FINAL

ACTIVITY-BASED SAMPLING SUMMARY REPORT
OPERABLE UNIT 4
LIBBY, MONTANA, SUPERFUND SITE

June 2, 2010

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APPROVAL PAGE

This *Activity-Based Sampling Summary Report for Operable Unit 4 at the Libby Asbestos Superfund Site* has been reviewed by EPA and is approved for external release and distribution.

________________________________ June 2, 2010
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TABLE OF CONTENTS

APPENDICES *(provided electronically)*

ATTACHMENTS *(provided electronically)*

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

95UCL	95% upper confidence limit of the sample mean
ABS	Activity-Based Sampling
cc	cubic centimeters
CI	Confidence Interval
cm	centimeter
CSF	Close Support Facility
CTE	Central Tendency Exposure
CV	Coefficient of Variation
DQA	Data Quality Assessment
DQO	Data Quality Objectives
EDD	Electronic Data Deliverable
EDS	Energy Dispersive Spectroscopy
EF	Exposure Frequency
EPA	U.S. Environmental Protection Agency
EPC	Exposure Point Concentration
ERT	Emergency Response Team
ET	Exposure Time
FSDS	Field Sample Data Sheet
GO	Grid Opening
HV	High Volume
IUR	Inhalation Unit Risk
L	liters
LA	Libby Amphibole Asbestos
LB	Lower Bound
LFO	Libby Field Office
LV	Low Volume
N	Number of Structures
ND	Non-Detect
NSUA	Non-Specific Use Area
OU	Operable Unit
PCC	Property Completion Checklist
PCM	Phase Contrast Microscopy
PCME	Phase Contrast Microscopy Equivalent
PLM	Polarized Light Microscopy
QC	Quality Control
RME	Reasonable Maximum Exposure
s	structures
SAED	Selected Area Electron Diffraction
SAP	Sampling and Analysis Plan
SOP	Standard Operating Procedure
SPP	Soil Preparation Plan
SQAPP	Supplemental Remedial Investigation Quality Assurance and Project Plan
SUA	Specific Use Area

ACRONYMS AND ABBREVIATIONS (cont.)

TEM	Transmission Electron Microscopy
TWF	Time Weighting Factor
UB	Upper Bound
VCS	Vermiculite-Containing Soil
VE	Visual Area Estimation

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EXECUTIVE SUMMARY

Introduction

Libby is a community in northwestern Montana that is located near a large open-pit vermiculite mine. Vermiculite from this mine contains varying levels of a form of asbestos referred to as Libby Amphibole (LA). Starting in 2000, the U.S. Environmental Protection Agency (EPA) began taking a range of cleanup actions at the site to reduce or eliminate sources of LA exposure to residents and workers. In December 2003, EPA developed a protocol (EPA 2003) for investigating sources of LA at homes and workplaces in the main residential and commercial areas of Libby and deciding when to take action. Cleanup actions taken under this protocol typically include removal of unenclosed vermiculite insulation from living spaces and other readily accessible spaces (e.g., unfinished attics), removal of some or all contaminated outdoor soils, and may, in some cases, include cleanup of indoor dusts.

In order to further investigate the residual levels of exposure and risk that may exist at post-cleanup[1] properties, EPA conducted the Indoor and Outdoor Activity-Based Sampling (ABS) programs which were designed to collect data on residual indoor and outdoor exposures (EPA 2007a,b). A brief description of these sampling programs and their findings are summarized below.

Outdoor ABS Program

Program Description

The Outdoor ABS program was designed to measure LA levels in outdoor air during three residential soil disturbance activities – raking, mowing, and digging. Sampling was conducted at 75 outdoor ABS areas which spanned a range of post-cleanup conditions and soil LA levels. Because the levels of LA in outdoor ABS air generated during soil disturbance scenarios may depend on factors that vary seasonally (e.g., soil moisture, wind speed, humidity), the Outdoor ABS program included two sampling events – one in the summer and one in the spring. During each sampling event, soil samples were collected from each outdoor ABS area and air samples were collected during each disturbance scenario for the analysis of LA.

Major Findings

- There was high variability in the concentration of PCME[2] LA observed in the outdoor ABS air samples, ranging from non-detect (usually < 0.001 s/cc) to more than 20 s/cc. On average, the concentration values associated with mowing and digging tended to be similar, with the

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[1] The term "*post-cleanup property*" is used to indicate any property where EPA has investigated sources and has either taken cleanup action or else determined that no cleanup action was needed under the current decision-making protocol (EPA 2003).

[2] Air concentrations used in risk computations are expressed in terms of phase contrast microscopy (PCM) fibers. LA structures that are indentified under transmission electron microscopy (TEM) that meet PCM counting rules are referred to as PCM-equivalent (PCME).

values for raking tending to be somewhat lower. There was relatively high variability between sampling rounds, with Round 1 (summer) tending to yield higher concentration values than Round 2 (spring).

- The relationship between LA levels in outdoor ABS air and the level of LA in soil was investigated using several different strategies for characterizing the level of soil contamination. In most cases, the average concentration of PCME LA in ABS air tended to increase as a function of increasing levels of LA in soil, although the strength of the trend varied somewhat between different methods for characterizing the level of soil contamination. No single method appeared to provide results that were inherently superior to others.

Indoor ABS Program

Program Description

The Indoor ABS program was designed to measure LA levels in indoor air during two residential disturbance conditions – active and passive behaviors. During active behaviors, a person may be moving about the building and potentially disturbing indoor sources (e.g., dusting, sweeping, vacuuming). During passive behaviors, a person is engaged in minimally energetic actions that will have low tendency to disturb any indoor sources (e.g., watching television). Sampling was conducted at 80 indoor ABS properties which spanned a range of post-cleanup conditions. Because the levels of LA in indoor air may depend on factors that vary seasonally (e.g., indoor activity patterns, humidity, building ventilation rate), the Indoor ABS program included four sampling events – summer, fall, winter, and spring. During each sampling event, indoor dust samples were collected from each indoor ABS property and air samples were collected during each disturbance condition for the analysis of LA. In addition, prior to the first sampling event, two soil samples were collected from each indoor ABS property for LA analysis. One soil sample was representative of all non-specific use areas (NSUAs) in the yard, and the other soil sample was representative of all specific use areas (SUAs). SUAs include areas such as gardens, flowerbeds, unpaved driveways, and play areas where human exposure is likely to occur on a frequent basis.

Major Findings

- The concentration of PCME LA observed in the indoor ABS air samples ranged from non-detect (usually < 0.0003 s/cc) to about 0.01 s/cc. On average, the concentration values associated with active behaviors were higher than for passive behaviors, supporting the concept that disturbance of an indoor source such as contaminated indoor dust is one contributing factor to indoor air levels of LA. Indoor air levels of LA tended to be lowest during the winter and highest during the summer for both active and passive behaviors.

- It was not possible to establish a quantitative relationship between LA levels in indoor air and indoor dust because nearly all of the dust samples (326 out of 336) were non-detect for LA (< 3 to 27 s/cm^2).

- A weak correlation could be detected between average indoor air concentrations of PCME LA and the level of LA in outdoor soil. These results support the concept that outdoor soil is a source that contributes to indoor air contamination. However, regression analysis suggests that other sources besides outdoor soil may also be important.

Screening Level Risk Characterization

In order to help place the ABS results into perspective, screening level estimates of cancer risk were calculated using presently available methods. The screening level risk calculations suggest that residual risks from indoor exposures at post-cleanup properties are likely to be within EPA's acceptable risk range. Residual risks from outdoor exposures to PCME LA in air appeared to depend on the level of residual LA in soil. At ABS areas with no detectable LA in soil, risks tend to be mainly within EPA's acceptable risk range. However, at areas with detectable levels of LA in soil, residual risks may approach or exceed the high end of EPA's acceptable risk range. Because of the high variability in ABS air values and the multiple sources of uncertainty in the process of estimating cancer risks, the boundary between acceptable and unacceptable is difficult to define with confidence.

