Data Summary Report:
Wood-burning Stove Ash Removal
Activity-Based Sampling

Libby Asbestos Superfund Site, Operable Unit 4
Libby, Montana

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Libby, Montana

Approvals:

Date: 8/22/13

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List of Acronyms and Abbreviations

%	percent
µm	micrometers
ABS	activity-based sampling
AHERA	Asbestos Hazard Emergency Response Act
CB&I	CB&I Federal Services, LLC
cc^{-1}	per cubic centimeter
CDM Smith	CDM Federal Programs Corporation
CH	chrysotile
CHISQ	Chi-square
cm	centimeter
cm^{-2}	per square centimeter
cm^2	square centimeters
DQA	data quality assessment
EDD	electronic data deliverable
EDS	energy dispersive spectroscopy
EPA	U.S. Environmental Protection Agency
ESAT	Environmental Services Assistance Team
FSDS	field sample data sheet
g	gram
g^{-1}	per gram (dry weight)
HV	high volume
ID	identification
IDW	investigation-derived waste
ISO	International Organization of Standardization
L	liter
L^{-1}	per liter
L/min	liters per minute
LA	Libby amphibole
LV	low volume
MCE	mixed cellulose ester
mL	milliliter
mm	millimeter
mm^2	square millimeters
Ms/cm^2	million structures per square centimeter of tree bark
Ms/g	million structures per gram of ash
NAM	non-asbestos material
NFG	National Functional Guidelines
NIOSH	National Institute for Occupational Safety and Health
NVLAP	National Voluntary Laboratory Accreditation Program
OA	other amphibole asbestos fibers
OU3	Operable Unit 3

OU4	Operable Unit 4
PCM	phase contrast microscopy
PCME	phase contrast microscopy-equivalent
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
QATS	Quality Assurance Technical Support
QC	quality control
ROM	record of modification
s/cc	structures per cubic centimeter of air
SAED	selected area electron diffraction
SAP	sampling and analysis plan
Site	Libby Asbestos Superfund Site
SOP	standard operating procedure
TEM	transmission electron microscopy

1 INTRODUCTION

1.1 Site Background

Libby is a community in northwestern Montana located 7 miles southwest of a vermiculite mine that operated from the 1920s until 1990. The mine began limited operations in the 1920s and was operated on a larger scale by the W.R. Grace Company from approximately 1963 to 1990. Studies revealed that the vermiculite from the mine contains amphibole-type asbestos, referred to as Libby amphibole (LA).

Epidemiological studies revealed that workers at the mine had an increased risk of developing asbestos-related lung disease (McDonald *et al.* 1986, 2004; Amandus and Wheeler 1987; Amandus *et al.* 1987; Whitehouse 2004; Sullivan 2007). Additionally, radiographic abnormalities were observed in 17.8 percent (%) of the general population of Libby including former workers, family members of workers, and individuals with no specific pathway of exposure (Peipins *et al.* 2003; Whitehouse *et al.* 2008; Antao *et al.* 2012; Larson *et al.* 2010, 2012a, 2012b). Although the mine has ceased operations, historic or continuing releases of LA from mine-related materials could be serving as a source of ongoing exposure and risk to current and future residents and workers in the area. The Libby Asbestos Superfund Site (Site) was listed on the U.S. Environmental Protection Agency (EPA) National Priorities List in October 2002.

1.2 Document Purpose

Previous investigations conducted at the Site have demonstrated that LA is present in environmental source media (e.g., soil, tree bark, duff material) at locations in and around the Site. However, asbestos fibers in source materials are typically not inherently hazardous, unless the asbestos is released from the source material into air where it can be inhaled (EPA 2008). If inhaled, asbestos fibers can increase the risk of developing lung cancer, mesothelioma, pleural fibrosis, and asbestosis. Thus, the evaluation of risks to humans from exposure to asbestos is most reliably achieved by the collection of data on the level of asbestos in breathing zone air during disturbance of asbestos source materials, referred to as "activity-based sampling" (ABS) (EPA 2008).

LA structures have been detected on the bark of trees located on the former mine site northeast of Libby and in surrounding areas within the Libby Valley. Trial burn experiments in wood stoves (Ward *et al.* 2009) and in test burn chambers (EPA 2012a) indicate that the majority of LA structures are retained in the ash when wood and duff materials are burned under experimental conditions. If contaminated firewood is burned in a residential wood stove, the removal of the resulting ash from the wood stove is a potential exposure scenario. Hence, data are required to assess whether residents in Libby would be exposed to unacceptable levels of airborne LA while removing ash generated from burning contaminated wood in residential wood-burning stoves.

In 2012, EPA conducted an ABS investigation designed to collect air samples during simulated activities that mimic potential exposures to airborne LA during the removal of ash from a wood-burning stove. The purpose of this document is to summarize the results from this study and provide an interpretation of the collected data.

1.3 Document Organization

In addition to this introduction, this report is organized into the following sections:

Section 2 This section summarizes data management procedures, including sample collection, documentation, handling, custody, and data management.

Section 3 This section summarizes the design of the study, and describes the data that were collected in this study, the analytical methods used for estimating the level of LA in various collected media, as well as the data reduction methods utilized in this report.

Section 4 This section summarizes the results for data that were collected as part of this study, including an evaluation of the levels of LA in each media type.

Section 5 This section presents the results of the data quality assessment, including a summary of program audits, modifications, data verification efforts, an evaluation of quality control samples, and a data adequacy assessment.

Section 6 This section provides full citations for all analytical methods, site-related documents, and scientific publications referenced in this document.

All referenced tables and figures are provided at the end of this document. All referenced appendices are provided electronically.

2 DATA MANAGEMENT

2.1 Sample Collection, Documentation, Handling, and Custody

All samples generated as part of this investigation were collected, documented, and handled in accordance with Libby-specific standard operating procedures (SOPs), as specified in the governing sampling and analysis plan/quality assurance project plan (SAP/QAPP), *Wood-Burning Stove Ash Removal Activity-Based Sampling, Libby Asbestos Site, Operable Unit 4* (CDM Smith 2012a).

All samples collected were identified with unique sample identification (ID) numbers that included a program-specific prefix of "WA" (e.g., WA-00001). Data on the sample type, location, collection method, and collection date of all samples were recorded both in a field logbook maintained by the field sampling team and on a field sample data sheet (FSDS) designed to facilitate data entry into the Libby site database (see below). All samples collected in the field were maintained under chain of custody during sample handling, preparation, shipment, and analysis.

2.2 Analytical Results Recording

Standardized data entry spreadsheets (electronic data deliverables, or EDDs) have been developed specifically for the Libby project to ensure consistency between laboratories in the presentation and submittal of analytical data. In general, a unique EDD has been developed for each analytical method and each medium. Each EDD provides the analyst with a standardized laboratory bench sheet and accompanying data entry form for recording analytical data. The data entry forms contain a variety of built-in quality control functions that improve the accuracy of data entry and help maintain data integrity. These spreadsheets also perform automatic computations of analytical input parameters (e.g., sensitivity, dilution factors, and concentration), thus reducing the likelihood of analyst calculation errors. The EDDs generated by the laboratories are uploaded directly into the Libby site database (see below).

2.3 Hard Copy Data Management

Hard copies of all FSDSs, field logbooks, and chain of custody forms generated during this investigation are stored in the CDM Smith field office in Libby, Montana. **Appendix A** of this report provides copies of the field documentation for this investigation.

All analytical bench sheets are scanned and included in the analytical laboratory job reports. These analytical reports are submitted to the Libby laboratory coordinator (i.e., EPA's Environmental Services Assistance Team [ESAT] contractor, TechLaw, Inc.) and stored electronically. **Appendix B** of this report provides copies of all the analytical laboratory reports for analyses performed as part of this investigation.

2.4 Electronic Data Management

Detailed information regarding electronic data management procedures and requirements can be found in the *EPA Data Management Plan for the Libby Asbestos Superfund Site* (EPA 2012b). In brief, sample and analytical electronic data are stored and maintained in the Libby Scribe project databases which are housed on a local computer located at the TechLaw office in Golden, Colorado, which is backed up daily to an external hard drive.

Because data for the Libby project are maintained in multiple Scribe projects (e.g., analytical data are managed in annual projects, field information is managed in a project separate from the analytical information), the data have been combined into one Microsoft Access® database by CDM Smith reflecting a compilation of tables from multiple Scribe projects.

Raw data summarized in this report were downloaded from Scribe.NET on 8/13/2013. A frozen copy of this Access database is provided in **Appendix C** of this report. Any changes made to these Scribe projects since this download will not be reflected in the Access database.

3 WOODSTOVE ASH ABS STUDY OVERVIEW

As discussed above, the goal of this study was to evaluate potential exposures to individuals from exposure to LA in air as a consequence of ash removal from a wood-burning stove. The basic tasks performed as part of this study included the burning of locally-collected wood in a wood-burning stove and collecting personal air samples under an ABS sampling scenario emulating a person emptying the ash from the stove. Tree bark and ash samples were collected prior to the stove-emptying activity to provide information on LA concentration in source materials. Perimeter air monitoring was also conducted during the wood burning and stove-emptying events to ensure that ABS activities did not result in releases to air outside of the ABS area. The basic study design, collection methods, and analysis methods are described in more detail below.

3.1 Study Design

3.1.1 Tree Collection Locations

Based on the assumption that tree bark concentrations of LA decrease as a function of distance from the mine, wood for burning during the ABS scenarios was collected from three locations, representing a range of distances from the source (near, intermediate, and far). Wood was gathered from two deadwood trees from each of the following three locations:

- Near" Location – In the vicinity of the mine in Operable Unit (OU3), located in an area with high LA levels measured in duff and tree bark (collocated with the area evaluated as part of the *OU3 Commercial Logging ABS Study* [CDM Smith 2012b]).

- "Intermediate" Location – In the vicinity of Flower Creek (collocated with a timber sale area that was evaluated as part of the *Comparative Exposure Study Addendum* [CDM Smith 2012c]).

- "Far" Location – A location a few miles south of Flower Creek (near a sampling point outside the NPL boundary evaluated as part of the *Nature & Extent of LA Contamination in the Forest Study* [CDM Smith 2012d])

Figure 3-1 provides a map that shows the near, intermediate, and far tree collection locations. Wood from the felled trees was transported in plastic bags used for containing investigation-derived waste (IDW) from the collection location to the ABS area.

3.1.2 ABS Area

All ABS activities were conducted inside a temporary enclosure in the vicinity of the Libby landfill. The temporary enclosure was constructed of posts with polyvinyl sheeting to serve as

walls (see **Figure 3-2**). A wood-burning stove was placed inside the enclosure. A total of three new EPA-certified wood-burning stoves were utilized (one stove was dedicated to each tree collection location). During wood burning, the walls of the enclosure were removed so that the heat generated by the stove could dissipate into the open air (see **Figure 3-3**). The enclosure walls were put in place for the ABS stove-emptying activities to simulate an indoor condition. Within this ABS area, the stove-emptying ABS scenario was repeated three times for the varying wood samples collected near, intermediate, and far from the source.

