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Research and Evaluation Concepts in Support of Asbestos Detection During Wildfire Operations – A Review

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Abstract *- An approach to research, recommend and evaluate alternative architectures and technologies in support of enhanced monitoring and response operations associated with the Libby, Montana Superfund Site and other high hazard wildland fire environments is presented.*

Key Words*:* *Asbestos, Sensors, Wildfires,*

1. INTRODUCTION

Libby, Montana (USA) is the site of a large vermiculite deposit that was mined between 1920 and 1990 to extract vermiculite for commercial applications such as insulation, gardening products, and construction materials. The Libby vermiculite deposit also contains amphibole minerals including tremolite, actinolite, richterite, and winchite.

Historically, Libby mine workers experienced high exposures to amphibole structures, and, as a group, have experienced the health consequences of those occupational exposures. It has been suggested that Libby residents also have been and continue to be exposed to amphibole structures released during the vermiculite mining operations and therefore are at increased risk for disease.

The Agency for Toxic Substance and Disease Registry (ATSDR) conducted two epidemiological-type studies of residents living in Libby and the surrounding areas to assess these risks. The Environmental Protection Agency (EPA) collected and analyzed exposure data in Libby and used those data to project risks of asbestos-associated disease for Libby residents.

The EPA has placed the Libby Asbestos Site, which includes the mine and the town of Libby, on its National Priority List of hazardous waste sites in need of clean up. Established by Congress in 1980, the Superfund Program governs the investigation and cleanup of the nation's most complex hazardous waste sites in order to convert those sites into community resources.

The National Priorities List (NPL) came into existence in 1983. It includes those sites that are of national priority among the known releases or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States. Each year, sites are listed and delisted based on criteria in EPA's regulations. As of June 21, 2017, there are 1,336 sites on the NPL, of which 1,179 are privately owned sites and 157 are federal facilities [1]. Figure 1 provides a U.S. Forest Service map of the region including the former W.R. Grace Vermiculite mine.

Figure 1. US Forest Service Map of Operable Unit 3 (OU3)
Libby Ranger District with W.R. Grace Boundary

2. Background

The challenges associated with the Libby, Montana site are persistent and recurring. As late as July of 2018 a forest fire burning near the site of Libby's now-closed vermiculite mine was fought by a crew outfitted with specialized respirators. Kootenai has a 10-person contract crew trained to work in the operating unit, and a "Modified Fire Response Zone" with specialized procedures around the unit. The Chloeta crew, a 10-person team out of Oklahoma, is contracted to suppress fire starts in and around Libby's modified response zone.

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The so-called Highway 37 fire was believed to have been human-caused. It measured 40 acres to 60 acres and was about 1 mile to 1.5 miles west of the Libby Superfund site's Operable Unit 3, a 35,000-acre forested zone where W.R. Grace mined asbestos-contaminated vermiculite for decades. Asbestos still lingers in Operable Unit 3's trees and soil. Research shows that when this material burns, the majority of asbestos fibers stay in the ash rather than go airborne. But the fibers' direction and impact can be difficult to predict, especially in a large fire, according to Jennifer McCully, public information officer for the Lincoln County (MT) Emergency Management Agency [2].

The presence of toxic substances heightens the already-major challenges of fighting wildfires. Protocols in that [modified response] area are such that if people are engaged in direct fire line construction (e.g., performing ground-disturbing acts) they wear the powered air purifying respirator, or PAPR. These devices, when fitted with asbestos-filtering cartridges, can remove almost all harmful particulate matter. After egress from the hazardous area, firefighters take steps to prevent contamination from their gear. Operable Unit 3's firefighters either dispose of their gear after an incident, or reserve it for exclusive use there. Vehicles, tools and machinery get decontaminated for return to serviceable status.