It is important to note that these preliminary risk calculations are for *screening purposes only.* Results are based on toxicity factors that are presently available, and include the indoor and outdoor ABS air exposure pathways only (i.e., do not account for cumulative exposures). Consequently, these screening level risk calculations are not intended to support final risk management decision-making at any specific locations. Final risk evaluations will be presented in the Human Health Risk Assessment for Libby Operable Unit 4 (OU4).

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1 Introduction

1.1 Site Background

Libby is a community in northwestern Montana that is located near a large open-pit vermiculite mine. Vermiculite from this mine contains varying levels of a form of asbestos referred to as Libby Amphibole (LA). Historic mining, milling, and processing operations at the Site, as well as bulk transfer of mining-related materials, tailings, and waste to locations throughout Libby Valley, are known to have resulted in releases of vermiculite and LA to the environment that have caused a range of adverse health effects in exposed people, including not only workers at the mine and processing facilities (Amandus and Wheeler 1987; McDonald et al. 1986, 2004; Whitehouse 2004; Sullivan 2007), but also in residents of Libby (Peipins et al. 2003, Noonan et al. 2006, Whitehouse et al. 2008).

Starting in 2000, the U.S. Environmental Protection Agency (EPA) began taking a range of cleanup actions at the site to reduce or eliminate sources of LA exposure to residents and workers. In the early stages, efforts were focused mainly on cleanup of locations containing the highest concentrations of LA and vermiculite-containing wastes and soil contamination, such as former vermiculite processing areas, area school running tracks, and some residences. As work progressed, attention shifted to cleanup of homes and workplaces in the main residential and commercial areas of Libby (Operable Unit [OU] 4). The protocol that EPA developed for investigating sources of LA at specific properties and deciding when to take action is detailed in a Technical Memorandum issued in December 2003 (EPA 2003). Cleanup actions taken under this protocol typically include removal of unenclosed vermiculite insulation from living spaces and other readily accessible spaces (e.g., unfinished attics), removal of some or all contaminated outdoor soils, and may, in some cases, include cleanup of indoor dusts.

1.2 Purpose of this Document

The purpose of the Indoor and Outdoor Activity-Based Sampling (ABS) efforts was to evaluate the efficacy and protectiveness of the cleanup strategy taken in OU4 at the Libby Asbestos Site. That is, the following questions were investigated:

- At a property that EPA has investigated and found no reason to take any cleanup actions under the approach described in EPA (2003), are the risks that remain sufficiently small to be considered acceptable?

- At a property where EPA has investigated and determined that one or more sources was present that required cleanup under the approach described in EPA (2003), are the risks that remain after the cleanup is complete sufficiently small to be considered acceptable?

Residual exposures that may remain at post-cleanup properties[3] may be divided into two main types – exposures that occur inside the building and exposures that occur outside the building. While previous sampling efforts at the Libby site provide some data that are applicable to an evaluation of residual exposures (e.g., the Phase 2 Investigation, the Supplemental Remedial Investigation Quality Assurance and Project Plan [SQAPP] Investigation), these data were determined to be too limited to support reliable risk assessment or risk management decisions (EPA 2007a,b).

In order to further investigate the residual levels of exposure and risk that may exist at post-cleanup properties, EPA developed two ABS programs designed to collect data on residual indoor and outdoor exposures. In brief, the Outdoor ABS program (EPA 2007a) measured asbestos in outdoor air in the immediate vicinity of an active soil disturbance under three soil disturbance scenarios – mowing, raking, and digging. The Indoor ABS program (EPA 2007b) measured asbestos in indoor air under two dust disturbance scenarios – active and passive conditions. Each ABS program also measured asbestos levels in the source materials that were disturbed (i.e., dust and soil).

The Indoor and Outdoor ABS sampling programs were conducted from May 2007 through June 2008. The purpose of this document is to summarize the results of the Indoor and Outdoor ABS studies and present estimates of residual exposure and risk that may exist inside and outside at post-cleanup properties in Libby to evaluate the efficacy and protectiveness of the current cleanup strategy.

This document also includes an analysis of the relationship between various metrics of LA in soil and measurements of LA in ABS air. This relationship is important because it is not feasible, due to both time and cost considerations, to perform ABS at every property in Libby. Instead, it is expected that risk managers will rely upon an extrapolation of ABS results between areas of similar LA contamination in soil to make cleanup decisions.

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 analytical methods used for estimating the level of LA in air, dust, and soil, and the data reduction methods utilized in this report.

Section 4 This section summarizes the data that were collected for outdoor ABS air, including an evaluation of the relationship between the level of LA in outdoor ABS air and in the soil being disturbed.

[3] The term "*post-cleanup property*" is used to indicate any property where EPA has investigated sources and has either taken cleanup action or else determined that no cleanup action was needed under the current decision-making protocol (EPA 2003).

Section 5 This section summarizes the data that were collected for indoor ABS air, including an evaluation of the relationship between the level of LA in indoor air and in potential source media.

Section 6 This section presents a screening-level risk characterization for residential exposures.

Section 7 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 8 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 and attachments are provided electronically on the included CDs.

2 Data Management

2.1 Sample Collection, Documentation, Handling, and Custody

All air, dust, and soil samples generated as part of the ABS program were collected, documented, and handled in accord with standard operating procedures (SOPs) as specified in the respective Indoor and Outdoor ABS Sampling and Analysis Plans (SAPs) (EPA 2007a,b). All ABS activities were conducted in accord with EPA's Emergency Response Team (ERT) SOP #2084, *Activity-Based Air Sampling for Asbestos*, with project-specific modifications (EPA 2007a,b).

All ABS samples collected were identified with sample index identification numbers (Index IDs) that included a program-specific prefix of "IN" for Indoor ABS program samples or "EX" for Outdoor ABS program samples (e.g., IN-00001, EX-00001). Data on the sample type, location, collection method, and collection date of all samples were recorded both in a field log book 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 type of analytical method. 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 log books, and chain of custody forms generated during the ABS sampling program are stored in the CDM field office in Libby, Montana. Appendix A of this report (provided electronically) provides copies of all the FSDS and chain of custody forms for samples collected as part of the ABS program.

Hard copies of all analytical bench sheets are included in the analytical laboratory reports. These analytical reports are submitted to the Libby Laboratory Coordinator and stored at the CDM offices in Denver, Colorado. Appendix A of this report provides copies of all the analytical laboratory reports for analyses performed as part of the ABS program.

2.4 *Electronic Data Management*

Sample and analytical electronic data are stored and maintained in the Libby site project database (referred to as the Libby2DB) which is housed on a SQL server at the EPA Region 8 office in Denver, Colorado. Raw data summarized in this report were downloaded from the Libby2DB on December 8, 2009, into a Microsoft Access® database by SRC, Inc. A copy of this Access database is provided in Appendix B of this report. Any changes made to the Libby2DB since this download will not be reflected in the Access database.

(Note: Since the collection of the Indoor and Outdoor ABS data in 2007-2008, addresses recorded in the Libby2DB were updated to reflect street naming conventions and house identifiers in the 911 emergency database (e911). For the purposes of this report, all addresses presented are pre-e911 (i.e., e911 changes are not reflected), to ensure consistency with the hard copy ABS documentation presented in Appendix A. Appendix B provides detailed information on which ABS property addresses have changed due to e911.)

3 Analysis Methods and Data Reduction

3.1 Transmission Electron Microscopy Analysis of Air and Dust Samples

3.1.1 Sample Preparation

If air samples were not deemed to be overloaded by particulates[4], filters were directly prepared for analysis by transmission electron microscopy (TEM) in accord with the preparation methods provided in ISO 10312 (ISO 1995).

If air samples were deemed to be overloaded, samples were prepared indirectly in accord with the procedures in SOP EPA-LIBBY-08. In brief, in an indirect preparation, rinsate or ashed residue from the original filter is suspended in water and sonicated, and an aliquot of this water is applied to a second filter which is then used to prepare a set of TEM grids. If there was no loose material present in the air cassette or adhering to the cowl, the indirect preparation method was performed as specified in ISO 13794, except that the total solution volume was increased from 40 mL to 100 mL, and a portion of the original filter was retained. If there was loose material present in the air cassette or adhering to the cowl, the indirect preparation procedure was performed as specified in ASTM D-5755, except that an ashing of the primary filter was included. A discussion of the potential influence of indirect preparation techniques on reported TEM air concentrations is presented in Section 6.4.