3.1.3 ABS Script

The stove-emptying ABS activities were conducted in basic accordance with the script provided in the SAP/QAPP (CDM Smith 2012a). In brief, one actor emptied out the ash from the woodstove using a long-handled metal shovel, placing the ash material into a metal ash bucket. Once all of the ash had been shoveled out, a soft-bristled brush was used to sweep up and gather any additional ash material for removal and placed into the ash bucket. There was no specified sampling duration requirement for this ABS scenario. Rather, the actor simply continued removing ash until all ash had been removed (regardless of how long the activity took).

3.2 Sample Collection Methods

Sample collection for this study was performed as follows:

1. Sampling began with the felling of two standing deadwood trees from each of the three tree collection locations (see **Figure 3-1**). The trees were cut to a size appropriate for burning in a woodstove and transported to the Libby landfill.
2. One tree bark sample was collected prior to burning the collected wood in an EPA-certified wood-burning stove.
3. Collected wood was burned for a period of 6 hours. Perimeter air monitoring was performed during the burning event.
4. After 6 hours of wood burning, the resulting ash was given sufficient time to cool[1] before performing ABS activities. One sample of the ash material was collected prior to performing ABS activities.
5. After the ash was cool, the ABS scenario was conducted to simulate removal of ash from the woodstove into a bucket. Perimeter air monitoring was performed during the ABS event.
6. Steps 2 through 6 were performed three times for each tree collection location.

[1] A record of modification (ROM) to the SAP/QAPP was submitted to EPA to allow the ash to cool over one night, rather than two nights as originally specified in the SAP/QAPP. See Section 5.2 for additional details.

A total of three ABS events were performed sequentially for each woodstove (i.e., tree collection location). Each ABS event lasted approximately two days – one day to burn the wood and to let the ash cool, and one day to perform the ABS event, as illustrated in **Figure 3-4**.

Detailed information on the sample collection methods for each media type is provided below.

3.2.1 Tree Bark

Tree bark samples were collected, handled, and documented in general accordance with Libby-specific SOP EPA-LIBBY-2012-12, *Sampling and Analysis of Tree Bark for Asbestos*, and the project-specific modifications specified in the SAP/QAPP (CDM Smith 2012a). In brief, two deadwood trees (Douglas fir) were felled from each tree collection location (i.e., near, intermediate, far). Felled trees were sawed/split such that they were an appropriate size for burning in a woodstove. Prior to burning the collected wood, a hole saw and chisel was used to collect five circular bark cores from the wood to be burned, and were composited into a single sample for analysis of asbestos by transmission electron microscopy (TEM) (see Section 3.3.4). A total of nine tree bark samples were collected (1 tree bark sample x 3 ABS events x 3 tree collection locations) (see **Figure 3-4**).

3.2.2 Ash

As noted in the SAP/QAPP (CDM Smith 2012a), there is no existing SOP for the collection of ash material. Ash samples were collected as specified in the SAP/QAPP. In brief, after the wood had been burned and the ash cooled, the ash was manually homogenized (using a long-handled shovel), and an aliquot of approximately 10-20 grams of ash placed into glass scintillation vials and shipped to the analytical laboratory for analysis of asbestos by TEM (see Section 3.3.5). A total of nine ash samples were collected (1 ash sample x 3 ABS events x 3 tree collection locations) (see **Figure 3-4**).

3.2.3 ABS Air

All ABS activities were performed at the Libby landfill by an EPA field contractor (CDM Smith) in accordance with the ABS scenario scripts provided in the SAP/QAPP (CDM Smith 2012a). Personal ABS air samples were collected in accordance with Libby-specific SOP EPA-LIBBY-2012-10, *Sampling of Asbestos Fibers in Air*. In brief, the ABS actor carried a battery-powered sampling pump in a backpack, with an air monitoring cassette connected to the pump via a plastic tube. The air cassette was affixed to the actor such that the cassette was located within the breathing zone. All air samples were collected using cassettes containing a 25-millimeter (mm) diameter mixed cellulose ester (MCE) filter with a pore size of 0.8-micrometers (µm).

For the ash removal ABS scenario, the actor wore two different types of sampling pumps. The primary air sample was collected using a sampling pump operating at a high flow rate (5.5 liters per minute [L/min]), and is referred to as the "high volume" (HV) sample. A backup air sample

was collected using a sampling pump operating at a low flow rate (2 L/min), and is referred to as the "low volume" (LV) sample. The HV and LV samples are field replicates (i.e., each filter represents the same sample collection duration, but different total sample air volumes).

At the start of each sampling day, each air sampling pump was calibrated using a rotameter that had been calibrated to the primary calibration standard (i.e., a Bios DryCal® DC-Lite). The HV pump was an F&J L-15P, or equivalent, and the LV pump was an SKC 224-PCXR4, or equivalent.

Three separate ash disturbance ABS events were performed – Event 1 on the morning of November 7, 2012, Event 2 on the morning of November 9, 2012, and Event 3 on the morning of November 13, 2012 (see **Figure 3-4**). A total of 18 ABS air samples were collected (9 HV filters and 9 LV filters) (2 ABS air sample x 3 ABS events x 3 tree collection locations). Only one of the filters for each ABS air sample (either the HV or the LV filter) was analyzed for asbestos by TEM (see Section 3.3.1).

3.2.4 Perimeter Air

All perimeter air samples were collected in accordance with Libby-specific SOP EPA-LIBBY-2012-10, *Sampling of Asbestos Fibers in Air*. Perimeter air samples were collected from a stationary air monitor placed at the perimeter of the landfill in a downwind direction from the woodstove to monitor any potential releases. Two perimeter air samples were collected for each ABS event. One perimeter air sample had a sample duration that encompassed the entire two days of an individual ABS event (i.e., the duration of the burning, cooling, and ABS activities). The other perimeter air sample was collected only during the 6-hour burning time period for rapid turn-around analysis to monitor potential releases from the woodstoves during the burning activity. The 6-hour perimeter air samples were collected at a flow rate of 5.0 L/min, while the 2-day perimeter air samples were collected at a flow rate of 2.5 L/min.

A total of three 2-day perimeter air samples and three 6-hour perimeter air samples were collected (two perimeter air samples for each of three ABS events) (see **Figure 3-4**), and analyzed by TEM (see Section 3.3.2).

3.2.5 Meteorological Data

A portable weather station was not used during the study, and there was no permanent weather station at the Libby landfill. Thus, meteorological data were downloaded using the University of Utah *MesoWest* surface weather almanac (University of Utah 2013) for a weather station located nearby at the Libby mine (ZONM8). **Figure 3-5** provides a summary of the environmental temperature and humidity measurements from this meteorological station for the study duration (November 6-13, 2012).

3.3 Sample Preparation and Analysis Methods

3.3.1 ABS Air Samples

3.3.1.1 ABS Air Sample Preparation Hierarchy

As noted previously, each ABS event resulted in two ABS air filters – one HV filter and one LV filter. The HV and LV filters are field replicates in that they were collected over the same sampling duration, but using different sampling pump flow rates (resulting in different total air sample volumes). The HV sample was analyzed in preference to the LV sample. If the HV sample was deemed to be overloaded (i.e., particulate loading on the filter is > 25%), the LV sample was analyzed in preference to performing an indirect preparation on the HV sample. If the LV sample was also deemed to be overloaded, an indirect preparation (with ashing) of the HV sample was performed in accordance with SOP EPA-LIBBY-08, *Indirect Preparation of Air and Dust Samples for Analysis by TEM.* In this study, all HV filters were prepared using an indirect-ashing procedure due to high particulate loading levels (> 25%) on both the HV and LV filters. A discussion of the potential influence of indirect preparation techniques on reported TEM air concentrations is presented in Section 5.3.5.

3.3.1.2 Analysis Method, Counting Rules, and Stopping Rules

<u>Analysis Method and Counting Rules</u>

The ABS air filter was used to prepare a minimum of three grids using the grid preparation techniques described in Section 9.3 of International Organization for Standardization (ISO) Method 10312:1995(E) (ISO 1995). The resulting grids were analyzed for asbestos using TEM in basic accordance with ISO 10312, as modified by the most recent versions of Libby Laboratory Modifications[2] LB-000016, LB-000029, LB-000066, LB-000067, and LB-000085.

Because of the high number of grid openings that were needed to achieve the target analytical sensitivity, all ABS air samples were examined using counting protocols for recording phase contrast microscopy-equivalent (PCME) structures only (per ISO 10312 Annex E). That is, filters were examined at a magnification of about 5,000x, and all asbestos structures that had appropriate selective area electron diffraction (SAED) patterns and energy dispersive spectroscopy (EDS), and had length > 5 micrometers (µm), width ≥ 0.25 µm, and aspect ratio ≥ 3:1, were recorded on the Libby-specific TEM laboratory bench sheets and EDDs for the recording of air samples.

[2] Copies of all Libby Laboratory Modifications are available in the Libby Lab eRoom.

When a sample is analyzed by TEM, the analyst records the size (length, width) and mineral type of each individual asbestos structure that is observed. Mineral type was determined by SAED and EDS, and each structure is assigned to one of the following four categories:

LA Libby amphibole. Structures having an amphibole SAED pattern and an elemental composition similar to the range of fiber types observed in ores from the Libby mine (Meeker *et al.* 2003). This is a solid solution series of minerals including winchite and richterite, with lower amounts of tremolite, magnesio-arfvedsonite, magnesio-riebeckite, and edenite/ferro-edenite. Depending on the valence state of iron, some minerals may also be classified as actinolite.

OA Other amphibole-type asbestos fibers. Structures having an amphibole SAED pattern and an elemental composition that is not similar to fiber types from the Libby mine. Examples include crocidolite, amosite, and anthophyllite. There is presently no evidence that these fibers are associated with the Libby mine.

CH Chrysotile fibers. Structures having a serpentine SAED pattern and an elemental composition characteristic of chrysotile. There is presently no evidence that these fibers are associated with the Libby mine.

NAM Non-asbestos material. These may include non-asbestos mineral fibers such as gypsum, glass, or clay, and may also include various types of organic and synthetic fibers derived from carpets, hair, etc. *Recording of NAM structures was not required for this study.*

In addition, information on the sodium and potassium content and mineral identification (e.g., winchite, tremolite), as determined by EDS, of each amphibole asbestos structure observed was also recorded.

<u>Stopping Rules</u>

The TEM stopping rules for all ABS air field samples were as follows:

- Count a minimum of two grid openings from each of two grids.
- Continue counting until one of the following was achieved:
    - The target analytical sensitivity (0.0058 per cubic centimeter [cc^{-1}]) was achieved.
    - 25 PCME LA structures were observed.
    - A total filter area of 10 square millimeters (mm^2) was examined (approximately 1,000 grid openings).

When one of these criteria had been satisfied, the examination stopped after completion of the last grid opening.

For lot blanks and field blanks, the TEM analysis included an examination of an area of 1.0 mm^2 (approximately 100 grid openings).