Jake Jeresek, a fire management officer on the Flathead National Forest, heads up the decontamination effort for the OU3 responders [3]. Anything that goes in needs be cleaned: the firefighters' bodies, their face masks, hand tools, cell phones, and clothes – even dollar bills in their wallets need to undergo three rinses or get thrown away as hazardous waste. Jeresek says "that for now, only the firefighters and a few pieces of hand equipment go through the full cleanup (i.e., hose, pumps, chainsaws). Bigger equipment stays in the dirty zone". It reportedly takes three to four hours to decontaminate the firefighters. After the fire is contained, attention is turned to larger equipment, such as skidgeons (i.e., a cross between a bulldozer and a fire engine) and trucks.

3. Asbestos: Details and Detection

"Asbestos" is a generic term for a number of hydrated silicates that, when crushed or processed, separate into flexible fibers made up of fibrils. Although there are many asbestos minerals, typically only six are of commercial importance: Chrysolite, a tubular serpentine mineral, accounts for 95% of the world's production; the others, all amphiboles, are amosite, crocidolite, anthophyllite, tremolite, and actinolite. The asbestos minerals differ in their metallic elemental content, range of fiber diameters, flexibility or harshness, tensile strength, surface properties, and other attributes. It is these attributes that determine their industrial applicability and may affect their respirability, deposition, retention, translocation, and biological reactivity.

The effects of fibers in humans may result not only from the properties of the fibers themselves, but also from contamination with inorganic or organic substances that occur naturally or are added during mining, milling, processing, shipping or use. Contaminants acquired from the atmosphere or in the respiratory tract may be carried on the surface of fibers. The proven or suspected effects of asbestos minerals on human health include nonmalignant changes, such as pulmonary and plural fibrosis and several types of malignancy, notably of the lung, pleura, and peritoneum.

- Because of its fiber strength and heat resistance asbestos has been used in a variety of building construction materials for insulation and as a fire retardant. Asbestos has also been used in a wide range of manufactured goods, mostly in building materials (roofing shingles, ceiling and floor tiles, paper products, and asbestos cement products), friction products (automobile clutch, brake, and transmission parts), heat-resistant fabrics, packaging, gaskets, and coatings.
- Exposure to asbestos increases your risk of developing lung disease. That risk is made worse by smoking. In general, the greater the exposure to asbestos, the greater the chance of developing harmful health effects. Disease symptoms may take many years to develop following exposure.

In early National Research Council reporting on asbestos and human health, it was concluded that all epidemiologic studies that appear to indicate differences in pathogenicity among types of asbestos are flawed by their lack of quantitative data on cumulative exposures, fiber characteristics, and the presence of cofactors.

Further, the Agency for Toxic Substances and Disease Registry (ATSDR [6]) reports that:

- Disturbing asbestos minerals or other asbestos-containing materials can release tiny asbestos fibers, too small to see, into the air.
- Asbestos occurs naturally in certain types of rock. Large amounts of asbestos in rocks can look like long fibers, but each asbestos fiber is too small to see with the naked eye. Asbestos fibers do not dissolve in water or

evaporate. They resist heat and fire and cannot be broken down easily by chemicals or bacteria.

- Beginning in the 1970s, the United States banned many uses of asbestos, but asbestos is still present in old materials and is still used in products such as automobile brakes and roofing materials. Asbestos may also be present in other commercial products, such as vermiculite (especially vermiculite from Libby, Montana) and talc.
- The legal definition of asbestos applies to six fibrous minerals in two general classes:
- Serpentine class: chrysotile (also known as white asbestos)
- Amphibole class: amosite (brown asbestos), crocidolite (blue asbestos), anthophyllite, tremolite, and actinolite.
- Exposure to either chrysotile or amphibole asbestos increases the risk of disease. However, amphiboles remain in the lung for a longer period of time. Exposure to amphiboles may result in a higher risk of developing mesothelioma than exposure to chrysotile.
- Asbestos fibers usually get into the air when something disturbs them in soil, rock, or older products, such as
- Weathering or erosion of natural deposits of asbestos at the ground surface or old asbestos-containing products
- Crushing rock with natural deposits of asbestos
- Handling, cutting, or crushing old asbestos-containing products, for example, during building renovation or demolition projects
- Disturbing soil contaminated by natural surface deposits or old asbestos-containing products during recreational or other outdoor activities.
- Handling or disturbing consumer products contaminated with asbestos (such as vermiculite or talc)
- Gardening in soil contaminated by asbestos from natural deposits or commercial products
- Cleaning or other household activities that might stir up dust containing asbestos from natural deposits or products
- The amount of asbestos that gets into the air people breathe depends on many factors, including
    - the location,
    - the type of material or soil the asbestos is in,
    - the age and characteristics of that material,
    - weather conditions and moisture, and
    - the intensity of the activity disturbing the asbestos.

