron beam interacts with the atoms on the surface of the sample and information on the sample's composition is then collected (Graham, 2008).

The advantage of using an SEM for asbestos analysis is it has better resolution than polarized light microscopy (PLM) and can be used at magnifications up to 5,000x resolution (Graham, 2008).

6.4. Polarized Light Microscopy (PLM)

Bulk samples of suspect ACM are commonly analyzed by polarized light microscopy (PLM). PLM utilizes a compound light microscope containing a polarized material in the light path below the sample and another in the light path above the sample to identify the fibers among the binders and fillers. Bulk analysis of asbestos using PLM methods involve identifying the type of asbestos present based on optical properties and then estimating the relative amount of asbestos in relation to the rest of the sample. PLM identification of asbestos fibers is limited to fibers approximately 1 μm in diameter (Dodson & Hammar, 2006).

Polarized light microscopy is frequently used for determining the asbestos content of bulk samples of insulation or other building materials and using NIOSH Method 9002 (NIOSH,

1994C) and OSHA Method ID-191 (OSHA, 1995). This method also enables qualitative identification of asbestos types using morphology, color, and refractive index.

7. Weatherization Project Background

7.1. Weatherization Project History

Every year in Montana, the Department of Public Health and Human Services (DPHHS), the Low Income Home Energy Assistance Program (LIHEAP), and the Weatherization Assistance Program actively participates in a grant funded to weatherize homes for low-income families to help reduce their energy usage and increase energy efficiency. There is an estimated 1,500 to 2,000 qualified homes to receive weatherization each year throughout Montana.

Due to the safety and health of residents and workers, the Department of Energy must deny weatherization services to roughly 200 high energy LIHEAP homes annually because of the presences of asbestos containing materials (ACM). The ACM present may be loose filled attic insulation (VAI), pipe duct insulation, or wall, ceiling, and siding material. These materials present a potential exposure to the residents and workers if exposed to friable, brittle asbestos or if the materials have the potential to become airborne.

The Montana DPHHS Intergovernmental Human Services Bureau received a LIEAP Residential Energy Assistance Challenge Program (REACH) grant. This grant funded the Safe Weatherization Demonstration Program. The challenge was to develop and test safe weatherization protocols for low-income homes that have asbestos-containing materials. Through this grant forty-six homes throughout Montana where weatherized and asbestos safe weatherization protocols were developed.

7.2. Weatherization Project Description

The research was conducted during two phases of the weatherization study; baseline assessment and weatherization activities.

The purpose of the baseline assessment was to confirm the presence of asbestos containing VAI or other ACM and evaluate living spaces exposure for asbestos concentration in 46 occupied homes. This evaluation included high volume air sampling (not discussed in this thesis), surface wet wipe and micro-vacuum sampling. The overall purpose of the project was to develop and test procedures that would define a safe and effective protocol to weatherize low-income homes where asbestos had been identified. The research aim during the baseline assessment was to develop sampling strategies, personal protective equipment (PPE) selections, and exposure control strategies.

The purpose of the weatherization phase of the study was to evaluate the impact of weatherization activities in the living spaces of homes. This impact was assessed through living space high volume air sampling, personal breathing zone sampling, and surface sampling. The personal breathing zone sampling is not discussed in this thesis.

7.3. Research Sampling Methods

The baseline study consisted of two methods of asbestos surface sampling; surface wet wipe and surface micro-vacuum. A minimum of five samples were randomly collected in the living space of the homes prior to any weatherization activities. One hundred thirty-four micro-vacuum samples were collected from carpets and porous materials in the horizontal plane using ASTM D 5755-02 sampling method. Two hundred forty-four surface wet wipe samples were collected from non-porous, hard, smooth surfaces in the horizontal plane using ASTM D6480-05 sampling method. Samples were sealed and sent to ALS Laboratory. High volume air sampling was also completed but not reported in this thesis.

Surface sampling conducted during the weatherization portion of the study consisted of individual surface wet wipe and side-by-side surface wet wipe and micro-vacuum samples. The

individual surface wet wipe followed the ASTM D 6480-05 sampling methods and were completed post-weatherization activities. Prior to any weatherization work, a .3 mil plastic template was secured to a horizontal surface of hard, smooth, non-porous materials to capture asbestos fibers that may become disturbed during the weatherization process. These templates were strategically placed in approximately the same locations as the baseline surface wet wipes locations. A minimum of five samples were collected in each home. A total of 216 surface wet wipes were collected.

Mid-way through the weatherization process, side-by-side sampling was investigated to determine if there was a correlation between wet wipe and micro-vacuum sampling. The methods followed ASTM D 6480-05 for wet wipes and ASTM D 5755-02 for micro-vacuum. The sample locations were strategically placed based on visible dust on a horizontal surface where asbestos had been previously identified prior to any weatherization activities. All samples were collected post-weatherization activities. A total of 14 side-by-side samples were collected. A summary of surface asbestos sampling methods employed during the baseline and weatherization phase of the project is illustrated in Table 2.