3.3.1.3 Calculation of Air Concentration

The concentration of PCME LA in air is given by:

$$C_{air} = N \cdot S$$

where:

C_{air} = Air concentration, expressed as structures per cubic centimeter of air (s/cc)
N = Number of PCME LA structures observed
S = Analytical sensitivity (cc^{-1})

For air, the analytical sensitivity is calculated as:

$$S = EFA / (GOx \cdot Ago \cdot V \cdot 1000 \cdot F)$$

where:

S = Analytical sensitivity (cc^{-1})
EFA = Effective area of the filter (mm^2)
GOx = Number of grid openings examined
Ago = Area of a grid opening (mm^2)
V = Volume of air passed through the filter (liters [L])
1000 = Conversion factor (cc/L)
F = Fraction of primary filter deposited on secondary filter (indirect preparation only)

Note that air samples with a count of zero (and hence a concentration of zero) are reported as zero. When computing the best estimate of the mean, samples with a count of zero are evaluated as zero, not at ½ the analytical sensitivity (EPA 2008). This approach yields an unbiased estimate of the true mean that does not depend on the analytical sensitivity of the samples included in the data set.

3.3.2 Perimeter Air Samples

3.3.2.1 Sample Preparation

Each ABS event resulted in two perimeter air samples – one 6-hour rapid-turn around sample (collected during the burning period) and one 2-day sample (collected over the entire ABS event duration). Each perimeter air filter was prepared for analysis by the laboratory using direct preparation methods. The filter was used to prepare a minimum of three grids using the grid

preparation techniques described in Section 9.3 of ISO 10312.

3.3.2.2 Analysis Method, Counting Rules, and Stopping Rules for 6-hour Samples

The analytical requirements for the 6-hour samples were modeled after the requirements specified for perimeter air samples collected as part of exterior removal actions (CDM Smith 2011).

Grids were examined by TEM in basic accordance with the recording procedures described in the Asbestos Hazard Emergency Response Act (AHERA) (EPA 1987), as modified by the most recent versions of Libby Laboratory Modifications LB-000029, LB-000031, LB-000067, and LB-000085. If observed, chrysotile structures were recorded using the same basic procedures.

The required turnaround time for the 6-hour perimeter air sample results was 24-hours to allow for the opportunity to modify the study design if there was the potential for migration of LA outside the study area[3]. Because of this rapid turn-around requirement, these samples were all analyzed by the EMSL Analytical, Inc. laboratory located in Libby.

For each 6-hour perimeter air sample, the analyst examined a minimum of two grid openings from each of two grids. Grid opening examination continued until an analytical sensitivity of 0.005 cc^{-1} was achieved.

3.3.2.3 Analysis Method, Counting Rules, and Stopping Rules for 2-day Samples

The analytical requirements for the 2-day samples were modeled after the requirements specified for perimeter air samples collected as part of the Operable Unit 4 (OU4) outdoor ambient air monitoring program (CDM Smith 2006).

Grids were examined by TEM in basic accordance with the recording procedures described in ISO 10312, as modified by the most recent versions of Libby Laboratory Modifications LB-000016, LB-000029, LB-000055, LB-000066, LB-000067, and LB-000085. That is, filters were examined at high magnification (~ 20,000x), and all amphibole structures (including not only LA but all other amphibole asbestos types as well) that had appropriate SAED patterns and EDS spectra, and had length ≥ 0.5 µm and aspect ratio ≥ 3:1, were recorded. If observed, chrysotile structures were recorded using the same basic procedures.

For each 2-day perimeter air sample, the analyst examined a minimum of two grid openings from each of two grids. Grid opening examination continued until an analytical sensitivity of 0.00004 cc^{-1} had been achieved.

[3] Due to a miscommunication in the field, the 24-hour turnaround time was not met for the 6-hour perimeter air samples. Depending upon the sample, analysis results were reported between 2-6 days after sample collection.

3.3.2.4 Calculation of Air Concentration

The concentration of LA in perimeter air samples was calculated using the same equations as presented above for ABS air (see Section 3.3.1.3).

3.3.3 Health & Safety Air Monitoring Samples

The personal air samples collected for the ongoing health and safety monitoring were analyzed in accordance with the *Response Action SAP* (CDM Smith 2011). In brief, air samples were prepared and analyzed by phase contrast microscopy (PCM) in accordance with National Institute for Occupational Safety and Health (NIOSH) Method 7400, Issue 2 and the most recent version of Libby Laboratory Modification LB-000015.

3.3.4 Tree Bark Samples

3.3.4.1 Sample Preparation

Tree bark samples were prepared and analyzed in basic accordance with the procedures specified in SOP EPA-LIBBY-2012-12, *Sampling and Analysis of Tree Bark for Asbestos*. In brief, each sample was dried and ashed, and the resulting ash residue was acidified, suspended in water, and filtered. A total of three replicate filters were created for each tree bark sample using equal aliquots of the ash residue. Replicate filters were prepared to provide information on the within-sample heterogeneity and a better estimate of the true mean LA level in the bark sample. Each replicate filter was used to prepare a minimum of three grids using the grid preparation techniques described in Section 9.3 of ISO 10312.

3.3.4.2 Analysis Method, Counting Rules, and Stopping Rules

Grids were examined by TEM using high magnification (~20,000x) in basic accordance with the recording procedures described in ISO 10312, as modified by SOP EPA-LIBBY-2012-12. In brief, all amphibole structures that had appropriate SAED patterns and EDS spectra, a length ≥ 0.5 µm, and an aspect ratio ≥ 3:1, were recorded. If observed, chrysotile structures were recorded using the same procedures.

The stopping rules for the TEM analysis of tree bark were as follows:

- Count a minimum of two grid openings from each of two grids.
- Continue counting until one of the following is achieved:
    - The target analytical sensitivity (100,000 per square centimeter [cm^{-2}]) is achieved.
    - 50 LA structures have been observed.

- A total filter area of 1.0 mm^2 has been examined (this is approximately 100 grid openings).

When one of these criteria had been satisfied, the examination stopped after completion of the last grid opening.

3.3.4.3 Calculation of Tree Bark Surface Loading

The results for each tree bark analysis are expressed in terms of million structures per square centimeter of tree bark (Ms/cm^2) (i.e., a surface area loading). The tree bark surface loading is calculated as follows:

$$L_{bark} = N \cdot S \cdot 1E\text{-}06$$

where:

L_{bark} = Tree bark loading (Ms/cm^2)
N = Number of total LA structures observed
S = Analytical sensitivity (cm^{-2})
1E-06 = Conversion factor

The analytical sensitivity for tree bark analyses is calculated as:

$$S = \frac{EFA}{GO \cdot Ago \cdot A \cdot F}$$

where:

S = Analytical sensitivity (cm^{-2})

EFA = Effective filter area (mm^2)

GO = Number of grid openings counted

Ago = Area of one grid opening (mm^2)

A = Area of tree bark sample being analyzed (square centimeters [cm^2]), calculated as:

$$A = N \cdot [(\pi \cdot (D_c/2)^2) - (\pi \cdot (D_p/2)^2)]$$

where:

N = number of cores

π = pi (3.14159265…)

D_c = diameter of the core (centimeter [cm])

D_p = diameter of the pilot hole (cm)

F = Fraction of original sample deposited on the filter, calculated as:

$$F = M_a/M_t \cdot V_a/V_t$$

where:

M_a = mass of ash aliquot used in the suspension (grams [g])

M_t = total mass of ash (g)

V_a = volume of suspension applied to filter (milliliters [mL])

V_t = total suspension volume of dilution (mL)

When computing the best estimate of the mean surface loading across tree bark filter replicates, analyses with a count of zero were evaluated as zero (EPA 2008).

3.3.5 Ash Samples

3.3.5.1 Sample Preparation

Ash samples were prepared and analyzed using procedures similar to those specified in SOP EPA-LIBBY-2012-11, *Sampling and Analysis of Duff for Asbestos*. In brief, an aliquot of the ash material was acidified, suspended in water, and filtered. A total of three replicate filters were created for each ash sample using additional aliquots of the ash residue. Replicate filters were prepared to provide information on the within-sample heterogeneity and a better estimate of the true mean LA concentration in the ash. Each filter was used to prepare a minimum of three grids using the grid preparation techniques described in Section 9.3 of ISO 10312.

3.3.5.2 Analysis Method, Counting Rules, and Stopping Rules

Grids were examined by TEM using high magnification (~20,000x) in basic accordance with the recording procedures described in ISO 10312, as modified by SOP EPA-LIBBY-2012-11 and the most recent versions of Libby Laboratory Modifications LB-000016, LB-000029, LB-000066, LB-000067, and LB-000085. In brief, all fibrous amphibole structures that had appropriate SAED patterns and EDS spectra, and had length ≥ 0.5 µm and an aspect ratio ≥ 3:1, were recorded. If observed, chrysotile structures were recorded using the same procedures.

The stopping rules for the TEM analysis of ash materials were as follows:

- Count a minimum of two grid openings from each of two grids.
- Continue counting until one of the following is achieved:

- The target analytical sensitivity (1E+07 per gram, dry weight [g^{-1}]) is achieved.
- 50 LA structures have been observed.
- A total filter area of 1.0 mm^2 has been examined (this is approximately 100 grid openings).

When one of these criteria had been satisfied, the examination stopped after completion of the last grid opening.

3.3.5.3 Calculation of Ash Concentration

The results for each ash analysis are expressed in terms of million structures per gram of ash (Ms/g). The ash concentration is calculated as follows:

$$C_{ash} = N \cdot S \cdot 1E\text{-}06$$

where:

C_{ash} = Ash concentration (Ms/g)
N = Number of total LA structures observed
S = Analytical sensitivity (g^{-1})
1E-06 = Conversion factor

The analytical sensitivity for ash analyses is calculated as:

$$S = \frac{EFA}{GO \cdot Ago \cdot Mass \cdot F}$$

where:

S = Analytical sensitivity (g^{-1})

EFA = Effective filter area (mm^2)

GO = Number of grid openings counted

Ago = Area of one grid opening (mm^2)

Mass = Mass of the ash aliquot used in the suspension (g)

F = Fraction of the ash sample applied to the filter, calculated as:

$$F = V_a/V_t$$

where:

V_a = volume of suspension applied to filter (mL)

V_t = total suspension volume (mL)

When computing the best estimate of the mean concentration across ash filter replicates, analyses with a count of zero were evaluated as zero (EPA 2008).

4 RESULTS

Table 4-1 presents a summary of tree bark surface loading and ash concentrations for total LA. In this table, results are presented for each filter replicate, across filter replicates (within an event), and across events. **Table 4-2** presents a summary of the measured LA concentrations in the 6-hour and 2-day perimeter stationary air samples and the ABS air samples. For the ABS air samples, results are presented for each event and across events. Detailed analytical results are provided in the project database (see **Appendix C**). An interpretation of these results is provided below.

4.1 Tree Bark and Ash

As seen in **Table 4-1**, the highest tree bark surface loading levels for LA were for the trees collected from near the mine (within OU3), with a mean surface loading of 6 total LA Ms/cm^2. Surface loading for Flower Creek (an intermediate distance from the mine) and Bear Creek (far from the mine) were much lower, with mean surface loadings of 0.08 total LA Ms/cm^2 and 0.009 total LA Ms/cm^2, respectively. As illustrated in **Figure 4-1**, mean levels tended to decrease as a function of distance from the mine.