3.1 Detection Methods

Currently, the most common way to identify hazardous airborne asbestos is to filter the air, count the number of fibers that are caught, and later analyze the fibers with X-ray technology to determine if they are asbestos. This approach requires expensive lab work and hours of wait time. An alternative method to evaluate work site safety is to use a real-time fiber detector, but the current, commercially available detectors are unable to distinguish between asbestos and other less dangerous fibers such as mineral wool, gypsum and glass.

A direct method of obtaining evidence on the likelihood of exposure of the general population would be the sampling of air to determine the presence and amount of respirable asbestos fibers. There have been many uncertainties as to the best methods of sampling, identifying, and quantitating airborne asbestos and interpreting data related thereto.

With respect to mining and milling of asbestos, fibers are emitted during removal of overburden and preparation of the ore body for open-pit mining. Further release occurs during drilling and ore-breaking. Waste dumps from mining and milling are exposed to wind and to disturbance by bulldozing. Fibers are emitted during drying, crushing, grinding, and screening of the ore.

Open source research suggests that present methods of sampling, identifying, and measuring airborne asbestos are not entirely satisfactory, especially when dealing with low concentrations and unidentified or mixed sources. Traditional laboratory confirmation techniques are time consuming and impractical for field operations where human health and safety decisions need to be made in the scale of minutes or hours, not days and weeks. Confirmatory electron microscopy is tedious and expensive and is not practical in any manner for US Forest Service wildland firefighting operations.

Fibers may be counted with either phase-contrast microscopy (PCM) or transmission electron microscopy (TEM). Of the two, TEM is the more sensitive and may measure higher concentrations in the same environment than PCM, because PCM may miss very thin fibers. In addition, PCM may fail to distinguish asbestos from other types of fibers. However, workplace exposures are generally measured with PCM, which is less expensive and considered adequate by regulatory agencies. Conversion between different measures of airborne units is problematic because conversion factors vary with the distribution of fiber thickness and length in the environment of interest.

Consideration needs to be given to the different measurement methods used when interpreting and comparing the reported levels of airborne exposure in various settings. Historically, airborne asbestos in workplaces was measured with a midget impinger to collect the fibers, a standard occupational hygiene method, and concentrations were expressed as millions of particles per cubic foot (mppcf). More recently, airborne fibers have been collected on membrane filters, and concentration has been reported in terms of either mass (such as nanograms per cubic meter, ng/m3) or number of fibers (such as fibers per milliliter, f/ml). The latter measure is most commonly used. In water, concentrations may be expressed in terms of fibers per liter. In a given measurement system, fibers may qualify for counting on the basis of criteria such as length (for instance, over 5 µm) or aspect (length:diameter) ratio (for instance, over 3:1), characteristics also relevant to their potential to cause health effects.

There are a number of techniques used in the measuring of asbestos content in other materials. For air samples, fiber quantification is traditionally done through PCM by counting fibers longer than 5 µm and with an aspect ratio (length: width) greater than 3:1. This is the standard method by which regulatory limits were developed. Disadvantages of this method include the inability to detect fibers thinner than 0.25 µm in diameter and the inability to distinguish between asbestos and nonasbestos fibers.