Table II: Surface Asbestos Sampling Methods Employed During the Baseline and Weatherization Phases of the Study

	Baseline Assessment		**Weatherization Activities**	
Type of Surface Sampling	Surface Wet Wipe	Surface Micro-Vacuum	Surface Wet Wipe	Side-by-Side Surface Wet Wipe and Micro-Vacuum
Sampling Method	ASTM D 6480-05	ASTM D 5755-02	ASTM D 6480-05	ASTM D 6480-05 ASTM D 5755-02
Minimum Number of Samples per Home	5	5	5	Varied 1-4
Material Sampled	Non-porous material Hard, smooth Horizontal	Porous furniture Carpets	3 ml plastic templates placed on non-porous material Hard, smooth Horizontal	Hard, smooth surfaces Horizontal
Total Numbers of Samples Collected	244	134	216	20

7.4. Surface Asbestos Concentration Clearance Levels Adopted for this Research

Surface sample concentrations adopted for baseline and clearance levels for this project were 10,000 s/cm^2 which is based on existing scientific literature . In terms of surface concentration, the available literature indicates that a surface may be considered "clean" when the asbestos concentration is below 1,000 structures per square centimeter and contaminated when the asbestos concentration is greater than 100,000 s/cm² (Millette, 1994). This means that any sample revealing asbestos concentrations greater than 10,000 s/cm^2 was considered above background level. If any of the surface samples revealed asbestos concentrations greater than this value, the home was cleaned and cleared by a licensed asbestos abatement contractor prior to re-occupancy.

8. Sample Analysis

All samples were sent to ALS Laboratories in Cincinnati, OH for analysis for asbestos using the stated methods. ALS Laboratory is accredited by the American Industrial Hygiene Association (AIHA), the National Voluntary Laboratory Accreditation Program (NVLAP), and the New York State Department of Health Environmental Laboratory Approval Program.

9. Results and Discussion

9.1. Baseline Surface Sampling Results

Forty-six homes participated in the baseline phase of this project. During the baseline assessment, one hundred thirty-four micro-vacuum samples were collected on porous surfaces. A summary of baseline micro-vacuum results are presented in Table 3. Of the 134 samples, 23 (17%) revealed detectable asbestos concentrations. Four samples (3%), collected in three separate homes, revealed asbestos concentrations greater than the background surface concentration of 10,000 s/cm^2.

Two hundred forty-four surface wet wipe samples were collected during the baseline phase. A summary of baseline wet wipe results are presented in Table 3. One hundred thirty-four (55%) of the samples revealed detectable levels of asbestos, while thirty-eight (16%) of total wet wipes collected revealed concentrations greater than the background surface concentration of 10,000 s/cm² adopted for the project. All thirty-eight samples that were above the background surface concentration were due to chrysotile contamination. All samples above the background surface concentration were collected in twenty separate homes. Total individual chrysotile structure count was 585, with three hundred thirty-four chrysotile structures < 5 µm and 251 were > 5 µm long. Total amphiboles structure count was seventeen, with ten of these amphibole structures were < 5 µm and seven of these structures were > 5 µm in length. Asbestos was detected in all forty-six homes during the baseline phase by surface wet wipe, micro-vacuum, or high volume air sampling.

The twenty homes that revealed asbestos contamination above the background level via surface or micro-vacuum sampling were all cleaned by a licensed asbestos abatement contractor

and cleared by air sampling prior to any weatherization activities. In terms of individual fiber counts, chrysotile structures were primarily reported (672) compared to amphiboles (17).

Table III: Baseline Surface Sample Results

	Total Samples Collected; Excluding Field Blanks (n=)	**Total Samples with Detectable Asbestos Structures (n=)**	**Total Samples with Asbestos Concentrations Above 10,000s/cm²**	**Individual Asbestos Structure Counts (n=) Asbestos Structure Morphology**
Baseline Micro-Vacuum	137	23 (17%)	4 (3%)	87 - Chrysotile
Baseline Wet Wipe	244	134 (55%)	38 (16%)	585 – Chrysotile 17- Amphibole

A comparison of the sampling techniques conducted during the baseline assessment revealed that asbestos was detected in homes through surface wet wipe, micro-vacuum and high volume air sampling methods. However, the frequency of asbestos contamination was highest with wet wipe sampling as illustrated in Figure 2.