Likewise, for ash samples, the highest LA concentrations were measured in ash following the burning of trees collected from near the mine (within OU3) with a mean concentration of 35 total LA Ms/g. Ash concentrations for trees collected from Flower Creek and Bear Creek were much lower and generally similar (approximately 0.7 total LA Ms/g and 2 total LA Ms/g, respectively). These data also show that a significant amount of LA remains in the ash after burning wood. This observation is consistent with trial burn experiments in woodstoves (Ward *et al.* 2009) and in test burn chambers (EPA 2012a), which indicated that the majority of LA structures were retained in the ash when either wood or duff materials were burned under experimental conditions.

For both source media, reported results for each location tended to be highly variable within a location, both across replicates within the same sample and across sampling events. These data demonstrate that LA concentrations in these source materials are inherently heterogeneous.

4.2 Perimeter Stationary Air

As described previously, two perimeter stationary samples were collected for each sampling event. A 6-hour perimeter stationary air sample was collected during the wood burning period of each event, and a 2-day air sample was collected across the duration of each event.

As seen in **Table 4-2**, no LA structures were detected by TEM in any of the perimeter air samples collected for this study. One chrysotile structure was noted in one of the 2-day perimeter air samples, but the presence of chrysotile is not expected to be mine-related. These

data support the conclusion that LA was not released into the surrounding air during either the wood-burning activities or the ABS activities.

4.3 ABS Air

As seen in **Table 4-2**, LA was detected in all of the ABS air samples collected during woodstove ash removal activities for trees collected from near the mine (within OU3) and for Flower Creek (intermediate). LA was detected in the ABS air sample for one of the three sampling events for trees collected from Bear Creek (far). As shown, the highest PCME LA air concentrations in ABS air were for activities performed on ash generated from trees collected from near the mine, with a mean ABS air concentration of 0.3 PCME LA s/cc. As illustrated in **Figure 4-1**, mean ABS air concentrations tended to decrease as a function of the tree collection distance from the mine. The results indicate that human exposure to LA from the disturbance of woodstove ash has the potential to be greatest when the wood being burned is obtained from trees located closer to the mine. As wood collection distance from the mine increases, the level of potential LA exposure decreases.

A significant amount of variability in ABS air concentrations was noted between ABS events for each tree collection location (coefficient of variation values ranged from 1.0 to 1.7). This variability is likely due to several factors, including the nature of the ABS activity (i.e., ash removal activities may have differed slightly from event to event), the heterogeneity of LA in the source materials (see Section 4.1), and differences in external environmental factors (e.g., temperature, humidity) (see Section 3.2.5). However, this variability is representative of the real variability that may be present in authentic exposure scenarios that may occur in Libby, and is not considered to be a data limitation.

Note that an evaluation of potential human health risks from exposures to LA in ash is beyond the scope of this document. These ABS results will be evaluated further as part of the Site-wide human health risk assessment.

5 DATA QUALITY ASSESSMENT

Data quality assessment (DQA) is the process of reviewing existing data to establish the quality of the data and to determine how any data quality limitations may influence data interpretation (EPA 2006).

5.1 Field and Laboratory Oversight

5.1.1 Field

Field surveillances consist of periodic observations made to evaluate adherence to investigation-specific governing documents. Field audits are broader in scope than field surveillances and are evaluations conducted by qualified technical or quality assurance (QA) staff that are independent of the activities audited.

A field audit was conducted for the Woodstove Ash ABS program on November 6-7, 2012 (CDM Smith 2013a). This audit reviewed ABS activities, including bark, ash, and air sample collection, global positioning system point collection, field QC sample collection, equipment calibration and decontamination procedures, and personal protective equipment. In addition, a review of field documentation, including field logbook entries, FSDS forms, and property background forms was performed. The following overall conclusions were noted:

- All teams had field access to the latest version of the governing SAP/QAPP.
- No deficiencies were noted regarding the collection of the bark, ash, or air samples; sampling requirements for each media specified in the SAP/QAPP were met by field personnel.
- No deficiencies were noted regarding general field processes; the general process requirements specified in the SAP/QAPP were met by field personnel.
- The field QC sample types and collection frequencies specified in the SAP/QAPP were met by field personnel.
- Field documentation reviewed was consistent, legible, and had few errors or omissions; field documentation requirements specified in the SAP/QAPP were met by field personnel.

In summary, no significant deficiencies were observed the days of the audit (CDM Smith 2013a).

5.1.2 Laboratory

Laboratory audits are conducted to evaluate laboratory personnel to ensure that samples are handled and analyzed in accord with the program-specific documents and analytical method requirements (or approved Libby laboratory modification forms) to make certain that analytical

results reported are correct and consistent. All aspects of sample handling, preparation, and analysis are evaluated. If any issues are identified, laboratory personnel are notified and retrained as appropriate.

A series of laboratory audits was performed in May through September 2012 to evaluate all of the Libby laboratories. Detailed audit findings for each laboratory are documented in separate laboratory-specific audit reports (CB&I Federal Services, LLC [CB&I], formerly Shaw Environmental & Infrastructure Group [Shaw E&I] 2012a-f). No critical deficiencies were noted during the 2012 laboratory audits that would be expected to impact data quality for TEM analyses.

5.2 Field and Laboratory Modifications

All deviations from, and modifications to, the governing SAP/QAPP were recorded on Libby-specific record of modification (ROM) forms. The ROM forms are used to document all permanent and temporary changes to procedures contained in guidance documents governing investigation that have the potential to impact data quality or usability. Any minor deviations (i.e., those that will not impact data quality or usability) are documented in the field logbooks.

During this study, one field modification (LFO-000174) was created that documented changes from sample collection and analysis methodology specified in the SAP/QAPP (CDM Smith 2012a). **Appendix E** provides a copy of LFO-000174. Review of this field ROM reveals that there were three deviations from the SAP/QAPP:

- A revision was made to reduce the one day/two night ash cooling period to an overnight cooling period prior to commencing ABS activities, and for ABS activities to occur the day following wood burning. This shortened cooling period reduced the "3-day" perimeter air sample to a "2-day" perimeter air sample.
- It was noted that CDM Smith was unable to procure a moisture meter in sufficient time prior to conducting tree bark sampling, and therefore the moisture content of the firewood was not recorded.
- It was noted that a single 20-mL glass scintillation vial did not have sufficient volume to hold the 10-20 gram ash aliquot required for ash sampling. A total of five 20-mL glass scintillation vials were needed to collect the required amount of ash sample.

No negative data quality implications resulted due to these modifications. The reduction of perimeter air sample time did not affect data usability or quality since the collected sample was representative of the full ABS event duration. The inability to record moisture content of the firewood did not negatively affect data usability or quality, as the field team was able to adequately monitor temperature and burn rate of firewood during the burning scenario. Collection of additional glass scintillation vials to gather the required 10-20 grams of ash sample

did not negatively affect data usability or quality as the laboratory was able to composite all collected vials for a given sample together prior to performing the analysis.

No laboratory modifications were created for samples collected as part of this study. However, as noted above, due to a miscommunication in the field, the 24-hour turnaround time was not met for the 6-hour perimeter air sample results. Depending upon the sample, analytical results were reported between 2-6 days after sample collection. The LA air concentration was non-detect in all of the 6- hour perimeter air samples. This deviation did not negatively affect data quality.

5.3 Data Verification and Validation

5.3.1 Data Verification

The Libby Scribe project databases have a number of built-in quality control checks to identify unexpected or unallowable data values during upload into the database. Any issues identified by these automatic upload checks were resolved by consultation with the field teams and/or analytical laboratory before entry of the data into the database. After entry of the data into the database, several additional data verification steps were taken to ensure the data were recorded and entered correctly.

In order to ensure that the database accurately reflects the original hard copy documentation, all data downloaded from the database were examined to identify data omissions, unexpected values, or apparent inconsistencies. In addition, 10% of all samples and analytical results underwent a detailed verification. In brief, verification involves comparing the data for a sample in the database to information on the original hard copy FSDS form or the original hard copy analytical bench sheets for that sample.

Appendix E presents a detailed summary of the findings of the FSDS and TEM review for this investigation. In brief, a total of 7 tree bark samples, 6 ash samples, and 8 air samples were verified. Hard copy FSDS forms were reviewed in accordance with SOP EPA-LIBBY-11. No critical[4] errors were discovered during the FSDS verification process.

Laboratory EDDs were reviewed for 10 tree bark analyses, 8 ash analyses, and 8 air analyses as part of the TEM verification effort. TEM analyses were reviewed in accordance with SOP EPA-LIBBY-09. Critical errors were identified in 1 tree bark analysis, 1 ash analysis, and 3 air analyses. In these analyses, the LA structure length, mineral class, EDS observation, and ashed residue aliquot fields in the EDD were either incorrect or missing. These fields have the potential to impact data interpretation and the reported LA concentration. Several non-critical

[4] A critical error is defined as an error that has the potential to impact the reported LA concentration or sample identification information.

issues were identified, which were related to data entry errors in the number of grids prepared, structure identification type, grid name, analysis date, etc. in the EDD.

All issues identified during the data verification effort were submitted to the field teams and/or analytical laboratories for resolution and rectification. All tables, figures, and appendices (including all hard copy documentation and the database, provided in **Appendices A-C**) generated for this report reflect corrected data.

5.3.2 Data Validation

Unlike data verification, where the goal is to identify and correct data reporting errors, the goal of data validation is to evaluate overall data quality and to assign data qualifiers, as appropriate, to alert data users to any potential data quality issues.

Data validation is performed by the EPA Quality Assurance Technical Support (QATS) contractor (CB&I), with support from technical support staff that are familiar with investigation-specific data reporting, analytical methods, and investigation requirements. For the Libby project, data validation of TEM results is performed in basic accordance with Libby-specific SOPs developed based on the draft *National Functional Guidelines (NFG) for Asbestos Data Review* (EPA 2011).

The EPA QATS contractor prepares an annual summary of the program-wide assessment of quality assurance/quality control (QA/QC). This annual addendum provides detailed information on the validation procedures performed and provides a narrative on the quality assessment for each type of analysis (e.g., TEM), including the data qualifiers assigned and the reason(s) for these qualifiers to denote when results do not meet acceptance criteria. This annual summary details any deficiencies, required corrective actions, and makes recommendations for changes to the QA/QC program to address any data quality issues.

A copy of the program-wide QA/QC summary report covering samples collected and analyzed in 2010-2012 (CB&I 2013) is currently pending. When this report is finalized, it will be located on the Libby Lab eRoom. Interpretation of the data quality is subject to change upon completion of this report.

5.5 Quality Control Evaluation

A number of quality control (QC) samples were collected as part of this ABS study to help characterize the accuracy and precision of the data obtained. QC samples included both field-based samples (which are submitted blind to the laboratories) and laboratory-based samples.

5.5.1 Field Quality Control

5.5.1.1 Air

Two types of field QC samples were collected as part of the air sampling portion of this investigation – lot blanks and field blanks.

Lot Blanks

A lot blank is a randomly selected filter cassette from a manufactured lot. Lot blanks are collected to ensure air samples for asbestos analysis are collected on asbestos-free filters. Lot blank sampling is performed at a frequency of one lot blank per every 500 cassettes. Only cassette lots where no asbestos is detected in the lot blank are placed into circulation for use in air sample collection, which ensures that the air cassette filters used in this study were free of asbestos fibers prior to sampling activities.