Asbestos content in soil and bulk material samples is commonly determined using polarized light microscopy (PLM), a method which uses polarized light to compare refractive indices of minerals and can distinguish between asbestos and nonasbestos fibers and between different types of asbestos. The PLM method can detect fibers with lengths greater than ~1 µm, widths greater than ~0.25 µm, and aspect ratios (length to width ratios) of greater than 3. Detection limits for PLM methods are typically 0.25-1% asbestos.

Scanning electron microscopy (SEM) and, more commonly, transmission electron microscopy (TEM) are more sensitive methods and can detect smaller fibers than light microscopic techniques. TEM allows the use of electron diffraction and energy-dispersive x-ray methods, which give information on crystal structure and elemental composition, respectively. This information can be used to determine the elemental composition of the visualized fibers. SEM does not allow measurement of electron diffraction patterns. One disadvantage of electron microscopic methods is that it is difficult to determine asbestos concentration in soils and other bulk materials. For risk assessment purposes, TEM measurements are sometimes multiplied by conversion factors to give PCM equivalent fiber concentrations. The correlation between PCM fiber counts and TEM mass measurements is very poor. A conversion between TEM mass and PCM fiber count of 30 micrograms per cubic meter per fiber per cubic centimeter (µg/m3)/(f/cc) was adopted as a conversion factor, but this value is highly uncertain since it represents an average of conversions ranging from 5 to 150 (µg/m3)/(f/cc). The correlation between PCM fiber counts and TEM fiber counts is also very uncertain, and no generally applicable conversion factor exists for these two measurements. Generally, a combination of PCM and TEM is used to describe the fiber population in a particular sample. Research into light scattering of airborne particles pioneered by the University of Hertfordshire (UH) in the late-1990s showed that when a particle is illuminated with a beam of light, it will scatter the light in a pattern dependent on the particle's size, shape, and structure. This scatter structure 'fingerprint' can be used to identify the particle shape, allowing fibers to be detected in the presence of other non-fibrous particles.

However, in order to discriminate between harmful asbestos fibers and other non-asbestos fibers, another step is required. The UH researchers developed this step by exploiting the unique magnetic properties of asbestos which cause it to be rotated in a magnetic field. They were able to measure this rotation in laboratory tests - the first step to a real-time warning device product. Despite this success, the cost of implementing the technology and overcoming the remaining technical challenges was, at that time, too high to make it commercially viable. So it sat on a shelf.

3.2. Detection via Dosimetry

For inhaled contaminants, such as asbestos fibers, concepts of exposure and dose have been developed for the respiratory system. Asbestos fibers are particulate matter that is distinguished from other particles present in air by having a length substantially greater than their width. Aspect ratio is the term used for the ratio of length to width. The Occupational Safety and Health Administration (OSHA) defines a fiber as having a length of at least 5 micrometers and an aspect ratio of 3:1, whereas EPA defines a fiber as having an aspect ratio of over 5:1. Airborne particles are generally characterized by their aerodynamic diameter, which is determined in reference to the behavior of a sphere of unit density; the aerodynamic diameter corresponds to the size of a unit-density sphere with the same aerodynamic characteristics as the particle of interest. In considering the potential risk posed by inhaled pollutants, including fibers, the critical determinant of injury is the amount of material that reaches the target site—a measure generally referred to as the biologically effective dose. As depicted in Figure 1, dose, without qualification, generally refers to the amount of material that enters the body; exposure refers to the amount of contact with material, with units expressed as concentration multiplied by time. For the respiratory system, models have been developed that relate dose to exposure for inhaled particles; the models are useful in characterizing the chain that begins with the source of an inhaled pollutant and terminates with injury to target tissues. The exposure and dose-response paradigm in toxicology is depicted in Figure 2.