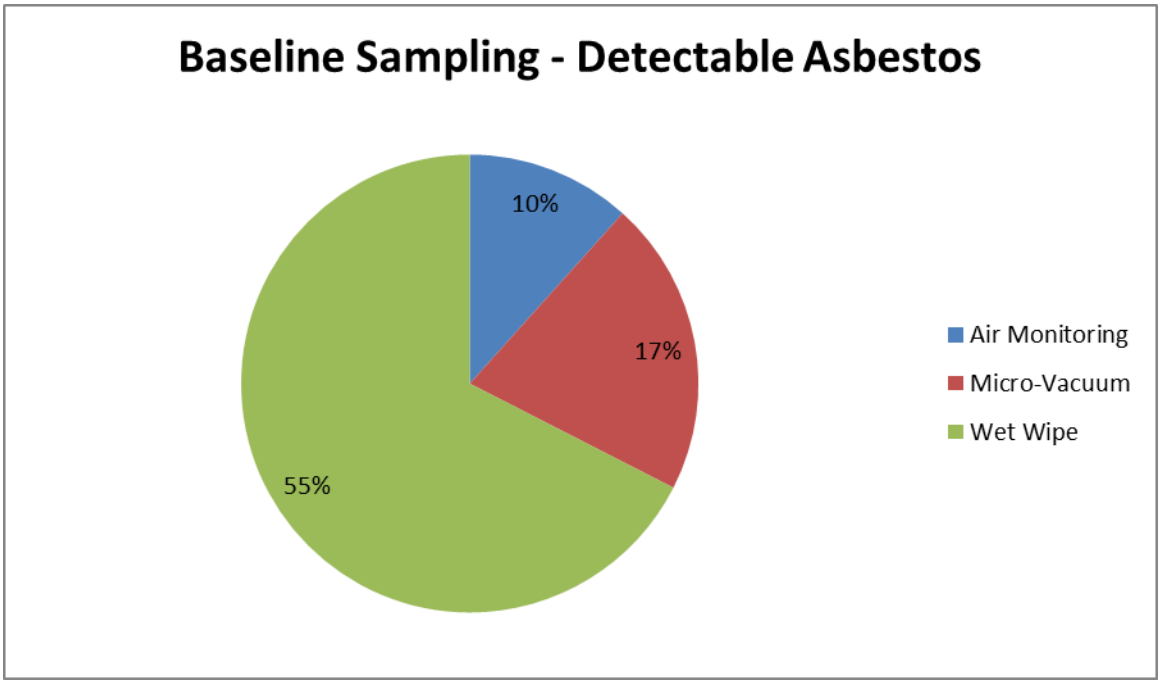

Figure 2: Baseline Sampling – Detectable Asbestos Through Air and Surface Sampling Techniques – Percentage of Total Samples Collected

Of the 46 homes, 20 revealed at least one sample with asbestos above the background concentration level of 10,000 s/cm² adopted for this project. When compared with high volume air sampling, only one sample was analyzed by TEM and exceeded the clearance concentration of 0.01s/mL (or 70 s/mm²). Living space contamination was primarily detected via surface sampling, most commonly through surface wet wipe sampling. Figure 3 demonstrates that surface wet wipe sampling presented a greater sensitivity for detecting asbestos fibers than high volume air sampling. Although, the homes that detected asbestos contamination from micro-vacuum were of higher concentration than surface wet wipe sampling, asbestos was more likely to be detected at varying concentrations with surface wet wipe sampling.

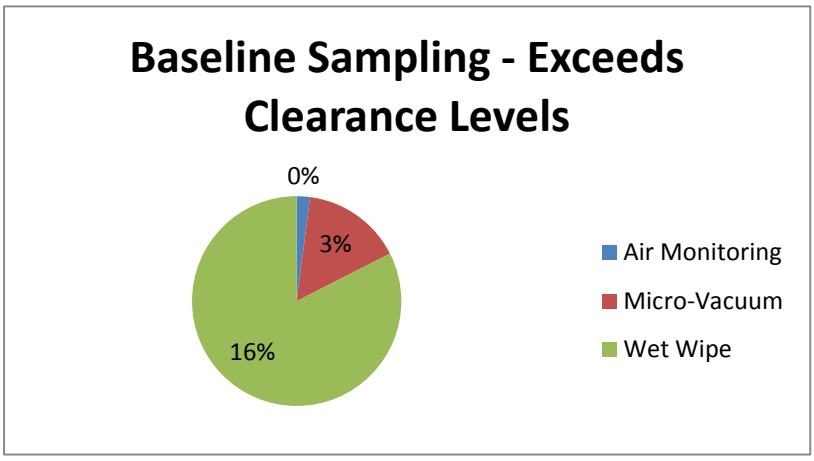

Figure 3: Baseline Sampling – Exceeds Clearance Levels

9.2. Weatherization Surface Sampling Results

9.2.1. Surface Wet Wipe Sampling

As summarized in Table 4, there were 216 surface wet wipe samples, excluding field blanks, collected at the end of the weatherization activities in thirty-seven homes (9 homes were disqualified from the baseline assessment). One hundred eighty-four samples revealed asbestos concentrations less than the analytical sensitivity (AS). Asbestos structures were detected in 30 of the 216 samples above the AS but below the surface background level of 10,000 s/cm² (14%). Two surface samples revealed asbestos concentrations greater than the background level established for this project, one was contaminated with chrysotile and Libby amphibole and the other with chrysotile.

Table IV: Weatherization Surface Wet Wipe Sample Results

Total Samples Collected; Excluding Field Blanks (n=)	**Total Samples with Detectable Asbestos Structures (n=)**	**Total Samples with Asbestos Concentrations Above 10,000 s/cm²**	**Individual Asbestos Structure Counts (n=) Asbestos Structure Morphology**
216	30 (14%)	2 (1%)	1 – Chrysotile 1 – Chrysotile and Libby Amphibole

Compared to high volume air sampling, analyzed by TEM (not reported in this thesis), 21% of samples revealed detectable levels of concentration as illustrated in Figure 4. It is hypothesized that the higher detection of asbestos in air samples versus surface wet wipe samples during and immediately after the weatherization phase may be due to the settling time for asbestos fibers that may have been disturbed from the weatherization phase.