All dust samples were prepared indirectly (usually without ashing, as determined by the analyst) in accord with the procedures in SOP EPA-LIBBY-08. For dust samples, the indirect preparation procedure is equivalent to the method specified in ASTM D-5755.

3.1.2 Sample Analysis

Air and dust samples collected as part of the ABS program were analyzed by TEM in basic accord with the counting and recording rules specified in ISO 10312 (ISO 1995), and the ABS-specific counting rule modifications specified in the respective Indoor and Outdoor ABS SAPs (EPA 2007a,b). These modifications included changing the recording rule to include structures with an aspect ratio ≥ 3:1. The medium- and task-specific target sensitivities for TEM were specified in the ABS SAPs (EPA 2007a,b).

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 is determined by Selected Area Electron Diffraction (SAED) and Energy Dispersive Spectroscopy (EDS), and each structure is assigned to one of the following four categories:

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[4] Overloaded is defined as >25% obscuration on the majority of the grid openings (see Libby Laboratory Modification #LB-000016 and SOP EPA-LIBBY-08).

LA *Libby-class 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 sodic tremolitic solid solution series of minerals including winchite, richterite, and tremolite, with lower amounts of magnesio-arfvedsonite, magnesio-riebechite, and edenite/ferro-edenite.

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.

C *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.

For the purposes of this report, air concentrations and dust loading values are based on countable LA structures only (i.e., results for other amphibole-type asbestos and chrysotile are not discussed). Two alternative estimates of concentration are used in this report:

- Total LA. This measure includes all LA structures that satisfy the TEM counting rules specified in the SAP (length > 0.5 um, aspect ratio ≥ 3:1).

- PCME LA. This measure includes only a sub-set of the total LA structures that satisfy the counting rules (length > 5 um, width ≥ 0.25 um, aspect ratio ≥ 3:1) used in Phase Contrast Microscopy (PCM). For convenience, structures that are indentified under TEM that meet PCM counting rules are referred to as PCM-equivalent (PCME).

In this document, results of TEM analyses are generally expressed in units of PCME LA s/cc (air) or PCME LA s/cm^2 (dust). This is because asbestos concentrations must be expressed as PCM or PCME in order to perform risk calculations (see Section 6). Tabular data summaries provide the data expressed in terms of total LA and PCME LA.

There are two alternative approaches available for deriving concentration values in units of PCME. The first (and most direct) approach is to express the concentration of each sample in terms of the PCME structures observed in that sample. The second approach is to express the concentration of LA in each sample in terms of the total LA in that sample, and then multiply the total LA concentration by a value that represents the average fraction of total LA structures that meet PCME counting rules. For this evaluation, the first approach was followed.

3.1.3 Calculation of Air Concentration and Dust Loading Values

The concentration of LA in air is given by:

Air Concentration (s/cc) = N · S

where:

N = Number of structures observed
S = Sensitivity (cc^{-1})

For air, the sensitivity is calculated as:

$$S = \frac{EFA}{GO \cdot Ago \cdot V \cdot 1000 \cdot F}$$

where:

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

For dust, results are expressed as loading (s/cm^2), which is calculated as follows:

Dust loading (s/cm^2) = N · S

For dust, the sensitivity is calculated as:

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

where:

S	=	Sensitivity for dust (cm^{-2})
EFA	=	Effective area of the filter (mm^2)
GO	=	Number of grid openings examined
Ago	=	Area of a grid opening (mm^2)
SA	=	Area of surface collection (cm^2)
F	=	Fraction of primary sample deposited on secondary filter

3.1.4 Combining Results from Multiple Samples

When the exposure metric of concern is the average concentration across a set of multiple samples, the best estimate of the mean concentration is calculated simply by averaging the individual concentration values. Note that samples with a count of zero (and hence a concentration or loading of zero) are evaluated as zero when computing the best estimate of the mean (EPA 2008b). 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.

3.1.5 Estimating Confidence Bounds

<u>For an Individual Sample</u>

The uncertainty around a TEM estimate of asbestos concentration in a sample is a function of the number of structures observed during the analysis. The 95% confidence interval around a count of N structures is given by:

LB = ½·CHIINV[0.025, 2N+1]
UB = ½·CHIINV[0.975, 2N+1]

where:

LB = Lower bound on the 95% confidence interval on N
UB = Upper bound on the 95% confidence interval on N
CHIINV = Inverse chi-squared cumulative distribution function
N = Number of structures observed

As N increases, the absolute width of the confidence interval increases, but the relative uncertainty [expressed as the confidence interval (CI) divided by the observed value (N)] decreases.

Using this approach, the equation for calculation of the upper and lower bounds on the air concentration or dust loading of asbestos structures is:

Air Concentration (s/cc) or Dust Loading (s/cm^2) = (LB or UB) · S

where:

LB or UB = Number of structures based on lower bound (LB) or upper bound (UB)
S = Sensitivity (cc^{-1} for air or cm^{-2} for dust)

<u>Across Multiple Samples</u>

Calculation of the uncertainty bounds around the average of a group of asbestos samples is complicated by the fact that the between-sample variability in the measured concentration values includes the between-sample variability that arises from both analytical measurement error in individual samples and from between-sample temporal or spatial variability. EPA has not developed a method for calculating uncertainty bounds around the mean of asbestos data sets, so no uncertainty bounds are provided in this report for mean values. However, it is important to recognize that the values are uncertain, and that actual values might be either higher or lower than reported.

3.2 Polarized Light Microscopy Analysis of Soil Samples

3.2.1 Sample Preparation

Soil samples collected as part of the ABS program were prepared for analysis in accord with SOP ISSI-LIBBY-01 as specified in the CDM Close Support Facility (CSF) Soil Preparation Plan (SPP) (CDM 2004). In brief, each soil sample is dried and sieved through a ¼ inch screen. Particles retained on the screen (if any) are referred to as the “coarse” fraction. Particles passing through the screen are referred to as the fine fraction, and this fraction is ground by passing it through a plate grinder. The resulting material is referred to as the “fine ground” fraction. The fine ground fraction is split into four equal aliquots; one aliquot is submitted for analysis and the remaining aliquots are archived at the CSF.

3.2.2 Sample Analysis

Soil samples collected as part of the ABS program were analyzed using polarized light microscopy (PLM). The coarse fractions were examined using stereomicroscopy, and any particles of asbestos (confirmed by PLM) were removed and weighed in accord with SRC-LIBBY-01 (referred to as “PLM-Grav”). The fine ground aliquots were analyzed using a Libby-specific PLM method using visual area estimation, as detailed in SOP SRC-LIBBY-03. For convenience, this method is referred to as “PLM-VE”.

PLM-VE is a semi-quantitative method that utilizes site-specific LA reference materials to allow assignment of fine ground samples into one of four “bins”, as follows:

- *Bin A (ND):* non-detect
- *Bin B1 (Trace):* detected at levels lower than the 0.2% LA reference material
- *Bin B2 (<1%):* detected at levels lower than the 1% LA reference material but higher than the 0.2% LA reference material
- *Bin C:* LA detected at levels greater than or equal to the 1% LA reference material

Of the 412 soil field samples collected during the ABS program, 155 samples had a coarse fraction, and all of these samples were reported as non-detect for LA when analyzed by PLM-Grav. Because of this, this report focuses on the PLM-VE results for the fine ground fraction only.

3.3 Soil Visual Inspection

At the time of soil sample collection for PLM analysis, the sampling team performed a visual inspection of the displaced soil at each sampling point to determine if visible vermiculite was present in accord with SOP CDM-LIBBY-06. A semi-quantitative estimate (none, low, moderate[5], high) of the amount of visible vermiculite present was noted for each sampling point. A count of the number of sampling points assigned to each visible vermiculite ranking was recorded on the FSDS in the sample comments (e.g., 18 none [X], 6 low [L], 4 moderate [M], 2 high [H]).