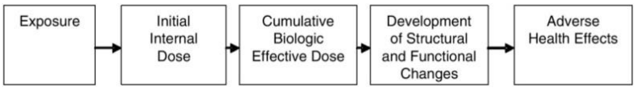

Figure 2 Exposure and dose-response paradigm in toxicology.

Various processes remove particles that are deposited in the lung in ways that depend on their size, physicochemical characteristics, and site of deposition. Particles that reach the upper airways will generally be removed as mucus is swept toward the nostrils or into the pharynx for passage through the esophagus and the gastrointestinal tract. Particles reaching the bronchi are cleared by the mucociliary apparatus, which moves mucus toward the trachea, where it exits and is swallowed. Particles that reach the smaller airways are gradually scavenged by the lung's macrophages; their fate depends on their toxicity to the macrophages. Particles may also penetrate the respiratory epithelium and remain in the airways or migrate to bronchopulmonary lymph nodes. Fibers that are not removed rapidly by the mucociliary escalator may penetrate into the interstitium of the alveolar walls, be cleared by lymphatic channels, or migrate to the pleura and other extra pulmonary sites. Fibers that are not effectively cleared from the lung may be removed by physicochemical processes, including leaching of ions, dissolution, and breakage [7].

Asbestosis was first diagnosed in a worker in 1924, when Nellie Kershaw died at thirty-three years old after handling the substance for twenty years. Her death would lead to the publication of the first Asbestos Industry Regulations in 1931. OSHA has set a permissible asbestos exposure limit (PEL) of 0.1 fiber per cubic centimeter (f/cc) for work in all industries, including construction, shipyards, and asbestos abatement work. This standard has also been adopted by the Environmental Protection Agency. OSHA is quick to add, however, that the asbestos PEL is a target guideline for regulatory purposes only, and does not establish any level of "safe" asbestos exposure. As OSHA writes in its Asbestos Final Rule: "The 0.1 f/cc level leaves a remaining significant risk." [8]

ATSDR, responding to concerns about asbestos fiber toxicity from the World Trade Center disaster, held an expert panel meeting in December 2002 to review fiber size and its role in fiber toxicity [9]. The panel concluded that fiber length plays an important role in toxicity. Fibers with lengths less than 5 μm are essentially nontoxic when considering a role in mesothelioma or lung cancer promotion. However, fibers less than 5 μm in length may play a role in asbestosis when exposure duration is long and fiber concentrations are high. It was concluded that more information is needed to definitively make this conclusion.

In industrial applications, asbestos-containing materials are defined as any material with greater than 1% bulk concentration of asbestos [10]. It is important to note that 1% is not a health-based level, but instead represents the practical detection limit in the 1970s when OSHA regulations were created. Studies have shown that disturbing soils containing less than 1% amphibole asbestos can suspend fibers at levels of health concern [11].

In response to the World Trade Center disaster in 2001 and an immediate concern about asbestos levels in homes in the area, the US Department of Health and Human Services, EPA and the US Department of Labor formed the Environmental Assessment Working Group. This work group was made up of ATSDR, US Environmental Protection Agency, US National Institute of Occupational Safety and Health, US CDC National Center for Environmental Health, Occupational Safety and Health Administration, New York City Department of Health and Mental Hygiene, the New York State Department of Health, and other state, local, and private entities. The workgroup set a re-occupation level of 0.01 f/cc after cleanup. Continued monitoring was also recommended to limit long-term exposure to this level [12].

EPA has calculated an inhalation unit risk for cancer (cancer slope factor) of 0.23 per f/cc of asbestos [13]. This value estimates additive risk of lung cancer and mesothelioma using a relative risk model for lung cancer and an absolute risk model for mesothelioma. This quantitative risk model has significant limitations. First, the unit risks were based on measurements with phase contrast microscopy and therefore cannot be applied directly to measurements made with other analytical techniques. Second, the unit risk should not be used if the air concentration exceeds 0.04 f/cc, since above this concentration the slope factor might differ from that stated. Perhaps the most significant limitation is that the model does not consider mineralogy, fiber size distribution, or other physical aspects of asbestos toxicity.