Field Blanks

Field blanks are collected to evaluate potential contamination introduced during sample collection, shipping and handling, or analysis. As specified in the SAP/QAPP (CDM Smith 2012a), field blanks were collected at a rate of one per field team per air sampling day (see **Figure 3-4**) for a total of six field blank samples, and two were chosen at random to be analyzed for asbestos by TEM**.** No asbestos structures were reported for either of the analyzed field blanks (1.0 mm^2 of filter was examined). The results demonstrate that asbestos was not introduced into the air samples as a consequence of sample collection, shipping and handling, or analysis.

5.5.1.2 Tree Bark

Two types of field QC samples were collected as part of the air sampling portion of this investigation – equipment rinsates and field duplicates.

Equipment Rinsates

Equipment rinsates are collected to evaluate potential contamination that arises to due inadequate decontamination of tree bark sampling equipment. Equipment rinsates were collected because non-dedicated tree bark field sampling equipment (i.e., hole saws, chisels) are utilized. Equipment rinsate samples were collected as specified in the SAP/QAPP (CDM Smith 2012a), and at a rate of one per team per sampling day, for a total of three equipment rinsate samples. All equipment rinsates were submitted for analysis by TEM (achieved sensitivity for all analyses was 50,000 L^{-1}).

One LA structure was observed in the equipment rinsate sample collected following the Event 1 tree bark collection. The two equipment rinsate samples that were collected following the Event 2 and Event 3 tree bark collection were both non-detect. These results suggests that the decontamination procedures for the tree bark sampling equipment (hole saw, chisel) may not have been entirely effective following Event 1. However, the fact that the levels of LA in the rinsate water were low, the other rinsates collected as part of this study were non-detect, and eight rinsates of tree bark sampling equipment collected for another 2012 tree bark study were all non-detect (CDM Smith 2013b) indicates that the presence of LA in tree bark due to inadequate decontamination is not a systematic issue or of significant concern.

Field Duplicates

As specified in the SAP/QAPP (CDM Smith 2012a), one field duplicate sample of tree bark was collected (during Event 3) for each tree collection location (near, intermediate, and far), for a total of three duplicate samples. Field duplicate collection techniques were the same as for the parent sample. For tree bark, the field duplicate sample was created by collecting a second set of bark cores within six inches of the original cores. All field duplicates were submitted for analysis by TEM.

A comparison of the field duplicate samples to their original parent sample was performed using the Poisson ratio test (Nelson 1982). Because three replicate filters were analyzed for each tree bark sample, results were pooled across replicates for the purposes of making comparisons, as follows:

$$\text{Loading}_{\text{pooled}} = (N_1 + N_2 + N_3) \;/\; (1/S_1 + 1/S_2 + 1/S_3)$$

where:

$\text{Loading}_{\text{pooled}}$ = Pooled asbestos bark surface loading (s/cm^2)
N_i = Number of structures observed in replicate 'i'
$1/S_i$ = Inverse of the achieved analytical sensitivity for replicate 'i' (cm^2)

Table 5-1 presents the results of the Poisson ratio comparison test for the tree bark field duplicates. As shown, field duplicate results were not statistically different from their original parent sample (based on a Poisson 90% confidence interval). These results show that the surface loading estimates for tree bark are reproducible and there are not significant differences in loading values due to small-scale media heterogeneity or sampling methods.

5.5.2 Laboratory Quality Control

The Libby-specific QC requirements for TEM analyses of asbestos are patterned after the requirements set forth by the National Voluntary Laboratory Accreditation Program (NVLAP). In brief, there are three types of laboratory-based QC analyses for TEM – laboratory blanks,

recounts, and repreparations. Detailed information on the Libby-specific requirements for each type of TEM QC analysis, including the minimum frequency rates, selection procedures, acceptance criteria, and corrective actions are provided in the most recent version of Libby Laboratory Modification LB-000029.

Laboratory QC analyses will evaluated by the EPA QATS contractor on a program-wide basis rather than on an investigation-specific basis. The rationale for this is that the number of laboratory QC samples directly related to this investigation is too limited to draw meaningful conclusions regarding overall data quality. However, a cursory review of a recount analysis performed for ABS air sample WA-00015 shows that TEM structure counts and mineral classification results are reproducible and reliable.

Refer to the pending program-wide QA/QC summary report covering samples collected and analyzed in 2010-2012 (CB&I 2013) for information regarding program-wide data quality of the preparation and analytical laboratories. As noted previously, interpretation of the data quality is subject to change upon completion of this report.

5.3 Data Adequacy Evaluation

A comparison of the data collected with the DQOs as summarized in the governing SAP/QAPP (CDM Smith 2012a) is presented below.

5.3.1 Spatial and Temporal Representativeness

The spatial and temporal goals of this ABS study included collecting representative data from three locations of varying distance from the Libby mine – near (OU3), intermediate (Flower Creek), and far (Bear Creek) – and to conduct the study during a season when wood burning activities in Libby would be expected to occur. Measured data on tree bark, ash, and ABS air was acquired successfully for each of the three designated locations (near, intermediate, and far).

The study occurred from November 6 to November 13, 2012, which was at a time likely for woodstove use in the Libby area. Three events were planned for each location, which were also completed successfully. As specified in the SAP/QAPP (CDM Smith 2012a), there was no set sampling duration specified for the collection period for the ABS air samples. Rather, the sampling duration was to be equal to length of time it took to complete the task of removing ash from the woodstove and placing the ash into a bucket. ABS sample times varied across events, but were generally about fifteen minutes in duration. Because the ABS was representative of authentic ash removal activities, the ABS air sample durations are considered to be of sufficient length to characterize potential human exposure to LA while emptying ash from a woodstove.

5.3.2 Sample Completeness

Completeness is defined as the fraction of samples that were planned that were successfully completed and analyzed. As described in the SAP/QAPP the following types and number of samples were to be collected and analyzed:

Medium	Number of samples collected per tree location	Total number of samples collected (across locations)	Number of samples analyzed (across locations)
Tree Bark	3	9	9+
Ash	3	9	9+
Perimeter Air (6-hour)	1	3	3
Perimeter Air (2-day)	1	3	3
ABS Air	6 (3 HV, 3 LV)	18	9*

+ Each sample was analyzed in triplicate.
* Either the HV or LV was to be selected for analysis, depending upon filter loading.

As shown in **Table 4-1** and **Table 4-2**, the samples and analyses that were planned were able to be successfully completed for all media types.

5.3.3 Analytical Sensitivity

Each media type analyzed by TEM had specific analytical requirements specified in the SAP/QAPP (CDM Smith 2012a). The following table specifies the analytical methods and target analytical sensitivity for each media type:

Medium	Analytical Method	Target Sensitivity
Tree Bark	TEM-ISO 10312 (high magnification)	100,000 cm^{-2}
Ash	TEM-ISO 10312 (high magnification)	1E+07 g^{-1}
Perimeter Air (6-hour)	TEM-AHERA (high magnification)	0.005 cc^{-1}
Perimeter Air (2-day)	TEM-ISO 10312 (high magnification)	0.00004 cc^{-1}
ABS Air	TEM-ISO 10312(low magnification, PCME only)	0.0058 cc^{-1}

As shown in **Table 4-1** and **Table 4-2**, all TEM analyses were performed in accordance with the analytical methods specified in the SAP/QAPP. All analyses achieved the target analytical sensitivity with the following exceptions:

- For two tree bark analyses (WA-00005, Replicate #2 and #3), the analysis was stopped before achieving the target analytical sensitivity because 50 or more LA structures were observed. For two ABS air samples (WA-00015 and WA-00037), the analysis was stopped before achieving the target analytical sensitivity because 25 or more LA structures were observed. Because of the high number of LA structures observed in

these analyses, there are no negative implications for not achieving the target analytical sensitivity for these analyses.

- For one ABS air sample (WA-00055), the analysis was stopped before achieving the target analytical sensitivity. For this sample, an indirect preparation (with ashing) was necessary due to particulate loading on the filter and achieving the target analytical sensitivity would have been cost prohibitive (requiring the analysis of more than 7,300 grid openings). The analysis for this sample continued even beyond the set maximum area examined stopping rule (i.e., 20 mm^2 of filter [1,555 grid openings] was examined). No LA structures were observed in the TEM analysis; however, this result has higher uncertainty because the achieved sensitivity was about 5 times higher than the other ABS air analyses.

5.3.4 Filter Loading

The TEM analysis of filters generated from air, tree bark, and ash samples examines only a small portion of the total filter. For the purposes of computing concentration in the associated sample, it is assumed that the filter is evenly loaded. The assessment of filter loading evenness is evaluated using a Chi-square (CHISQ) test, as described in ISO 10312 Annex F2 (ISO 1995). If a filter fails the CHISQ test for evenness, the reported result may not be representative of the true concentration in the sample, and the results should be given low confidence.

An evaluation of filter loading for the 83 filters analyzed by TEM for this study showed that, with the exception of two analyses, all filters passed the CHISQ test (i.e., p value ≥ 0.001) (see **Table 5-2**). One ash sample filter replicate (WA-00019, Replicate #3) and one ABS air sample (WA-00015) did not pass the CHISQ test. In both analyses, the filters were prepared using an indirect preparation method; thus, the uneven loading present on these filters may simply be a consequence of random variability. Because these two filters may have had uneven loading, results for these samples have a higher level of uncertainty. The frequency of CHISQ failure was about 2% for this study, which indicates that uneven filter loading is a rare occurrence.

5.3.5 Air Filter Preparation Methods

During TEM analysis of the ABS personal air samples, the analytical laboratories noted that all of the HV and LV filters were significantly overloaded with particulates. As a result, the HV filters for all ABS air samples were analyzed using an indirect preparation method after ashing. For chrysotile asbestos, indirect preparation can increase structure counts up to 1,000-fold due to dispersion of bundles and clusters (Hwang and Wang 1983; Chesson and Hatfield 1990; HEI-AR 1991; Breysse 1991). For amphibole asbestos, the effects of indirect preparation are generally much smaller (Bishop *et al.* 1978; Sahle and Laszlo, 1996; Harris 2009).

A Libby-specific evaluation of the effect of indirect preparation on reported LA air concentrations shows that indirect preparation does increase reported concentrations, but the ratio of the indirect preparation concentration to the direct preparation concentration is usually

within a factor of about 2-3 for PCME LA (Berry *et al.* 2013). This relative insensitivity of PCME LA concentration estimates to preparation method is likely due to the fact that complex LA structures (e.g., bundles, compact clusters) that might be subject to dispersal during an indirect preparation are rarely present in most Libby air samples.

Based on these considerations, it is likely that analysis of ABS air samples for LA using an indirect preparation method is a relatively minor source of uncertainty, but should be taken into consideration by risk managers when interpreting human exposure and risk estimates.

All perimeter air filters (both the 6-hour samples and the 2-day samples) were able to be prepared using direct preparation methods.

5.4 Conclusions

Based on a review of each of these data quality metrics, it is concluded that, although there are some sources of uncertainty, the ABS air, perimeter air, tree bark, and ash sampling results from this study are of adequate quality to support their intended use.