There are several alternative ways that this visual inspection data can be used to characterize the level of vermiculite contamination (and presumptive LA contamination) in an ABS area. It is not possible to identify, *a priori*, a preferred visual inspection metric without investigating which may be the most useful predictor of ABS air concentrations (see Sections 4.2.4 and 5.2.4).

Option 1: Present/Absent

The simplest strategy classifies an ABS area either as "Vis –" if all sampling points in the composite were assigned a value of "none", or as "Vis +" if one or more of the sampling points were assigned a value of "low", "moderate", or "high".

A potential limitation to this ranking strategy is that it does not account for differences in the amount or frequency of visible vermiculite detections. For example, an ABS area with 1 "low" point and 29 "none" points and an ABS area with 30 "high" points would both be ranked as "Vis +".

Option 2: Detection Frequency

In this approach, an ABS area is assigned a value equal to the detection frequency by visible inspection. For example, an ABS area with 1 "low" point and 29 "none" points would receive a value of 1/30 (3.3%), while an ABS area with 1 "none" point and 29 "high" points would receive a score of 29/30 (97%).

While it is expected that detection frequency will tend to increase as a function of the level of soil contamination, it is important to note that detection frequency is not sensitive to the levels of contamination observed. For example, an ABS area with 5 "low" points and 25 "none" points would have the same detection frequency (5/30) as an ABS area with 5 "high" points and 25 "none" points.

Option 3: Amount-Weighted Score

In this approach, both the frequency and the level of vermiculite are considered. This is achieved by assigning a weighting factor to each level, where the weighting factors are intended to represent the relative levels of vermiculite in each category. As presented in SOP CDM-LIBBY-06, the guidelines for assigning levels are as follows:

[5] The visual inspection SOP CDM-LIBBY-06 uses the terminology "intermediate" to refer to the "moderate" classification. For the purposes of this document, the term "moderate" is retained to correspond with the accompanying ABS field documentation.

None = No flakes of vermiculite detected observed within the inspection point.

Low = A maximum of a few flakes of vermiculite observed within the inspection point.

Moderate/High = Vermiculite easily observed throughout the inspection point, including the surface. A ranking of High is reserved for samples that are 50% or more vermiculite. Others (<50%) are assigned a ranking of Moderate.

Based on these descriptions, the weighting factors that were used in this evaluation are as follows:

Visible Vermiculite Level (L_i)	Weighting factor (W_i)
None	0
Low	1
Moderate	3
High	10

The score is then the weighted sum of the observations for the area:

$$Score = \frac{\sum_{i=1}^{30} L_i \cdot W_i}{30}$$

This value can range from zero (all 30 points are "none") to a maximum of 10 (all 30 points are "high"). For example, an ABS area with 1 "low" point and 29 "none" points would receive a score of 1/30 = 0.033, while an ABS area with 25 "moderate" points and 5 "high" would receive a score of (25·3 + 5·10) / 30 = 4.17.

4 Outdoor Activity-Based Sampling Summary and Evaluation

4.1 Study Design

Detailed information on the Outdoor ABS study design and program-specific data quality objectives (DQOs) are provided in the Outdoor ABS SAP (EPA 2007a; 2008a). In brief, the purpose of the study was to obtain sufficient outdoor ABS air data to determine if any of the residual sources of LA contamination in outdoor soil pose an unacceptable risk to human health. The DQOs identified two decisions that were to be addressed by the Outdoor ABS study:

1. Is the current strategy for cleaning up outdoor soil in OU4 adequate to provide health protection from exposures that occur when residents disturb the soil?

2. If not, what characteristics of the soil (e.g., presence of visible vermiculite and/or PLM VE result) can be used to recognize areas that require further cleanup?

An overview of the study design developed to address these questions is summarized below.

4.1.1 Sampling Locations

Sampling locations evaluated as part of the Outdoor ABS program were selected to be representative of the range of types and levels of residual sources that may remain in post-cleanup areas. In brief, outdoor ABS locations were stratified into 5 soil categories based on the existing PLM-VE soil sample results and the existing information on visual presence or absence of vermiculite, as follows:

Soil Category	Residual Source	
	PLM-VE Analysis for LA	Visual Presence of Vermiculite
1	None (Clean Fill[6])	
2	Bin A (ND)	No
3		Yes
4	Bin B1 (Trace)	Either Yes or No
5	Bin B2 (<1%)	Either Yes or No

After soliciting cooperation from area residents, a total of 75 outdoor ABS locations were selected for participation in the study, with 14-16 properties per category:

[6] "Clean fill" is soil material that is brought in from borrow pits located in the Libby Valley and in Eureka, Montana to replace materials that have been removed as part of a soil cleanup. Because these fill materials are not exposed until excavation, it is believed that they are not impacted by mining-related releases.

Category	Number of locations
1	15
2	15
3	15
4	14
5	16
Total	75

These outdoor ABS sampling locations were selected to provide a reasonable spatial representation in OU4 (i.e., north, central, and south Libby). A total of 75 outdoor ABS locations at 62 different properties were sampled. Figure 4-1 shows the locations of these properties. Table 4-1 provides detailed information on the types of cleanup actions that have been performed at each property.

4.1.2 Disturbance Scenarios

Residents may disturb soil in their yards by a wide variety of activities. Because it is not feasible to evaluate every possible type of disturbance that may occur under residential land use conditions, the Outdoor ABS program focused on three standardized scenarios which are considered to be realistic examples of relatively vigorous soil disturbance activities:

- Raking the lawn or yard with a metal-tined leaf rake
- Mowing the yard with a gasoline-powered rotary lawn mower
- Digging in the soil with a shovel and pail (simulating a child playing)

During each ABS sampling event, soil disturbance activities were performed over a 6-hour time interval, divided into three sub-periods of 2 hours each (one for each disturbance scenario). All soil disturbance activities were performed in accord with a standard ABS “script” by EPA contractor personnel.

4.1.3 Sampling Dates

Because the levels of LA in outdoor ABS air generated during soil disturbance scenarios may depend on factors that vary seasonally (e.g., soil moisture, wind speed, humidity), the Outdoor ABS program targeted two sampling periods intended to span a range of soil moisture and meteorological conditions. Outdoor ABS Round 1 (summer) was performed from July to August 2007 and Outdoor ABS Round 2 (spring) was performed from April to June 2008. The same outdoor ABS locations were evaluated in both rounds.

4.1.4 Sample Collection and Analysis

4.1.4.1 Air Samples

As noted above, three different disturbance scenarios were evaluated at each outdoor ABS location. During each disturbance scenario, the individual performing the activity wore two personal air monitors (high volume and low volume) to collect air samples for asbestos analysis. The filter cassette for each monitor was placed such that the samples collected were representative of the breathing zone of the individual performing the disturbance activity (i.e., a hemisphere approximately 6 to 9 inches around an individual's face). All outdoor ABS air samples were collected in basic accord with procedures provided in EPA-LIBBY-01 and ERT SOP#2084.

The high volume sample was collected using a pump with a flow rate of 10 L/min (total air volume of 1,200 L), and the low volume sample was collected using a pump with a flow rate of 3 L/min (total air volume of 360 L) (EPA 2007d). The high volume sample was analyzed in preference to the low volume sample because maximizing the total air volume collected reduced the level of effort needed to achieve the target analytical sensitivity. In cases where the high volume sample was damaged or lost, the low volume was substituted. Unanalyzed low volume samples were archived at the Libby Field Office in Libby, MT. Prepared TEM grids and unused portions of the analyzed filters were archived at the analytical laboratory.

As specified in the Outdoor ABS SAP, each soil disturbance activity was planned to span a 2-hour time interval. However, in Round 1, the laboratories reported that a high number of filters were overloaded and would require indirect preparation. In an attempt to reduce the number of overloaded samples, the sample collection protocol was modified (see Outdoor ABS SAP Mod 1 in Appendix F) to stop the sample collection if the filter became overloaded (based on a visual inspection in the field). This modification was in effect in Round 1 from August 16 through August 24, 2007[7]. Section 7.5.1 discusses the potential impact of air samples with sample durations less than 2 hours on data interpretation. After August 24, 2007 (i.e., in Round 2), this modification was no longer implemented and sampling methods continued in accord with the procedures presented in the Outdoor ABS SAP.