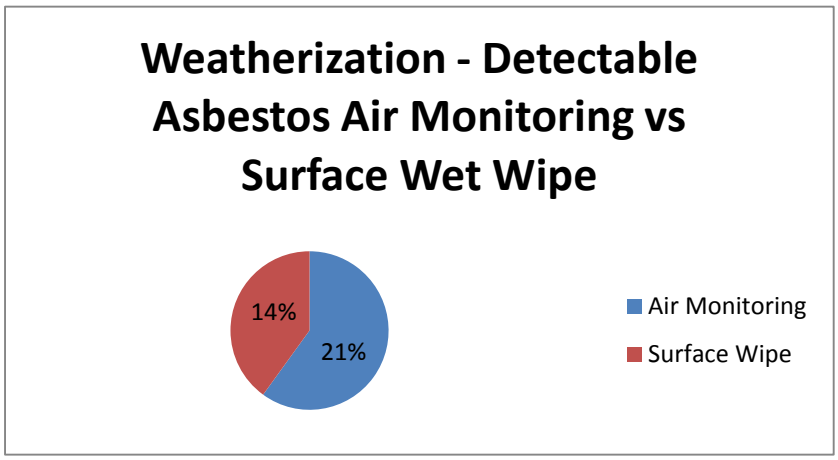

Figure 4: Weatherization Sampling – Detectable Asbestos Air Monitoring vs Surface Wet Wipe

Weatherization surface samples were analyzed based on length of the asbestos structure. There was a total of 216 surface wet wipe sample collected and analyzed by TEM. The samples types were analyzed for structures per square centimeters less than 5 µm and greater than or equal to 5 µm. As illustrated in Table 5, the mean concentration for structures < 5 µm was 471 while the mean concentration for structures ≥ 5 µm was 78.8. Structures less than 5 µm per square centimeters identified the highest maximum concentration which resulted in higher mean and standard deviation statistics.

TEM allows for magnification of about 100,000 with a resolution greater than 10 µm and is used as an analytical technique for air and surface samples when specific identification of individual asbestos fibers is required. This supports the result that more fibers, even as small as 0.02 µm in diameter, were identified.

Table 5: Surface Wet Wipe Sample Statistics

Sample Type	Number of Samples	Mean (s/cm²)	Standard Deviation	Maximum (s/cm²)
TEM s/cm² < 5 µm	216	471.0	2,624.0	34,127
TEM s/cm² ≥ 5 µm	216	78.8	385.1	3,413
TEM Total s/cm²	216	534.0	2,911.0	37,540

9.2.2. Surface Wet Wipe and Micro-Vacuum Side-by-Side Sampling

Side-by-side surface wet wipe and micro-vacuum sampling was conducted in seven homes with a total of 20 side-by-side surface samples. Side-by-side data is presented in Table 6. Considering both sampling techniques in total, ten of the 20 (50%) of the side-by-side samples revealed detectable asbestos contamination. Eight of these ten samples (80%) were collected

using wet wipe sampling and two samples (20%) were collected with through micro-vacuum sampling, as shown in Figure 5. In the two samples where asbestos was detected by micro-vacuum sampling, the concentrations revealed were slightly higher. Results from the side-by-side samples showed that there is no statistical difference between the methods.