The National Institute of Occupational Safety and Health (NIOSH) set a recommended exposure limit of 0.1 f/cc for asbestos fibers longer than 5 μm. This limit is a TWA for up to a 10-hour workday in a 40-hour work week [14]. The American Conference of Government Industrial Hygienists (ACGIH) has also adopted a TWA of 0.1 f/cc as its threshold limit value. EPA has set a maximum contaminant level (MCL) for asbestos fibers in water of 7,000,000 fibers longer than 10 μm per liter, based on an increased risk of developing benign intestinal polyps. Many states, including Colorado, use the same value as a human health water quality standard for surface water and groundwater.

Asbestos is a known human carcinogen. Historically, EPA has calculated an inhalation unit risk for cancer (cancer slope factor) of 0.23 per f/cc of asbestos. This value estimates additive risk of lung cancer and mesothelioma using a relative risk model for lung cancer and an absolute risk model for mesothelioma. This quantitative risk model has significant limitations. First, the unit risks were based on measurements with phase contrast microscopy and therefore cannot be applied directly to measurements made with other analytical techniques. Second, the unit risk should not be used if the air concentration exceeds 0.04f/cc, since above this concentration the slope factor might differ from that stated.

Occupational (past and present) – records generated by W.R. Grace indicate that workers were exposed to high levels of Libby asbestos in the air at the plant. Time-weighted averages (TWAs) for employees from the years 1975 to 1981 (found from Grace internal records) showed TWAs ranging from 0.02f/cc to 2.37 f/cc. Most of the TWAs are higher than the current OSHA limit of 0.1f/cc (although it should be noted that OSHA limits were higher at the time of sampling). In addition, records exist of very high fiber counts (>30 f/cc) in the furnace feed room, a room workers had to pass through on their way to work or to the locker rooms.

Recent EPA-led studies have addressed the comparative toxicity and pathological mechanisms of environmental asbestos samples from Libby, Montana and other communities in the United States. Longer amosite fibers induce a 4-10 fold greater induction of pro-inflammatory mediators COX-2 and HO-1 than Libby fibers in human airway epithelial cells, as well as a number of other genes involved in cellular stress and toxicity. Similarly, equal mass doses of longer amosite fibers administered intratracheally to F344 rats cause greater pathological effects than Libby fibers, from 1 day to 2 years post-exposure. However, both intratracheal and inhalation studies show comparable effects of Libby fibers and shorter UICC amosite fibers. Dosimetry modeling and potency analysis studies are using these data to predict effects in humans.

Libby fibers induce an acute phase response and systemic increases in selected markers of inflammation, and induce components of the NALP-3 inflammasome in the lung, while surface complexed iron inhibits these responses. Libby fibers alter genes involved in inflammation, immune regulation, and cell-cycle control, and also induce autoimmune responses in a rat model. Comparative toxicity studies showed that chrysotile fibers from Sumas Mountain, Washington caused greater lung interstitial fibrosis than Libby fibers, which were significantly more potent than tremolite fibers from El Dorado, California and actinolite “cleavage fragments” from Ontario, Canada. These data are improving the scientific basis for the risk assessment of asbestos-contaminated communities, defining key determinants of internal dose, and providing critical insight on additional key health or pathologic endpoints. The research continues.

4. Research on Sensor Characteristics

For several decades remote sensing has earned a place as an increasingly important science for advancing understanding of environmental processes, conditions, and changes for both human and ecological health. Major advancements in sensor technology and processing algorithms have resulted in technical capabilities that can record and identify earth surface materials based on the interaction of electromagnetic energy with the molecular structure of the material being sensed.