All outdoor air samples were submitted to one of the subcontracted Libby laboratories for asbestos analysis by TEM in basic accord with the counting and recording rules specified in ISO 10312 (ISO 1995), and the ABS-specific counting rule modifications (EPA 2007a). The target analytical sensitivity for all outdoor ABS air samples was 0.001 cc^{-1}.

4.1.4.2 Soil Samples

In each sampling round, prior to the start of ABS activities, a qualitative estimate of soil moisture at each ABS location was determined in the field by the "hand appearance" method. A detailed description of this method is provided in the Outdoor ABS SAP. In brief, this procedure is performed by firmly squeezing a handful of soil and observing how easily the soil forms a ball and breaks apart under pressure. This evaluation was performed using a soil sample collected from a minimum of 5 sub-areas representing the ABS area from a depth of 0-2 inches below ground surface. In Round 1, ABS activities were not performed if the soil moisture deficiency was less than 50% or if greater than 1/10-inch of rain had fallen in the previous 36 hours. In Round 2, a strict soil moisture deficiency restriction was not applied; but, ABS activities were not performed in areas with standing water or while it was raining (EPA 2008a).

[7] Round 1 of sampling ended on August 24, 2007.

In Round 1, one 30-point composite soil sample was collected from each outdoor ABS location. The composite sample was collected such that the entire ABS location was represented by the sample (i.e., the 30 sampling points were spread across the entire ABS area). Upon reviewing the preliminary results from Round 1, it was determined that, while this 30-point composite sample was representative of the areas disturbed during the mowing and raking scenarios, it was not necessarily a reliable indicator of the soil where the digging scenario occurred, since digging was conducted at only two specific sub-areas within the ABS area. To address this issue, two different soil samples were collected from each outdoor ABS location in Round 2 (EPA 2008a). The first soil sample was a 30-point composite sample representative of the entire ABS area utilized in the raking and mowing scenarios (equivalent to what was collected in Round 1). The second soil sample was a 2-point composite sample collected from the two digging sub-areas (1 grab from each sub-area).

All soil samples collected as part of the Outdoor ABS program were sampled in accord with SOP CDM-LIBBY-05, and were prepared (dried, ground, sieved) and submitted for asbestos analysis by PLM. In addition, visual inspection data were collected and reported as described in Section 3.3 above.

4.2 Results

Appendix C presents the detailed raw data for all samples collected as part of the Outdoor ABS program.

4.2.1 Overview of the Outdoor ABS Air Data

Results of the ABS air samples, stratified by ABS area and disturbance scenario, are presented in Table 4-2 (Round 1) and Table 4-3 (Round 2). Figure 4-2 displays the PCME LA air concentration data using two different formats to characterize the distribution of values observed. The upper panel presents the data in a “scatterplot” format and the lower panel presents the data as a “box-and-whisker”. Note that, in both graphs, air concentration (the y-axis) is presented using a log-scale. Because samples with a concentration of zero cannot be plotted on a log-scale, for plotting purposes only they were assigned a value of 0.0001 s/cc, which is equal to the x-axis in the figure. Because scatterplots are often more difficult to assess and interpret than box-and-whisker graphs, especially when the emphasis is on a statistic rather than individual data points, this document will primarily utilize a box-and-whisker format for data presentation.

One important observation is the high variability between samples. In most cases, the range is at least 3 to 4 orders of magnitude. The cause of such high variability is not certain, but is probably a consequence of random variations in a number of factors that influence the release of LA from soil to air (e.g., concentration of LA in the soil, soil moisture, soil cover, duration and intensity of the disturbance, wind speed) as well as random sampling variation and Poisson counting error.

Although there is substantial overlap between all of the data sets, two trends seem apparent[8]:

- Within each of the two rounds, air concentrations associated with the mowing and digging scenarios tend to be higher than concentrations associated with raking.
- For all activities, air concentrations in Round 1 (summer) tend to be higher than in Round 2 (spring).

The reason for the generally lower release of LA in Round 2 compared to Round 1 is not known. Two factors that might be important are the moisture content of the soil and the extent of vegetative cover at the time of the ABS event. Data on soil moisture and percent vegetative cover were collected at each ABS study area in both Round 1 and Round 2. Pair-wise comparisons of the data are summarized below:

Round 2 vs. Round 1	Metric	
	Soil Moisture	Vegetative Cover
Increase	39	16
Decrease	4	12
No Change	32	47
Total	75	75

As seen, 39 of the outdoor ABS areas were ranked as having higher soil moisture in Round 2 than Round 1, while only 4 ABS areas were ranked as having lower soil moisture in Round 2 than Round 1. This suggests that increased soil moisture might be one factor contributing to the generally lower releases in Round 2 compared to Round 1. Differences in the extent of vegetative cover do not appear to be as important. Defining a meaningful change in grass cover as an increase or a decrease of more than 10%, there were approximately an equal number of ABS areas with increased cover (16) and decreased cover (12) in Round 2 compared to Round 1, with a change of less than 10% in the remaining areas.

4.2.2 Correlation of ABS Air Within and Between Rounds

Table 4-4 presents the Pearson product moment and the Spearman rank order correlation coefficients that characterize the degree to which there is a relationship in the ABS air concentrations between ABS samples associated with different activities performed at a location within a sampling round. As seen, for Round 1 there was a fairly high correlation between the ABS air concentrations associated with different activities at a location. This means that if the ABS air sample for one activity at a location was high, then the ABS air samples for the other two activities also tended to be high at that location. In Round 2, the correlations tended to be somewhat lower.

[8] At present, no statistical method has been developed that is suitable for use with data sets that are similar to those observed in Libby for comparing two asbestos data sets in order to estimate the probability (*p* value) that one set is different from another.

Table 4-5 presents the Pearson and Spearman coefficients that characterize the degree of correlation between ABS air samples for the same activity performed at the same location at different times (Round 1 vs. Round 2). As indicated, the correlations are not strong, especially for the Pearson product moment method. This indicates that the between-round variability at a location is relatively large compared to the between-location variability.

4.2.3 Overview of the Soil Data

4.2.3.1 Observed Levels

As discussed above, the level of LA in soil at each ABS study area was characterized using two alternative soil metrics (PLM-VE and visible vermiculite inspection) in both Round 1 and Round 2. Table 4-6 presents the Outdoor ABS soil data.

Table 4-7 summarizes the frequency of soil levels observed in Round 1 and Round 2 based on the 30-point composite samples. As seen, the soil data span a range of levels, although a majority of the samples are at the low end of the range, both for PLM-VE (more than ⅔ of the results are Bin A) and for visual inspection score (more than ⅔ of the samples have a score < 0.5). This is expected for outdoor areas that have undergone inspection and cleanup.

4.2.3.2 Comparison of PLM-VE Results Between Sampling Rounds

Table 4-8 presents a pair-wise comparison of the PLM-VE results from Round 1 and Round 2. Results were ranked as concordant if both the Round 1 and the Round 2 PLM-VE soil sample results were the same semi-quantitative classification (cells shaded in dark grey). Results were ranked as weakly discordant if the Round 1 result and the Round 2 result differed by one semi-quantitative classification (e.g., Bin A vs. Bin B1) (cells shaded in light grey). Results were ranked as strongly discordant if the results differed by more than one semi-quantitative classification (e.g., Bin A vs. Bin B2) (cells are not shaded).

As seen, 56 of 75 outdoor ABS areas (75%) were ranked as having concordant PLM-VE results. When results were discordant, they were usually only weakly discordant (17 out of 75 = 23%). There were only two samples (<3%) ranked as strongly discordant. The differences noted between sampling rounds may be due to one or more of the following factors: a) authentic changes in soil levels between rounds, b) spatial variability in LA levels within each ABS area, and c) analytical variability associated with the PLM-VE method.