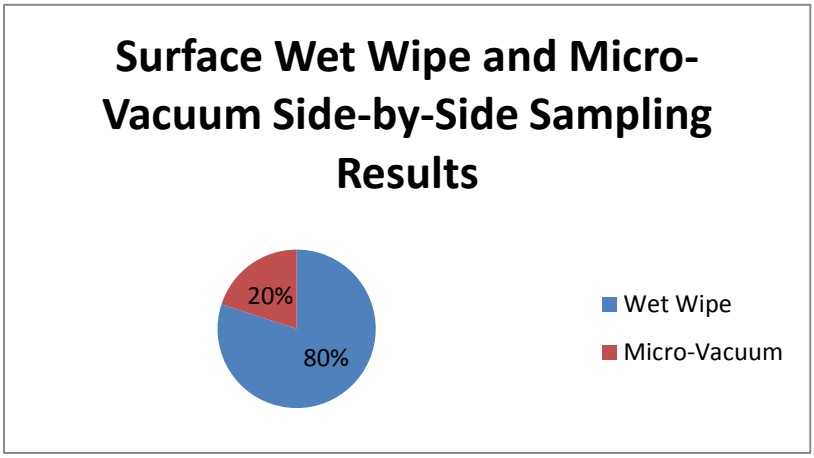

Figure 5: Surface Wet Wipe and Micro-Vacuum Side-by-Side Sampling Results

Table VI: Side-by-Side Surface Sampling Summary

Home Code	Sample Type	Location	TEM < 5 µm (s/ml)	TEM > 5 µm (s/ml)	Total Asbestos (s/ml)	Asbestos Type
JC-1	Wet Wipe	Top of Toaster Oven	< LOD	< LOD	< LOD	NA
	Micro-vacuum	Top of Toaster Oven	< AS	< AS	< AS	NA
B-1	Wet Wipe	Top of Water Heater – Basement	78182	39091	117273	Chrysotile
	Micro-vacuum	Top of Water Heater – Basement	87955	39091	127045	Chrysotile
B-2	Wet Wipe	Apartment TV Shelf	5864	1955	7818	Chrysotile
	Micro-vacuum	Apartment TV Shelf	< LOD	< LOD	< LOD	NA
S-1	Wet Wipe	Top of TV W. Bedroom	< AS	814	814	Chrysotile
	Micro-vacuum	Top of TV W. Bedroom	< LOD	< LOD	< LOD	NA
S-2	Wet Wipe	Top of Refrigerator	52121	11944	64066	Chrysotile
	Micro-vacuum	Top of Refrigerator	< LOD	< LOD	< LOD	NA
S-3	Wet Wipe	Top of Water heater	5864	3909	9773	Chrysotile
	Micro-vacuum	Top of Water heater	< LOD	< LOD	< LOD	NA
Sh-1	Wet Wipe	Top of Water heater	814	< AS	814	Chrysotile
	Micro-vacuum	Top of Water heater	< LOD	< LOD	< LOD	NA
GF-1	Wet Wipe	Basement Shelf	13682	8564	19545	Chrysotile
	Micro-vacuum	Basement Shelf	195455	< LOD	205227	Chrysotile
D-1	Wet Wipe	Top of Refrigerator	814	< AS	814	Chrysotile
	Micro-vacuum	Top of Refrigerator	< LOD	< LOD	< LOD	NA
SC-1	Wet Wipe	Top of Kitchen Cabinet	< AS	< AS	< AS	NA
	Micro-vacuum	Top of Kitchen Cabinet	< LOD	< LOD	< LOD	NA

< LOD = Below level of detection; < AS = Below analytical sensitivity of one asbestos structure in total area analyzed

10. Hypothesis Testing

The hypothesis that there will not be a greater number of detectable asbestos samples collected via surface wet wipe versus micro-vacuum techniques during baseline sampling rejects the null. The data collected from the baseline study supports the finding to reject the null. Wet wipe sampling method revealed detectable asbestos 55% of the samples, with 16% of the samples above 10,000 s/cm². When compared to the micro-vacuum sampling method which revealed detectable asbestos 17% of the samples, with 3% above the 10,000 s/cm².

The hypothesis that there will not be a greater number of detectable asbestos samples collected via side-by-side surface wet wipe versus micro-vacuum techniques collected during weatherization rejects the null. The data collected from the side-by-side surface wet wipe versus micro-vacuum sampling supports the finding to reject the null. Of the ten samples that revealed detectable asbestos, eight (80%) of the samples were wet wipe and two (20%) were micro-vacuum. Although, the micro-vacuum samples revealed slightly higher asbestos concentrations but no statistical difference was observed.

The hypothesis there will not be measurable concentrations of asbestos in surface dust post weatherization activities rejects the null. The data collected from the weatherization surface wet wipe sampling supports the finding to reject the null. Surface wet wipes did detect measureable amounts of asbestos in surface dust with thirty sample (14%) revealing detectable amounts and two (1%) above the 10,000 s/cm².

11. Conclusion

There are several recognized methods for assessing surface asbestos contamination. This study assessed the detection frequency of two of these surface sampling methods under two phases of a weatherization study.

The EPA recognizes ASTM methods D5755, Test Method for Micro-vacuum Sampling and Indirect Analysis of Dust by Transmission Electron Microscopy for Asbestos Structure Number Surface Loading and D5756, Test Method for Micro-vacuum Sampling and Indirect Analysis of Dust by Transmission Electron Microscopy for Asbestos Mass Surface Loading for surface sampling. The ultrasonic method is the official EPA method specific to carpet, and is preferred when feasible (method was not explored in this project).

Living space contamination was assessed through surface sampling methods, ASTM D5755 and ASTM D6480. While ASTM D5755 is recognized by the EPA, ASTM D6480 is not. Asbestos contamination was most commonly detected via surface sampling, specifically surface wet wipe sampling. Surface wet wipe sampling presented a greater sensitivity for detecting asbestos fibers in living spaces during baseline sampling then micro-vacuum sampling.

During the baseline portion of the study, samples were collected from horizontal surfaces in the living spaces of homes. It is difficult to assess how asbestos was dispersed on the surfaces and when this dispersion most likely occurred. The detection frequency was substantially higher with wet wipe sampling than micro-vacuum sampling during this phase of the study (55% vs 17%). Based on the results of the baseline portion of this study, surface wet wipe sampling techniques are more likely to detect asbestos contamination in living spaces than micro-vacuum techniques.

This hypothesis was strengthened by the results of the side-by-side surface wet wipe and micro-vacuum surface sampling conducted during the weatherization phase of the study. Comparing side-by-side surface wet wipe and micro-vacuum sampling methods, a total of 20 samples were collected with ten (50%) revealing detectable asbestos contamination. Eight of these ten samples (80%) were collected with wet wipe sampling and two samples (20%) were collected with through micro-vacuum sampling. The limitation of this study is the sample size.