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Data Summary Report:
Wood-burning Stove Ash Removal Activity-Based Sampling
Libby Asbestos Superfund Site, Libby, Montana

FIGURES

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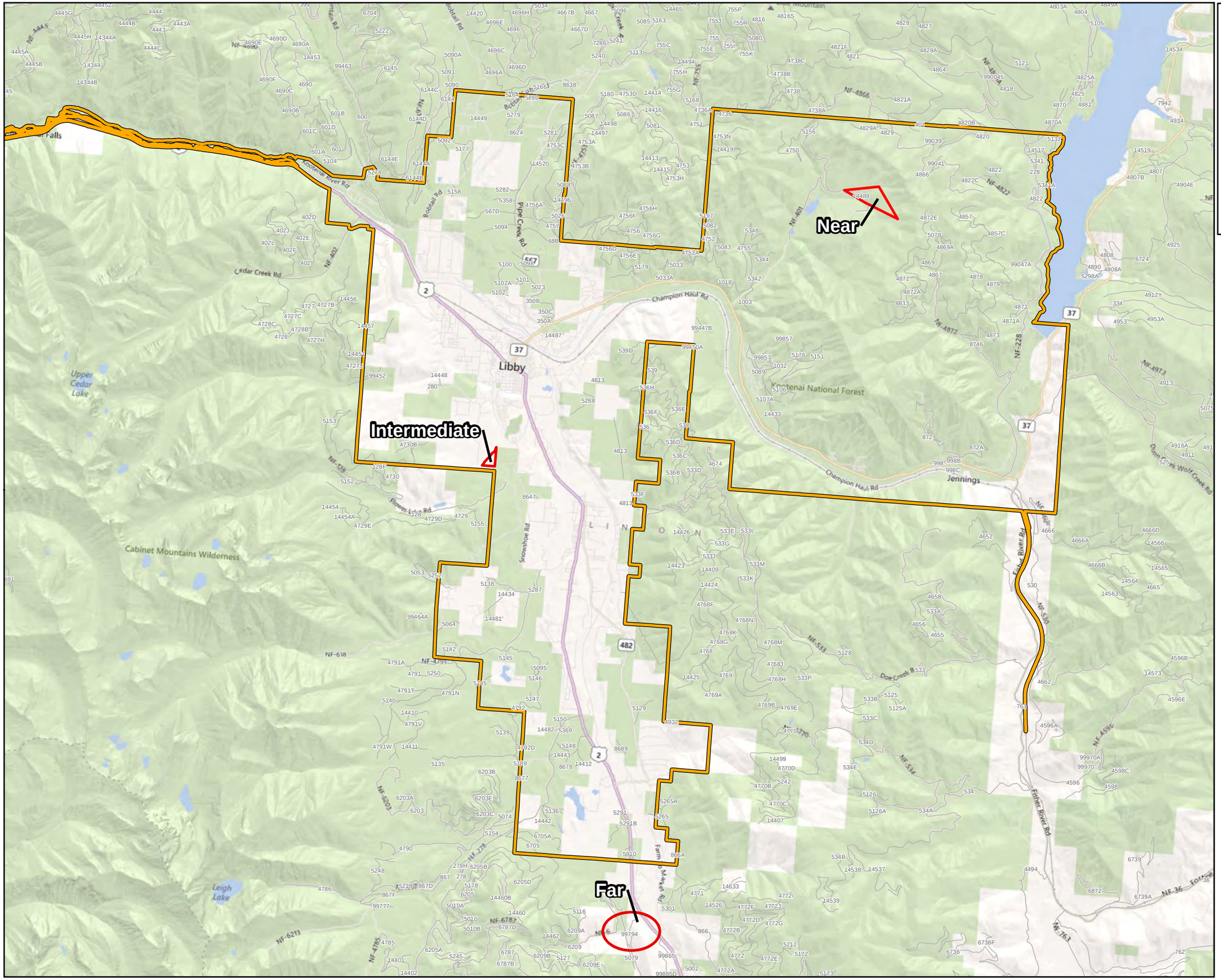


Legend

- Tree Collection Location
- Libby Asbestos NPL Boundary
- Forest Service Roads

N
W E
S

Miles

0 1 2 4

1 inch = 2 miles

Data Sources:
NPL Boundary - U.S. EPA Region 8 (2011);
Base - Microsoft Bing (2011)

For Official Use Only

Figure 3-1

Tree Collection Locations

CDM Smith

Path: R:\2603-Volpe\SAP\Figure3-1_TreeCollectionLocations_120925.mxd

FIGURE 3-2

PHOTOGRAPH OF THE TEMPORARY ENCLOSURE

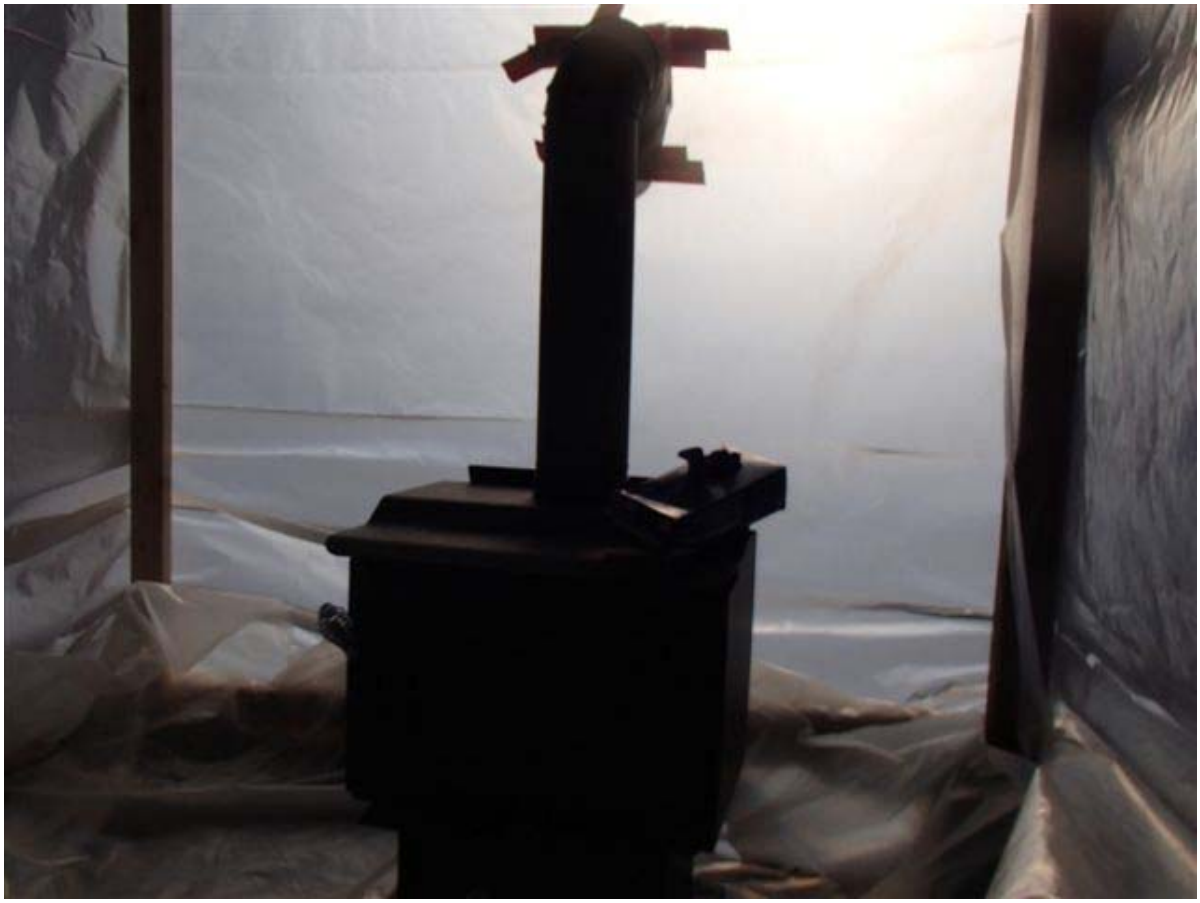
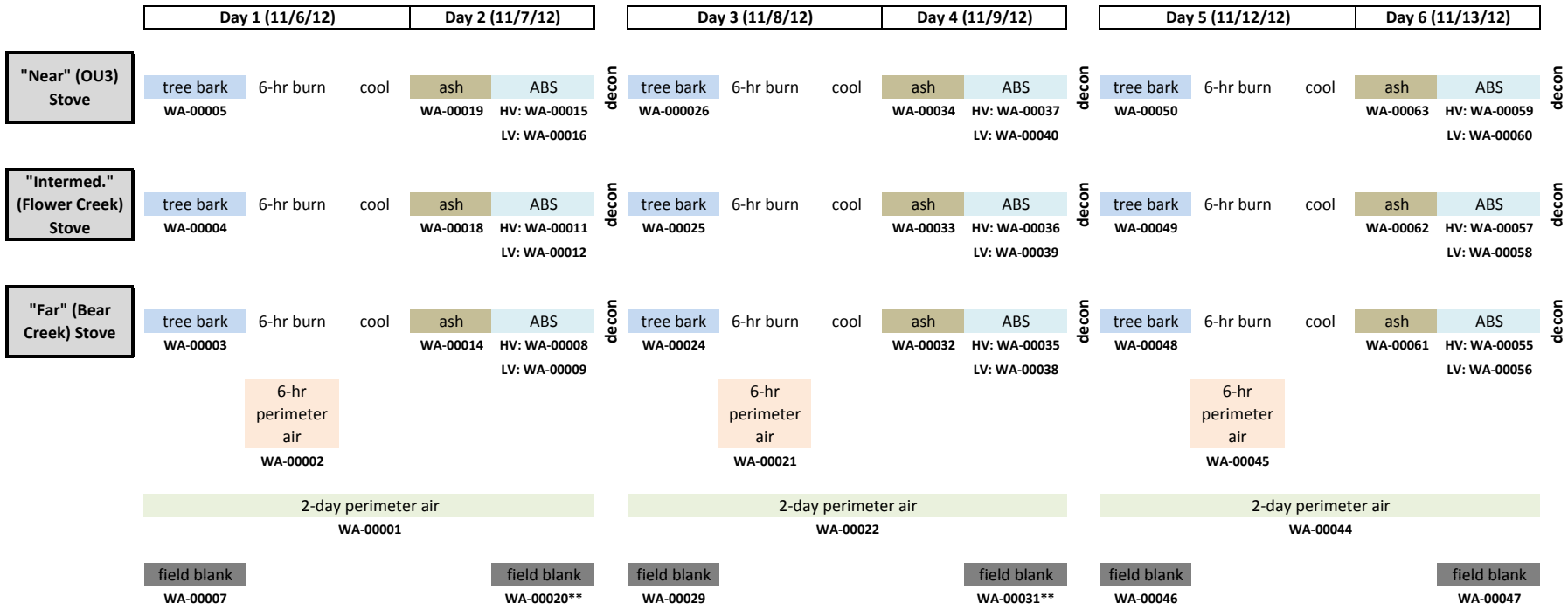