4.2.3.3 Comparison of Visible Vermiculite Data Between Sampling Rounds

Figure 4-3 compares the visible vermiculite results from Round 1 with Round 2. Results based on the detection frequency approach are shown in Panel A, and results based on the visible score are shown in Panel B. The Pearson correlation coefficients are 0.775 for detection frequency and 0.731 for score, both of which are statistically significant ($p < 0.001$). This indicates that, on average, there is a clear relationship in visible inspection results between rounds. However, there is still substantial between-round variability in individual results, both for detection frequency (Panel A) and visible score (Panel B). This variability is likely due to the combined effect of two factors: sampling variability and "analytical" variability. Sampling variability arises because vermiculite levels are not uniform over the entire ABS area, and the 30 sampling points selected for examination in Round 2 are not identical to the 30 sampling points selected for examination in Round 1. "Analytical" variability (i.e., differences in the assignment of level [none, low, moderate, high] at each point) arises from the inherently subjective nature of the assignment, as well as variations in site conditions between rounds (e.g., cloud cover vs. sunshine, amount of ground cover, soil moisture, etc.).

4.2.3.4 Relative Sensitivity of PLM-VE vs. Visible Inspection

Inspection of the data in Table 4-6 reveals that, if an ABS area contains LA that is detectable by analysis of a 30-point PLM-VE composite sample, it nearly always (43 out of 45 cases) also contains vermiculite that is detectable by visible inspection in soil from one or more inspection points. However, there are a number of ABS sampling locations (44 out of 104 cases) where vermiculite was detected by visible inspection at one or more points, but LA was not detected by PLM-VE analysis of the 30-point composite:

		Visible Inspection	
		Not Detect	Detect
PLM-VE	Non-Detect	60	44
	Detect	2	43

These results suggest that visible inspection for vermiculite may be a somewhat more sensitive method for detecting contamination in soil than PLM-VE analysis of 30-point composite sample.

4.2.4 Correlation of LA in ABS Air to LA in Soil

One of the potential uses of the data generated during the outdoor ABS study is to determine if the concentration of LA observed in outdoor air at an ABS study area can be correlated with (and predicted by) the concentration of LA in the soil being disturbed at that ABS study area.

In this regard, the relationship that is most important for the purposes of evaluating human exposure and risk is the correlation between the area-wide average level of vermiculite or LA in soil and the long-term average concentration of PCME LA in ABS air, combining across both activity and time (sampling round). This is because humans are expected to be exposed intermittently over a long period of time via a wide variety of different soil-disturbing activities. For this reason, the analyses that follow focus on the relation between soil and PCME LA ABS air values combined across activities and time. Analyses that display the relation stratified by both activity and round are presented in Appendix D.

Because two soil metrics are available (PLM-VE result and visible inspection data), either metric alone, or a combination of the two metrics, may be used to characterize the level of soil contamination at the time of the ABS event. Because the values of both metrics tended to vary somewhat between rounds (see above), the round-specific data were used rather than attempting to combine the soil metrics across rounds.

Note that the data needed for evaluation of the relationship between soil and ABS air are somewhat different for the digging activity than for the raking and mowing activities. This is because the digging activity occurred only in two discrete sub-locations of each ABS study area, so the area-wide 30-point PLM-VE and visible inspection data may not accurately reflect the conditions at the digging locations. In Round 2, both PLM and visible inspection data were collected for the two sub-locations where digging was performed, and these data are used to characterize the soil levels associated with the digging ABS air values for Round 2. However, in Round 1, soil data were not collected at the specific sub-locations where digging occurred. In the absence of these data, the 30-point PLM-VE and visible inspection data from Round 1 are used as an estimate of the soil level where digging occurred. This approach should be recognized as an approximation, and actual soil levels in Round 1 digging activities might be either higher or lower than the area-wide data indicate.

4.2.4.1 Air-Soil Correlation Based on PLM-VE Bins

Figure 4-4 summarizes the PCME LA concentrations measured in outdoor ABS air (combined across all disturbance scenarios), stratified by the PLM-VE bin result for the ABS area. In this figure, because there were only two ABS areas with a result of Bin C, results for Bin B2 and Bin C were combined.

As seen, there is substantial overlap in the distributions of ABS air concentration values for the three PLM-VE bins, but there is an apparent trend toward increased median concentrations in Round 1, Round 2, and both rounds combined. This trend is less apparent based on mean concentrations, principally due to a single high value reported in Bin A in Round 1.

Figure 4-5 shows the same data as Figure 4-4, except that the results for Bin A are stratified into three sub-groups: clean fill, Bin A without visible vermiculite (V-), and Bin A with visible vermiculite (V+). As seen, PCME LA air concentrations at outdoor ABS areas that were clean fill (i.e., where a cleanup had been performed) and at Bin A areas where visible vermiculite was absent (V-) generally tended to be lower than Bin A areas where visible vermiculite was present (V+). When combined across both rounds, a similar pattern is retained, with the mean PCME LA concentration values for clean fill and Bin A (V-) being similar to each other but lower than Bin A (V+).

4.2.4.2 Air-Soil Correlation Based on Visual Vermiculite Observations

Qualitative Approach

Figure 4-6 summarizes the distribution of PCME LA concentrations measured in ABS air (combined across all disturbance scenarios) stratified into two bins, depending on whether or not visible vermiculite was detected in any one of the soil inspection points assessed (e.g., 30 soil inspection points were evaluated for the 30-point composite soil sample). As seen, although there is substantial overlap of the distributions, the median and the mean both tend to be higher at locations where vermiculite was detected at least once than at locations where it was never detected.

Figure 4-7 presents a variation of this approach, in which each ABS area is stratified according to whether or not visible vermiculite was detected in each inspection round:

Visible Vermiculite Detected?		Category
Round 1	Round 2	
No	No	Never Detected
No	Yes	Sometimes Detected
Yes	No	
Yes	Yes	Always Detected

Similar to the results for Figure 4-6, even though there is substantial overlap of the distributions, there is a tendency for both the median and the mean to increase as a function of between-round detection frequency (never < sometimes < always).

Semi-Quantitative Approaches

Figure 4-8 presents a graph that shows the distribution of PCME LA concentrations measured in ABS air stratified into four bins, depending on the frequency that visible vermiculite was observed in each ABS area during the visible soil inspection (see Table 4-6). Figure 4-9 presents a similar figure, except that ABS areas are stratified according to the average visible vermiculite score (see Table 4-6) rather than the detection frequency. As seen, in both cases there is a general tendency for the mean concentration of PCME LA in ABS air to increase as the detection frequency or visible vermiculite score in soil increases.

One potential limitation to this semi-quantitative approach is that the choice of bin-widths for use in graphing is arbitrary (e.g., 0, >0 to 0.1, >0.1 to 0.5, etc.), and the statistics (especially the mean) of the bins and the appearance of the graphs may be altered by choosing different bin-widths. Because of this, the results generated using this approach should recognized as potentially variable.

Quantitative (Regression) Approach

One way to minimize the problems associated with analysis of visible inspection data using a binning approach is to evaluate the data without binning, as shown in Figure 4-10 (based on detection frequency) and Figure 4-11 (based on visible score). Note that the mean PCME LA ABS air concentration values (averaged across scenarios) are plotted on the y-axis using a log-scale.

Inspection of these graphs re-emphasizes the relative high variability in ABS air concentrations that is observed, even when variations in soil concentration are accounted for. However, despite the high variability, there is an apparent upward trend in the data as detection frequency (Figure 4-10) or visible score (Figure 4-11) increases.

One of the potential advantages of plotting the data in this way is that the relationship between ABS air and the visible vermiculite soil metric may be quantified by fitting an appropriate mathematical model to the data. The detailed approach is presented in Attachment 1. In brief, it is assumed that at any location “j” where the level of LA contamination in soil is “x_j”, the set of ABS air concentrations observed at that location ($C1_j$, $C2_j$, $C3_j$, ...) will be characterized by a right-skewed distribution that is reasonably characterized as a Poisson-gamma distribution, with a mean concentration that tends to increase as the soil level “x” increases. The best fit model parameters for this model based on the combined data from Rounds 1 and 2 are summarized below:

Soil Metric	Parameter Value	
	a (f/cc)	b (f/cc per unit soil contamination)
Visible detection frequency	0.0089	0.28
Visible score	0.0093	0.21

This approach may be used to predict the mean concentration of PCME LA in outdoor ABS air at a location where soil has been characterized by visual inspection, as follows:

Mean Concentration (PCME LA f/cc) = a + b · (Soil metric)

4.3 Evaluation of Results from Clean Fill Areas

As noted above, clean fill is soil material that is brought in from borrow pits to replace materials that have been removed as part of a soil cleanup. Because these fill materials are not exposed until excavation, it is believed that they are not impacted by mining-related releases. There are multiple borrow pits located throughout the Libby Valley that have been used as a clean fill source. In addition, there is a borrow pit located in Eureka, Montana (which is 40 miles northeast of the site and outside the Libby Valley). Outdoor ABS data were collected at 15 ABS areas that were classified as having clean fill. Of these, 13 of the 15 locations had clean fill from borrow pits in the Libby Valley, and 2 locations had clean fill from Eureka.