Post weatherization surface wet wipe sample collection may not capture the presence or distribution of asbestos fibers due to the lack of settle time for asbestos fibers. Asbestos fibers have the potential to remain airborne for extended periods of time. At the end of weatherization activities, 216 surface wet wipe samples collected, excluding field blanks, from the thirty-seven homes. Asbestos structures were detected in thirty of the two hundred sixteen (14%) samples above the AS but below the surface background level of 10,000 s/cm². Only two (1%) surface samples revealed asbestos concentrations greater than the background level established. When comparing the sensitivity of wet wipe sampling to high volume air sampling, wet wipe sampling detected asbestos structures 14%, while high volume air sampling detected asbestos structures 21%. The higher detection of asbestos in air samples versus surface wet wipe samples during and immediately after the weatherization phase may be due to the settle time for asbestos fibers that may have been disturbed from the weatherization phase. Therefore, high volume air monitoring is recommended for post-weatherization clearance.

12. References Cited

Ashley, K. P. (2006). Beryllium Sampling and Analysis. Conshohocken, PA: American Society for Testing and Materials International.

Ashley K., Brisson M..White K. 2011. Review of Standards for Surface and Dermal Sampling. Journal of ASTM International, Vol. 8, No. 6. Paper ID JAI103678, Retrieved March 31, 2015, from ASTM International: http://www.astm.org,

American Society for Testing Materials Standards (ASTM) (2006). (American Society for Testing Materials Standards) "ASTM D6480-05 Standard Test Method for Wipe Sampling of Surfaces, Indirect Preparation, and Analysis for Asbestos Structure Number Concentrations by Transmission Electron Microscopy." Retrieved June 22, 2013, from ASTM International: http://www.astm.org

American Society for Testing Materials Standards (ASTM) (2007). (American Society for Testing Materials Standards) "ASTM D5755-03, Standard Test Method for Micro-Vacuum Sampling and Indirect Analysis of Dust by Transmission Electron Microscopy for Asbestos Structure Number Surface Loading." Retrieved June 22, 2013, from ASTM International: http://www.astm.org

American Society for Testing Materials Standards (ASTM) (2011). ASTM International. Retrieved March 6, 2015, from E1216-11, Standard Practice for Sampling for Particulate Contamination by Tape Lift: www.astm.org

American Society for Testing Materials Standards (ASTM) (2013) "ASTM D6966 Standard Practice for Collection of Settled Dust Samples Using Wipe Sampling Methods for Subsequent Determination of Metals." Retrieved from ASTM: www.astm.org

Atkinson GR, R. D. (1982). Collection, analysis, and characterization of vermiculite samples for fiber content and asbestos contamination. Prepared for EPA Office of Pesticide and Toxic Substances, Field Studies Branch by Midwest Research Institute. Washington DC: US Environmental Protection Agency.

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

Agency for Toxic Substances and Disease Registry (ATSDR) (2006). Cigarette Smoking, Asbestos Exposure, and Your Health. Retrieved from ATSDR: http://www.atsdr.cdc.gov/asbestos/site-kit/docs/CigarettesAsbestos2.pdf

Agency for Toxic Substances and Disease Registry (ATSDR) (2008). Health Effects - General Infomation. Retrieved July 21, 2014, from ATSDR: http://www.atsdr.cdc.gov/asbestos/asbestos/health_effects/

Agency for Toxic Substances and Disease Registry (ATSDR) (2008b). Summary Report: Exposure to Asbestos-Containing Vermiculite from Libby, Montana at 28 Processing Sites in the United States. U.S. Department of Health and Human Services Agency for Toxic Substances Disease Registry Division of Health Assessment and Consultation.

Agency for Toxic Substances and Disease Registry (ATSDR) (2008). What is Asbestos. Retrieved 24 July 2014, from Agency for Toxic Substances and Disease Registry: http://www.atsdr.cdc.gov/asbestos/more_about_asbestos/what_is_asbestos/#vermiculite

Bernstein D, Dunnigan J, Hesterberg T, Brown R, Velasco J, Barrera R, Hoskins J, Gibbs A. 2013. Health risk of chrysotile revisited. Critical Reviews in Toxicology Vol. 43, No. 2 , Pages 154-183 (doi:10.3109/10408444.2012.756454)

Besson P, Lalanne FX, Wang Y, and Guyot F. (1999). Multi-parameter observation of environmental asbestos pollution at the Institut de Physique du Globe de Paris. Jussieu Campus, France: Annals of Occupational Hygiene, 43:527-541.

Bull, S. (2007). Asbestos Toxicological Overview. Health Protection Agency. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/337513/HPA_ASBESTOS_toxicological_overview_v1.pdf

Castranova V, Driscoll K, Harkema J, Jarabek A, Morgan D, Nauss K, Olin S, Vallyathan VVV, Warheit D, Costa D. 2000. The relevance of the rat lung response to particle overload for human risk assessment: A workshop consensus report. Inhal Toxicol 12:1-17.