FIGURE 3-3

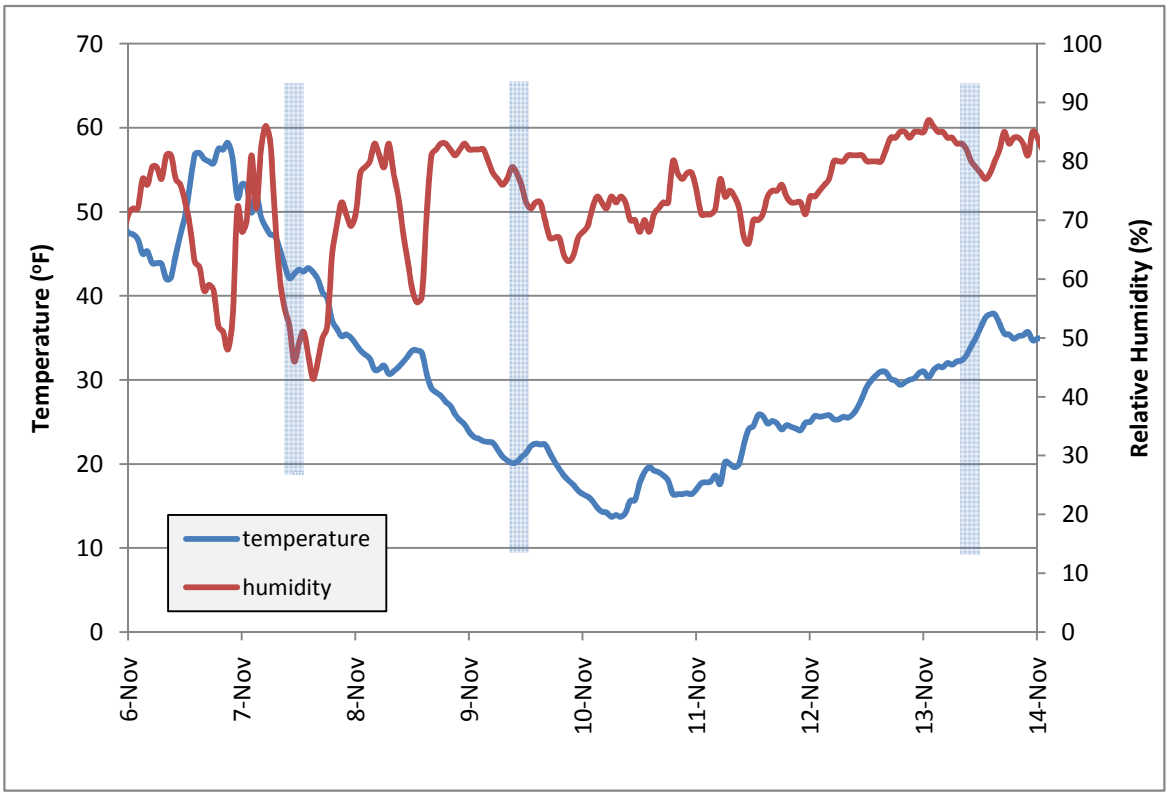
PHOTOGRAPH OF WOODSTOVE BURNING CONDITIONS

Figure 3-4. Illustration of Woodstove Ash ABS Study Design



**Field blank was selected for analysis

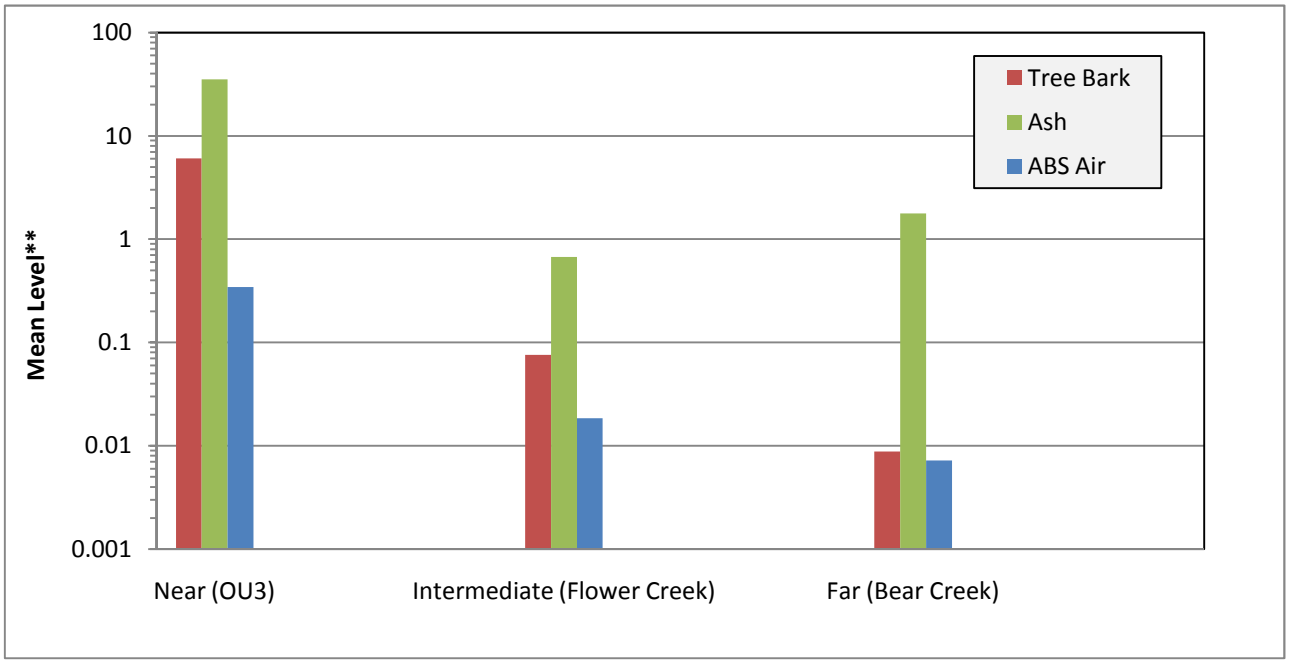
FIGURE 3-5
TEMPERATURE AND RELATIVE HUMIDITY DURING THE STUDY



Event 1 11/7/2012, 9:30-11AM
Event 2 11/9/2012, 9:15-10:30AM
Event 3 11/13/2012, 9:15-10:15AM
Approximate ABS event periods are shaded

% = percent
°F = degrees Fahrenheit

FIGURE 4-1 MEAN LEVELS IN EACH MEDIUM AS A FUNCTION OF DISTANCE FROM THE MINE



**Mean level (across events); reported units for each media type are as follows:

Tree bark = total LA Ms/cm^2
Ash = total LA Ms/g
ABS Air = PCME LA s/cc

ABS = activity-based sampling
LA = Libby amphibole
Ms/cm^2 = million structures per square centimeter of bark surface
Ms/g = million structures per gram of ash
OU3 = Operable Unit 3
PCME = phase contrast microscopy-equivalent
s/cc = structures per cubic centimeter of air

Data Summary Report:
Wood-burning Stove Ash Removal Activity-Based Sampling
Libby Asbestos Superfund Site, Libby, Montana

TABLES

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TABLE 4-1 RESULTS FOR TREE BARK AND ASH SAMPLES COLLECTED DURING THE WOODSTOVE ASH ABS STUDY

Panel A: Tree Bark Samples

Location	Event	Sample ID	Replicate #1			Replicate #2			Replicate #3			Mean Surface Loading, across reps (Ms/cm^2)	Mean Surface Loading, across events (Ms/cm^2)
			Sensitivity ($1/cm^2$)	N Total LA Structures	Total LA Surface Loading (Ms/cm^2)	Sensitivity ($1/cm^2$)	N Total LA Structures	Total LA Surface Loading (Ms/cm^2)	Sensitivity ($1/cm^2$)	N Total LA Structures	Total LA Surface Loading (Ms/cm^2)		
Near (OU3)	1	WA-00005	9.8E+04	28	3	3.7E+05	50	18	3.7E+05	87	32	18	6
	2	WA-00026	7.5E+03	0	0	9.8E+03	0	0	1.6E+04	0	0	0	
	3	WA-00050	9.5E+04	6	0.6	9.5E+04	4	0.4	9.5E+04	6	0.6	0.5	
Intermediate (Flower Creek)	1	WA-00004	9.8E+04	1	0.1	1.2E+04	43	0.5	1.2E+04	3	0.04	0.2	0.08
	2	WA-00025	1.1E+04	1	0.01	1.1E+04	0	0	1.1E+04	1	0.01	0.007	
	3	WA-00049	3.8E+04	0	0	3.8E+04	0	0	3.8E+04	0	0	0	
Far (Bear Creek)	1	WA-00003	9.2E+04	0	0	6.7E+03	0	0	7.3E+03	4	0.03	0.01	0.009
	2	WA-00024	2.5E+04	0	0	2.5E+04	0	0	2.5E+04	2	0.05	0.02	
	3	WA-00048	3.8E+04	0	0	3.8E+04	0	0	3.8E+04	0	0	0	

Samples analyzed by TEM-ISO (high magnification, target sensitivity 100,000 cm^{-2})

Panel B: Ash Samples

Location	Event	Sample ID	Replicate #1			Replicate #2			Replicate #3			Mean Ash Conc., across reps (Ms/g)	Mean Ash Conc., across events (Ms/g)
			Sensitivity (1/g)	N Total LA Structures	Total LA Ash Conc. (Ms/g)	Sensitivity (1/g)	N Total LA Structures	Total LA Ash Conc. (Ms/g)	Sensitivity (1/g)	N Total LA Structures	Total LA Ash Conc. (Ms/g)		
Near (OU3)	1	WA-00019	9.9E+06	2	20	9.9E+06	2	20	1.0E+07	11	109	50	35
	2	WA-00034	8.2E+06	8	66	6.5E+06	2	13	8.1E+06	11	89	56	
	3	WA-00063	1.0E+07	0	0	1.0E+07	0	0	1.0E+07	0	0	0	
Intermediate (Flower Creek)	1	WA-00018	1.0E+07	0	0	9.9E+06	0	0	9.9E+06	0	0	0	0.7
	2	WA-00033	6.2E+06	0	0	6.3E+06	0	0	6.1E+06	1	6	2	
	3	WA-00062	1.0E+07	0	0	1.0E+07	0	0	1.0E+07	0	0	0	
Far (Bear Creek)	1	WA-00014	1.0E+07	0	0	1.0E+07	0	0	9.9E+06	0	0	0	2
	2	WA-00032	6.0E+06	1	6	7.2E+06	0	0	6.3E+06	0	0	2	
	3	WA-00061	1.0E+07	1	10	1.0E+07	0	0	1.0E+07	0	0	3	

Samples analyzed by TEM-ISO (high magnification, target sensitivity of 1E+07 g^{-1})

cm^2 = square centimeters
g = grams
ID = identifier
ISO = International Organization of Standardization
LA = Libby amphibole
Ms/cm^2 = million structures per square centimeter of bark surface
Ms/g = million structures per gram of ash
N = Number
OU3 = Operable Unit 3 (mine site)
TEM = transmission electron microscopy

TABLE 4-2 RESULTS FOR AIR SAMPLES COLLECTED DURING THEWOODSTOVE ASH ABS STUDY

Panel A: 6-hour Perimeter Stationary Air Samples (Collected During Burning)

Location	Event	Sample ID	Sensitivity (1/cc)	N Total LA Structures	Total LA Air Conc. (s/cc)
Downwind, during burn	1	WA-00002	0.0028	0	0
	2	WA-00021	0.0037	0	0
	3	WA-00045	0.0040	0	0