Figure 4-12 shows the ABS data from these 15 locations, stratified by source of the fill material (Libby = triangles, Eureka = squares) and by the PLM and visual vermiculite observations of the soil at the time of the ABS activity. Contrary to what might have been expected, LA and/or visible vermiculite was observed in ABS areas that had clean fill, both from Libby and Eureka. As shown in the figure, there tends to be wide variability in the ABS results and substantial overlap of the data for Libby and Eureka soils. Mean concentrations of PCME LA in ABS air tend to be higher for locations where soil contamination was detected than for areas where it was not detected. However, in considering this observation, it is important to recognize that mean values can be strongly influenced by a few high data points, and that additional data would be needed to strengthen this conclusion. When results for Libby and Eureka are compared for similar soil levels, the results are generally similar. This suggests that the source of the fill material may not be a critical issue. However, because of the limited size of the dataset for areas with fill from Eureka, it is important to recognize that this conclusion is not certain.

4.4 Evaluation of Unexpected Results

During the evaluation of the ABS data and their relationship to soil, several air sample results were reported that were higher than had been anticipated based on the range of air levels measured for EPA workers doing cleanup activities at the site. In order to determine if these sample results were reliable, two follow-up activities were performed, as described below.

4.4.1 Sample Reanalysis

There were several outdoor ABS air samples collected in Round 1 where measured PCME LA air concentrations were unexpectedly high. In order to determine if the reported concentrations were in error, ten of the highest samples from Round 1 were re-analyzed to verify the reported concentrations.

Several options were considered for the best way to perform the re-evaluation and to detect any errors that might have occurred. One approach would be to simply re-count the same grids as were analyzed originally. However, if an error occurred at the level of grid identification, re-counting the same grids would not reveal the error. Likewise, preparing new grids from the same filter would not detect an error at the level of filter mis-identification or preparation. For these reasons, the re-analysis was based on the low volume (LV) samples collected at the same time as the high volume (HV) samples that were used in the original analysis. Because the only difference between the HV and LV samples is the pump rate (and hence the amount of air passing through the filter), it is expected that the results for both samples should be similar.

Figure 4-13 presents a comparison of the original HV sample results to the corresponding LV re-analysis sample results. In this figure, the error bars represent the 95% CI. LV samples with results that were statistically different from the HV sample are circled. As seen, for 8 of the 10 samples re-analyzed, PCME LA concentrations in the LV sample were not statistically different from the HV sample (this included the four HV samples with the highest reported PCME LA concentrations). For 2 of the 10 samples, the LV result was lower than the HV result. The reason for the difference between the HV and LV results for these samples is not known, but the differences are relatively small and could be attributable to simple random variation. In any event, the results do not suggest that analytical error is a likely explanation for the relatively high and unexpected concentration values observed. In addition, because most LV results were not statistically different from the HV result, use of the LV samples in place of the HV samples would not significantly change estimates of exposure utilized in the screening level risk calculations (see Section 6, below).

4.4.2 Review of Field Documentation

In order to determine if the field crews had observed anything during the sample collection process that might help explain unexpectedly high air values, the field documentation (e.g., field logbooks, cleanup checklists) were reviewed for potentially relevant information on two types of samples: a) the single highest air sample; and b) air samples collected at locations that were classified as “clean fill”.

Highest Sample

In Round 1, the highest measured PCME LA air concentration was 21 s/cc for the digging ABS sample (EX-00662) from 241 South Central Road. A review of the field documentation for this sample found that high levels of visible vermiculite were observed in the digging area during Round 1. However, visible levels noted in the corresponding 30-point soil composite were much lower (10-none; 15-low; 5-moderate). As noted previously, a digging-specific soil sample was not collected in Round 1. The field documentation review suggests that the 30-point composite results (both the PLM-VE and visual inspection) are not representative of soil conditions in the digging area. In addition, subsequent outdoor ABS soil sampling at this property conducted in Round 2 showed trace (Bin B1) LA levels in the front yard (in the same location that the Round 1 ABS sampling was performed).

Sample EX-00662 was one of the samples that was reanalyzed in November 2008 (see Section 4.4.1 above). The LV reanalysis reported a PCME LA air concentration of 12 s/cc, which was not statistically different from the original HV analysis. This indicates that the high result is not due to an analytical error in the original analysis.

Clean Fill

In Round 1, several measured PCME LA air concentrations at outdoor ABS areas designated as “clean fill” were higher than had been expected. In order to determine if the areas where this occurred might have been misclassified (i.e., the ABS area was not entirely clean fill), field sampling conditions (as recorded in the field logbooks) and cleanup details (as recorded in the Property Completion Checklist [PCC]) were reviewed for each of the clean fill areas.

Table 4-9 summarizes the sampling conditions and property cleanup details for each clean fill area. Inspection of this table shows that sampling conditions at several “clean fill” properties may have influenced measured PCME LA concentrations in air.

For 280 South Central Road, inspection of the field documentation revealed that contamination may have migrated into the clean fill area from locations that were not remediated as part of the cleanup. At this property, significant amounts of visible vermiculite (moderate to high levels) were noted in the wooded areas completely surrounding this property. The yard soil cleanup performed at this property in June 2003 extended to the boundary between the wooded area and the maintained grass lawn (i.e., cleanup was not performed in the wooded area). Since the cleanup, the boundary between these areas has eroded back into the wooded area. In May 2008, field teams noted that vermiculite which clearly originated in the wooded area was present about 5-6 feet into the maintained lawn. Prior to the cleanup, LA levels in yard soils at this property were as high as 2% (as measured by PLM NIOSH 9002). In addition, the PCC for this property also noted that soil contamination in and on the side of the road (South Central Road) was not part of the exterior cleanup. Therefore, despite the fact that the 30-point soil sample was reported as non-detect by PLM-VE and “Vis –“, it is possible that some portion of the ABS area may have been influenced by vermiculite contamination.

ABS activities at property 281 South Central Road (located across the street from property 280 South Central Road) may have also been influenced by residual soil contamination along the road.

For both of these properties, low levels of visible vermiculite were noted in the sub-locations selected for the digging scenario, despite the fact that the ABS area was ranked as "Vis –" based on the 30-point visual inspection. This soil contamination in the areas of digging may explain the higher than expected air results.

Based on these findings, it is concluded that the ABS air results from some of the clean fill ABS areas may have been influenced by contamination that is not inherently associated with the clean fill material. However, review of the field documentation for a number of other clean fill ABS areas did not reveal any reliable indications of contamination. Consequently, results from the ABS sampling at clean fill properties are used without exclusion of any of the data points.

4.5 Summary and Discussion

In this effort, a total 75 outdoor ABS sampling areas at 62 different properties in Libby were investigated. At each outdoor ABS area, 3 outdoor ABS air samples were collected in each of two sampling rounds, generating a total of 450 ABS air samples. Each air sample was analyzed for LA using TEM.

There was high variability in the concentration of PCME LA observed in the outdoor ABS air samples, ranging from non-detect (usually < 0.001 s/cc) to more than 20 s/cc. On average, the air concentration values associated with mowing and digging tended to be similar, with the values for raking tending to be somewhat lower. There was relatively high variability between sampling rounds, with Round 1 (summer) tending to yield higher air concentration values than Round 2 (spring). This between-round variability may be attributable to variability in soil moisture content between rounds.