Chesson, J., Rench, J.D.., Schultz, B.D., and Milne, K.L. 1990. Interpretation of Airborne Asbestos Measurements. Risk Analysis, 10: 437-447. (DHHS/ATSDR) Libby Asbestos Site; ATSDR CERCLIS No. MT0009083840. (December, 2000)

DeMalo, R. (2004). In A Discussion of Asbestos Detection Techniques for Air and Soil. August 2004. Prepared by Anthony Perry National Network of Environmental Management Studies Fellow for U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response Office of Superfund Remediation and Technology Innovation Program Washington, DC. HYPERLINK "http://www.clu-in.org" www.clu-in.org

Dodson RF, Hammar SP. (2006). Asbestos: Risk assessment, epidemiology, and health effects. Taylor & Francis Group, LLC. Boca Raton, Florida.

Dodson RF, Atkinson MAL, and Levin, JL. (2003). Asbestos fiber length as related to potential pathogenicity: A critical review. Am. J. Ind. Med., 44: 291–297. doi: 10.1002/ajim.10263

Donaldson K, Murphy F, Duffin R, and Poland C. (2010). Asbestos, carbon nanotubes and the pleural mesothelium: a review of the hypothesis regarding the role of long fibre retention in the parietal pleura, inflammation and mesothelioma. Particle and Fibre Toxicology 7:5

Fowler DP, Chatfield DF (1997). Surface Sampling for Asbestos Risk Assessment. Ann. occup. Hyg., Vol. 41, Supplement 1, pp 279-286

Global Environmental and Technology Foundation (GETF). 2003. Asbestos strategies lessons learned about management and use of asbestos. Report of Findings and Recommendations on the Use and Management of Asbestos. HYPERLINK "http://www.mass.gov/anf/docs/dcam/mafma/manuals/asbestos-strategies-report.pdf%20(2" http://www.mass.gov/anf/docs/dcam/mafma/manuals/asbestos-strategies-report.pdf (2 March 2015)

Graham, A. (2008). Asbestos Identification and Quantification in Bulk Samples. The Environmental Reporter, Vol 6, Issue 12.

Gunter ME, Singleton E, Bandli BR, Lowers HA, Meeker GP, et al. (2005). Letter Differentiation of commerical vermiculite based on statistical analysis of bulk chemical data: Fingerprinting vermiculite from Libby, Montana U.S.A. American Minerlogist, 90:749-754.

HEI-AR. (1991). Asbestos in Public and Commerical Buildings: A Literature Review and Synthesis of Current Knowledge. Cambridge, MA: Health Effects Institute - Asbestos Research.

Hodgson, JT and Darnton, A (2000). The quantitative risks of mesothelioma and lung cancer in relation to asbestos exposure. Annals of Occupational Hygiene, 44:565-601.

Kane AB. 1992. Fiber dimensions and mesothelioma: a reappraisal of the Stanton Hypothesis. Mechanisms in Fibre Carcinogenesis. NATO ASI Series. 223:131-141

Karaffa MA, Amick RS, Crone A, and Zimmer C. (1987). Assessment of Assay Methods for Evaluating Asbestos Abatement Technology at the Corvallis Environmental Research Laboratory. EPA 600-S2-86-070.

Kauffer E, Billon-Galland MA, Vigneron JC, Veissiere S, and Brochard P. (1996). Effect of preparation methods on the assessment of airborne concentrations of asbestos fibres by transmission electron microscopy. Annals of Occupational Hygiene, 40:321-330

Kennedy ER, Fischbach TJ, Song R, Eller PM, & Shulman SA. (1995). Guidelines for Air Sampling and Analytical Method Development and Evaluation. Cincinnati: U.S. Department of Health and Human Services.

Kerr, K. (2004). Sampling Beryllium Surface Contamination Using Wet, Dry, and Alcohol Wipe Methods. Warrenburg, Missouri.

Kurunthachalam, S. K. (2013). Asbestos and Its Toxicological Concern. Hydrology Current Research, Volume 4: Issue 3.

Meeker GP, Bern AM, Brownfield IK, Lowers HA, Sutley SJ, Hoefen TM, Vance JS, et al. (2003). The composition and morphology of amphiboles from the Rainy Creek Complex, near Libby, Montana. American Mineralologist , 1955-1969.

Millette JR, Hays SM. (1994). Settled asbestos dust sampling and analysis. Boca Raton, Florida: Lewis Publishers.

Mossman BT, Bignon J, Corn M, Seaton A, & Gee JBL. (1990). Asbestos: Scientific Developments and Implications for Public Policy. Science, 247:294-301. National Institute for Occupational Safety and Health (NIOSH). Asbestos (bulk): Method 9002, Issue 2, dated 15 August 1994. NIOSH Manual of Analytical Methods (NMAM) 4th ed.

National Cancer Institute. (2009, May 1). Asbestos Exposure and Cancer Risk. Retrieved from National Cancer Institute at the National Instituties of Health: http://www.cancer.gov/cancertopics/factsheet/Risk/asbestos

National Institute for Occupational Safety and Health (NIOSH) (1994). NIOSH Manual of Analytical Methods: Lead in Surface Wipe Samples. Cincinnati, OH.