Samples analyzed by TEM-AHERA (high magnification, target sensitivity of 0.005 cc^{-1})

Panel B: 2-day Perimeter Stationary Air Samples (Collected for Duration of ABS Event)

Location	Event	Sample ID	Sensitivity (1/cc)	N Total LA Structures	Total LA Air Conc. (s/cc)
Downwind, during ABS	1	WA-00001	0.000040	0	0
	2	WA-00022	0.000040	0	0
	3	WA-00044	0.000040	0	0 *

Samples analyzed by TEM-ISO (high magnification, target sensitivity of 0.00004 cc^{-1})

** 1 chrysotile structure observed in this sample (0.000040 s/cc)*

Panel C: Personal ABS Air Samples

Location	Event	Sample ID		Sensitivity (1/cc)	N PCME LA Structures	PCME LA Air Conc. (s/cc)	Mean PCME LA Air Conc., across events (s/cc)
		HV	LV				
Near (OU3)	1	WA-00015	WA-00016	0.0060	25	0.2	0.3
	2	WA-00037	WA-00040	0.026	32	0.8	
	3	WA-00059	WA-00060	0.0057	7	0.04	
Intermediate (Flower Creek)	1	WA-00011	WA-00012	0.0058	1	0.006	0.02
	2	WA-00036	WA-00039	0.0055	8	0.04	
	3	WA-00057	WA-00058	0.0057	1	0.006	
Far (Bear Creek)	1	WA-00008	WA-00009	0.0058	0	0	0.007
	2	WA-00035	WA-00038	0.0054	4	0.02	
	3	WA-00055	WA-00056	0.027	0	0	

Samples analyzed by TEM-ISO (low magnification, PCME only; target sensitivity of 0.0058 cc^{-1})

All HV filters were analyzed using indirect-ashing preparation.

ABS = activity-based sampling
AHERA = Asbestos Hazard Emergency Response Act
cc = cubic centimeters
HV = high volume filter
ID = identifier
ISO = International Organization of Standardization
LA = Libby amphibole
LV = low volume filter
N = Number
OU3 = Operable Unit 3 (mine site)
PCME = phase contrast microscopy-equivalent
s/cc = structures per cubic centimeter of air
TEM = transmission electron microscopy

TABLE 5-1 EVALUATION OF FIELD DUPLICATES FOR TREE BARK

Location	Sample ID	Sample Type	Replicate #1			Replicate #2			Replicate #3			Pooled**			Possion Ratio Comparison (90% Confidence Interval)
			Sensitivity ($1/cm^2$)	N Total LA Structures	Total LA Surface Loading (Ms/cm^2)	Sensitivity ($1/cm^2$)	N Total LA Structures	Total LA Surface Loading (Ms/cm^2)	Sensitivity ($1/cm^2$)	N Total LA Structures	Total LA Surface Loading (Ms/cm^2)	Sensitivity ($1/cm^2$)	N Total LA Structures	Total LA Surface Loading (Ms/cm^2)	
Near (OU3)	WA-00050	Field Sample	9.5E+04	6	0.6	9.5E+04	4	0.4	9.5E+04	6	0.6	3.2E+04	16	0.5	[0.36-1.13] The rates are not different
	WA-00053	Field Duplicate	9.5E+04	12	1	9.5E+04	6	0.6	9.5E+04	7	0.7	3.2E+04	25	0.8	
Intermediate (Flower Creek)	WA-00049	Field Sample	3.8E+04	0	0.0	3.8E+04	0	0.0	3.8E+04	0	0.0	1.3E+04	0	0.0	Both counts are 0; the rates are not different
	WA-00052	Field Duplicate	3.8E+04	0	0.0	3.8E+04	0	0.0	3.8E+04	0	0.0	1.3E+04	0	0.0	
Far (Bear Creek)	WA-00048	Field Sample	3.8E+04	0	0.0	3.8E+04	0	0.0	3.8E+04	0	0.0	1.3E+04	0	0.0	Both counts are 0; the rates are not different
	WA-00051	Field Duplicate	3.8E+04	0	0.0	3.8E+04	0	0.0	3.8E+04	0	0.0	1.3E+04	0	0.0	

Samples analyzed by TEM-ISO (high magnification, target sensitivity 100,000 cm^{-2})

**Pooled values are calculated as:

Pooled Sensitivity = $1/(1/S_1 + 1/S_2 + 1/S_3)$

Pooled N = $N_1 + N_2 + N_3$

Pooled Loading = Pooled N * Pooled Sensitivity

cm^2 = square centimeters
ID = identifier
ISO = International Organization of Standardization
LA = Libby amphibole
Ms/cm^2 = million structures per square centimeter of bark surface
N = Number
OU3 = Operable Unit 3 (mine site)
S = sensitivity
TEM = transmission electron microscopy

TABLE 5-2 CHISQ TEST FOR EVENNESS OF FILTER LOADING

Media	Sample ID	Analysis Replicate	Laboratory	Analysis Method	Preparation Method	CHISQ p-value	CHISQ test conclusion
Air	WA-00001		ESATR8	TEM-ISO	Direct	---	pass
Air	WA-00002		EMSL27	TEM-AHERA	Direct	---	pass
Air	WA-00008		Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Air	WA-00011		Hygeia	TEM-ISO	Indirect - Ashed	4.9E-01	pass
Air	WA-00015		Hygeia	TEM-ISO	Indirect - Ashed	8.5E-04	fail
Air	WA-00020		ESATR8	TEM-ISO	Direct	---	pass
Air	WA-00021		EMSL27	TEM-AHERA	Direct	---	pass
Air	WA-00022		ESATR8	TEM-ISO	Direct	---	pass
Air	WA-00031		ESATR8	TEM-ISO	Direct	---	pass
Air	WA-00035		RESI	TEM-ISO	Indirect - Ashed	5.3E-01	pass
Air	WA-00036		RESI	TEM-ISO	Indirect - Ashed	5.9E-01	pass
Air	WA-00037		RESI	TEM-ISO	Indirect - Ashed	3.0E-01	pass
Air	WA-00044		ESATR8	TEM-ISO	Direct	---	pass
Air	WA-00045		EMSL27	TEM-AHERA	Direct	---	pass
Air	WA-00055		EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Air	WA-00057		EMSL27	TEM-ISO	Indirect - Ashed	4.9E-01	pass
Air	WA-00059		EMSL27	TEM-ISO	Indirect - Ashed	5.6E-01	pass
Ash	WA-00014	Rep1	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00014	Rep2	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00014	Rep3	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00018	Rep1	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00018	Rep2	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00018	Rep3	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00019	Rep1	Hygeia	TEM-ISO	Indirect - Ashed	5.1E-01	pass
Ash	WA-00019	Rep2	Hygeia	TEM-ISO	Indirect - Ashed	5.1E-01	pass
Ash	WA-00019	Rep3	Hygeia	TEM-ISO	Indirect - Ashed	6.0E-11	fail
Ash	WA-00032	Rep1	RESI	TEM-ISO	Indirect - Ashed	4.5E-01	pass
Ash	WA-00032	Rep2	RESI	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00032	Rep3	RESI	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00033	Rep1	RESI	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00033	Rep2	RESI	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00033	Rep3	RESI	TEM-ISO	Indirect - Ashed	4.5E-01	pass
Ash	WA-00034	Rep1	RESI	TEM-ISO	Indirect - Ashed	2.9E-01	pass
Ash	WA-00034	Rep2	RESI	TEM-ISO	Indirect - Ashed	5.3E-01	pass
Ash	WA-00034	Rep3	RESI	TEM-ISO	Indirect - Ashed	5.6E-01	pass
Ash	WA-00061	Rep1	EMSL27	TEM-ISO	Indirect - Ashed	4.3E-01	pass
Ash	WA-00061	Rep2	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00061	Rep3	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00062	Rep1	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00062	Rep2	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00062	Rep3	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00063	Rep1	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00063	Rep2	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Ash	WA-00063	Rep3	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00003	Rep1	RESI	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00003	Rep2	RESI	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00003	Rep3	RESI	TEM-ISO	Indirect - Ashed	2.8E-01	pass
Bark	WA-00004	Rep1	RESI	TEM-ISO	Indirect - Ashed	4.1E-01	pass

TABLE 5-2 CHISQ TEST FOR EVENNESS OF FILTER LOADING

Media	Sample ID	Analysis Replicate	Laboratory	Analysis Method	Preparation Method	CHISQ p-value	CHISQ test conclusion
Bark	WA-00004	Rep2	RESI	TEM-ISO	Indirect - Ashed	3.5E-02	pass
Bark	WA-00004	Rep3	RESI	TEM-ISO	Indirect - Ashed	3.0E-01	pass
Bark	WA-00005	Rep1	RESI	TEM-ISO	Indirect - Ashed	4.7E-01	pass
Bark	WA-00005	Rep2	RESI	TEM-ISO	Indirect - Ashed	1.6E-01	pass
Bark	WA-00005	Rep3	RESI	TEM-ISO	Indirect - Ashed	4.5E-01	pass
Bark	WA-00024	Rep1	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00024	Rep2	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00024	Rep3	EMSL27	TEM-ISO	Indirect - Ashed	1.1E-01	pass
Bark	WA-00025	Rep1	EMSL27	TEM-ISO	Indirect - Ashed	3.9E-01	pass
Bark	WA-00025	Rep2	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00025	Rep3	EMSL27	TEM-ISO	Indirect - Ashed	3.9E-01	pass
Bark	WA-00026	Rep1	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00026	Rep2	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00026	Rep3	EMSL27	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00048	Rep1	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00048	Rep2	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00048	Rep3	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00049	Rep1	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00049	Rep2	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00049	Rep3	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00050	Rep1	Hygeia	TEM-ISO	Indirect - Ashed	4.3E-01	pass
Bark	WA-00050	Rep2	Hygeia	TEM-ISO	Indirect - Ashed	1.7E-01	pass
Bark	WA-00050	Rep3	Hygeia	TEM-ISO	Indirect - Ashed	3.8E-02	pass
Bark	WA-00051	Rep1	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00051	Rep2	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00051	Rep3	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00052	Rep1	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00052	Rep2	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00052	Rep3	Hygeia	TEM-ISO	Indirect - Ashed	---	pass
Bark	WA-00053	Rep1	Hygeia	TEM-ISO	Indirect - Ashed	4.6E-02	pass
Bark	WA-00053	Rep2	Hygeia	TEM-ISO	Indirect - Ashed	3.8E-02	pass
Bark	WA-00053	Rep3	Hygeia	TEM-ISO	Indirect - Ashed	2.6E-01	pass
Water	WA-00006		EMSL27	TEM-ISO	Direct	4.8E-01	pass
Water	WA-00030		EMSL27	TEM-ISO	Direct	---	pass
Water	WA-00054		EMSL27	TEM-ISO	Direct	---	pass

--- = sample was non-detect; no p-value calculated

AHERA = Asbestos Hazard Emergency Response Act
CHISQ = chi-square
ID = identifier
ISO = International Organization of Standardization
TEM = transmission electron microscopy

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Data Summary Report:
Wood-burning Stove Ash Removal Activity-Based Sampling
Libby Asbestos Superfund Site, Libby, Montana

APPENDICES

[provided electronically upon request and approval by EPA]