Hyperspectral remote sensing records reflected and emitted electromagnetic energy in hundreds of very narrow wavelengths. This results in data for a particular location that can be analyzed with the same spectroscopic techniques that have been used by chemists and astronomers for over a century. Spectral reflectance of vegetation and other landscape conditions has received renewed interest by the remote sensing community during the past decade because of the development of this new class of imaging technology. Many of the early and definitive studies in spectral reflectance utilized spectroscopic measurement instruments in a laboratory setting. These instruments measured reflected energy and produced spectra that could be analyzed using standard spectral analysis techniques.

Spectroscopic analysis techniques can be employed outside of the laboratory through the use of hyperspectral remote sensing-imaging techniques and portable field spectroradiometer. The geospatial collection of coregistered hyperspectral imagery in very narrow bandwidths across the solar-reflected part of the electromagnetic spectrum (from 400 to 2,500 nm) results in what is often called an “image cube”.

After processing, the image cube represents an imagery version of the same energy and matter interactions measured in the laboratory. The image cube can be analyzed with a variety of standard and emerging statistical methods in spectroscopy, signal processing, and remote sensing. Reflectance spectra can be used to identify certain compounds, materials, and their conditions based on the interaction of photons of light with the molecular structure of the target material.

Reflectance of the surface of a material is its effectiveness in reflecting radiant energy. It is the fraction of incident electromagnetic power that is reflected at an interface. The reflectance spectrum or spectral reflectance curve is the plot of the reflectance as a function of wavelength. The spectral reflectance of any surface is measured with the help of a testing instrument called spectrophotometer. The spectrophotometer is used for sending a cluster of electromagnetic radiation to a sample and then measures its spectral reflectance by measuring the amount of radiation reflected by the surface. Figure 3 depicts the spectrum profile of the Libby Amphibole GDS591 material.

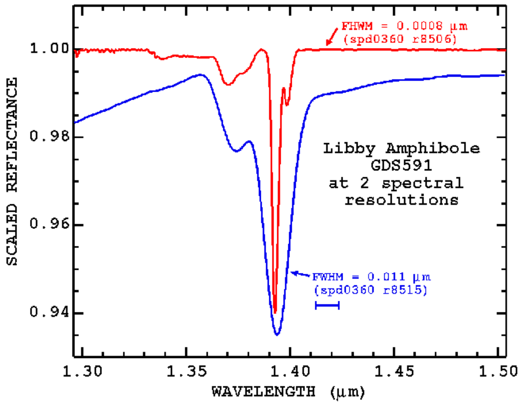

Figure 3. Spectrum Profile – Libby Amphibole GDS591

Mid-infrared (MIR) and near-infrared (NIR) spectroscopic methods have been applied to the analysis of fibrous (asbestos) and non-fibrous forms of serpentine and amphibole minerals. In the paper "Vibrational spectroscopic studies of asbestos and comparison of suitability for remote analysis" Lewis et al. describe the first application of NIR diffuse reflectance spectroscopy to the study of asbestos minerals. Improvements in spectral quality over previously published MIR spectroscopic data indicate the NIR diffuse reflectance spectroscopy appears to be the preferred method for the remote analysis of asbestos. This may be due to the relatively simple spectra in the wavenumber range 7400-6900 cm−1, the highsignal-to-noise ratio and spectral contrast of the spectra, the capability of using silica fiber optic cables, and the time required to perform the analysis relative to the other vibrational spectroscopic techniques.

5. Summary

This review has presented the past, present and envisioned future alert and warning technologies and associated information management architecture in use by USFS and the interagency partners to determine options for effective use of newly acquired asbestos monitoring data for local or regional information sharing.

While tailored for the OU3 area in northwest Montana, the project outcomes are relevant to fire-prone areas throughout the world. The benefits and best practices of sharing near real-time reports of airborne asbestos concentrations with state and local jurisdictions in both normal and in active fire states will be reviewed and a concept of operations for the alert and warning information management capability should be documented.

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