National Institute for Occupational Safety and Health (NIOSH). (1994B). Asbestos by TEM: 7402. Retrieved June 3, 2013, from NIOSH Manual of Analytical Methods (NMAN), Fouth Edition: http://www.cdc.gov/niosh/docs/2003-154/pdfs/7402.pdf

National Institute for Occupational Safety and Health (NIOSH). 1994C. Asbestos (bulk) by PLM: 9002. NIOSH Manual of Analytical Methods (NMAM) 4th ed. HYPERLINK "http://www.cdc.gov/niosh/docs/2003-154/pdfs/9002.pdf%20(18" http://www.cdc.gov/niosh/docs/2003-154/pdfs/9002.pdf (18 March 2015)

Occupational Safety and Health Administration (OSHA) (1994). United States Department of Labor. Retrieved March 6, 2015, from Toxic and Hazardous Subsances, Asbestos 1910.1001: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9995

Occupational Safety and Health (OSHA). (1995 revised). Polarized light microscopy of asbestos method ID-191. OSHA Manual of Analytical Methods. Occupational Safety and Health Administration. HYPERLINK "http://www.osha.gov/dts/sltc/methods/inorganic/id191/id191.html" http://www.osha.gov/dts/sltc/methods/inorganic/id191/id191.html

Occupational Safety and Health Administration (OSHA). 1997. Asbestos in Air. ID-160. www.osha.gov/dts/sltc/methods/inorganic/id160.html (27 April 2015). Occupational Safety and Health Administration (OSHA), Asbestos Permissible Exposure Limit, 29 Code of Regulations 1910.1001, 2001.

Palomaki J, Valimaki E, Sund J, Vippola M, Clausen P, Jensen K, Savolainen K, Matikainen S, and Alenius H. 2011. Long, Needle-like Carbon Nanotubes and Asbestos Activate the NLRP3 Inflammasome through a Similar Mechanism. American Chemical Society, 2011, 5(9), pp 6861-6870

Peipins L, Lewin M, Campolucci S, Lybarger J, Miller A, Middleton D, et al. (2003). Radiographic Abnormalities and Exposure to Asbestos-Contaminated Vermiculite in the Community of Libby, Montana, USA. Environ Health Perspect.

Ryan G, Buchan R, Keefe T, McCammon C. (1997). An Evaluation of the Adhesive Tape Sampling Method for Estimating Surface Asbestos Concentrations, Applied Occupational and Environmental Hygiene, 12:4, 288-292.

Spear, T. M., Hart, J. F., Spear, T. E., Loushin, M. M., Shaw, N. N., & Elashhab, M. I. (2012). The Presence of Asbestos - Contaminated Vermiculite Attic Insulation or Other Asbestos-Containing Materials in Homes and the Potential for Living Space Contamination. *Journal of Environmental Health*, 24-29.

Stanton MF, Layard M, Tegeris A, et al. 1981. Relation of particle dimension to carcinogenicity in amphibole asbestoses and other fibrous minerals. J Natl Cancer Inst 67(5): 965-975

Sullivan, P. A. (2007). Vermiculite, Respiratory Disease, and Asbestos Exposure in Libby, Montana: Update of a Cohort Mortality Study. Environ Health Perspect.

United States Environmental Protection Agency (USEPA) (1989). 40 CFR Part 763. Fed. Reg., 54, 29507.

United States Environmental Protection Agency (USEPA) (2000). Asbestos Laws and Regulations. Retrieved from United States Environmental Protection Agency: http://www.gpo.gov/fdsys/pkg/CFR-2011-title40-vol8/pdf/CFR-2011-title40-vol8-part61-subpartM.pdf

United States Environmental Protection Agency (USEPA) (2002). United States Environmental Protection Agency. Retrieved June 5, 2013, from Testing Carpet, The Asbestos Reservoir: http://old.911digitalarchive.org/objects/109.pdf

United States Environmental Protection Agency (USEPA) (2011). Toxicological Review of Libby Amphibole Asbestos. Washington, DC: U.S. Environmental Protection Agency.

United States Environmental Protection Agency (USEPA) (2014). Additional frequent questions on vermiculite. Retrieved October 6, 2014, from U.S. Environmental Protection Agency: http://www2.epa.gov/region8/background-libby-asbestos-site

United States Environmental Protection Agency (USEPA) (2013). U.S. Environmental Protection Agency. Retrieved June 1, 2013, from Learn About Asbestos: http://www2.epa.gov/asbestos/learn-about-asbestos#asbestos

Unitied States Environmental Protection Agency (USEPA) (1987). 40 CFT Part 763. Fed. Reg., 52:41826-41905

Verma, D.K., and Clark, N.E. 1995. Relationships between Phase Contrast Microscopy and Transmission Electron Microscopy Results of Samples from Occupational Exposure to Airborne Chrysotile Asbestos. American Industrial Hygiene Association Journal, 56: 866873.

Zalac, F. (2003, February 7). Deadly dust. Retrieved March 6, 2015, from The National, CBC News: http://www.sterlingiaq.com/photos/1049134528.pdf

SIGNATURE SHEET

This is to certify that the thesis prepared by Natalie Shaw entitled "Comparison of Wet Wipe vs Micro-Vacuum Sampling Techniques for Determining Concentrations of Asbestos in Surface Dust" has been examined and approved for acceptance by the Department of Safety and Health, and Industrial Hygiene, Montana Tech of the University of Montana, Butte, Montana on the first day of May, 2015.

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