The relationship between LA levels in outdoor ABS air and the level of LA in soil was investigated using several different strategies for characterizing the level of soil contamination, including:

- Binning based on PLM-VE results
- Binning based on PLM-VE combined with visible vermiculite data
- Binning based on visible vermiculite detection frequency or visible score
- Poisson regression based on visible vermiculite detection frequency or visible score

In most cases, the average level of PCME LA in ABS air tended to increase as a function of increasing levels of LA in soil, although the strength of the trend varied somewhat between different methods for characterizing the level of soil contamination. No single method appeared to provide results that were inherently superior to others.

5 Indoor Activity-Based Sampling Summary and Evaluation

5.1 Study Design

Detailed information on the Indoor ABS study design and program-specific DQOs are provided in the Indoor ABS SAP (EPA 2007b). In brief, the purpose of the study was to collect data needed to characterize the level of residual exposure and risk from indoor exposures that may remain at post-cleanup properties, and, if some properties had residual risk above a level of concern, to identify the most likely residual source(s) contributing to the contamination so that the cleanup strategy may be revised to increase protectiveness. A secondary goal of the study was to collect sufficient data on the levels of LA in indoor air and in potential source media (e.g., indoor dust, outdoor soil, ambient air) that a quantitative model may be developed to predict indoor air levels from data on source levels with sufficient accuracy to support cleanup and risk management decisions. Based on these objectives, the DQOs identified three decisions that were to be addressed by the Indoor ABS study:

1. Are current strategies for cleaning up properties in OU4 adequate to provide health protection from exposure in indoor air?

2. If indoor air levels are above a level of concern in some post-cleanup building, what are the residual indoor or outdoor sources most likely to be responsible?

3. Do the data indicate a quantifiable relationship between the level and extent of LA in residual sources and the level observed in indoor air? If so, can long-term average exposure levels be predicted with sufficient accuracy to be useful in risk assessment and risk management decision-making?

An overview of the study design developed to address these questions is summarized below.

5.1.1 Sampling Locations

Sampling locations evaluated as part of the Indoor ABS program were selected to be representative of the range of types and levels of residual sources that may remain at post-cleanup locations. In brief, post-cleanup properties were to be stratified into 4 categories based on whether or not previous outdoor soil cleanup actions had been taken and on what levels remained in soil post-cleanup as follows:

Category	Did outdoor soil cleanup take place?	Post-cleanup Surface Soil		
		VCS		PLM
1	No	-	and	-
2		+	or	+
3	Yes	-	and	-
4		+	and	-

VCS: vermiculite-containing soil is present (+) or absent (-)
PLM: LA result is detect (+) or non-detect (-)

After soliciting cooperation from area residents, a total of 80 indoor ABS properties (with one extra property selected as a backup in Category 2) were selected for participation in the study, with 19-21 properties per category:

Category	Number of properties
1	19
2	21
3	20
4	20
Total	80

These properties were selected to provide a reasonable spatial representation in OU4 (i.e., north, central, and south Libby). Figure 5-1 shows the locations of the properties that were sampled as part of the Indoor ABS program. Table 5-1 provides detailed information on the types of indoor and outdoor cleanup actions that have been performed at each property.

5.1.2 Disturbance Scenarios

Conceptually, indoor air samples could be collected under a wide range of differing activity patterns. For the purposes of this effort, indoor ABS samples were collected under two representative conditions:

- Active behaviors – This category includes indoor activities in which a person is moving about the building and potentially disturbing indoor sources. For example, walking from room to room, sitting down on upholstered chairs, sweeping, and vacuuming would all be included.

- Passive behaviors – This category includes activities such as sitting and reading a book, watching television, and working at a desk. The key attribute is that the person is engaging in minimally energetic actions that will have low tendency to disturb any indoor source materials.

During each sampling event, indoor disturbance activities were performed over an 8-hour time interval divided into two sub-periods of 4 hours each (one for each disturbance scenario)[9]. All active and passive disturbance activities were performed by EPA contractor personnel. Residents did not participate in the disturbance activities and were required to leave the house during the time period of indoor sample collection.

5.1.3 Sampling Times

Human health risk from exposure to LA in indoor air is related to the long-term average concentration in indoor air. Because the levels of LA in indoor air may depend on factors that vary seasonally (e.g., indoor activity patterns, humidity, building ventilation rate), the Indoor ABS

[9] Depending on what is most convenient for the resident, sampling either occurred over one 8-hour time interval or was divided into two 4-hour samples on two sequential days.

program was performed four times at intervals that provided good seasonal representativeness, as follows:

- Round 1 (summer): July to August 2007[10]
- Round 2 (fall): September 2007 to January 2008
- Round 3 (winter): January to April 2008
- Round 4 (spring): April to June 2008

The same properties were evaluated in each round, although the backup property in Category 2 was removed from the program after the first round of sampling.

5.1.4 Sample Collection and Analysis

5.1.4.1 Air Samples

During each disturbance scenario, EPA contractors wore personal air monitors placed such that the samples collected were representative of the breathing zone of the individual performing the disturbance activity (i.e., a hemisphere approximately 6 to 9 inches around an individual's face). All indoor ABS air samples were collected in basic accord with procedures provided in EPA-LIBBY-01 and ERT SOP#2084.

Two personal air monitoring samples were collected for each scenario – a high volume sample and a low volume sample. The high volume sample was collected using a pump with a flow rate of 10 L/min (total air volume of 2,400 L), and the low volume sample was collected using a pump with a flow rate of 3 L/min (total air volume of 720 L) (EPA 2007d). The high volume sample was analyzed in preference to the low volume sample because maximizing the total air volume collected reduced the level of effort needed to achieve the target analytical sensitivity. In cases where the high volume sample was damaged, the low volume was substituted. Unanalyzed low volume samples were archived at the Libby Field Office in Libby, MT. Prepared TEM grids and unused portions of the analyzed filters were archived at the analytical laboratory.

In order to ensure that each air sample is spatially representative of the home, the 4-hour time period for the disturbance scenario was divided evenly among the total number of rooms in which routine living activities occur. If both active and passive ABS scenarios were performed on the same day, the passive ABS scenario was performed first, to minimize the likelihood of cross-contamination between the ABS scenarios. When activities were conducted over two days, the order of the activities was randomized to equally represent the morning and afternoon sampling periods over the four rounds.

All indoor air samples were submitted to one of the subcontracted Libby laboratories for asbestos analysis by TEM in basic accord with the counting and recording rules specified in ISO 10312 (ISO 1995), and the ABS-specific counting rule modifications (EPA 2007b). The target analytical sensitivity for all indoor ABS air samples was 0.0002 cc^{-1}.

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[10] Date range represents when air samples were collected in Round 1; soil samples were collected at Indoor ABS properties in May-June 2007.

5.1.4.2 Indoor Dust Samples

For each indoor ABS property, a single 10-point composite indoor dust sample was collected in accord with SOP CDM-LIBBY-10 using a microvacuum sampling technique during each round of sampling[11]. The 10 dust sampling points which were composited were representative of 4 accessible areas (e.g., window sills, flooring in living areas), 4 infrequently accessed areas (e.g., top of refrigerator or bookcase, beneath bed), and 2 inaccessible areas (e.g., beneath refrigerator or washing machine, inside air vents) within the rooms where the ABS activities were performed. At each dust sampling point, the sample was collected by vacuuming a 10 cm x 10 cm area (100 cm^2). Therefore, the total sampling area of each dust composite sample was 1,000 cm^2. All dust samples were collected prior to the commencement of indoor ABS activities.

All indoor dust samples were submitted to one of the subcontracted Libby laboratories for asbestos analysis by TEM in basic accord with the counting and recording rules specified in ISO 10312 (ISO 1995), and the ABS-specific counting rule modifications (EPA 2007b). The target analytical sensitivity for all indoor ABS dust samples was 20 cm^{-2}.

5.1.4.3 Soil Samples

At each indoor ABS property, two 30-point composite soil samples were collected prior to the first round of indoor ABS sampling. One soil sample was representative of all non-specific use areas (NSUAs) on the property, and the other soil sample was representative of all specific use areas (SUAs). SUAs include areas such as gardens, flowerbeds, unpaved driveways, and play areas where human exposure is likely to occur on a frequent basis. NSUAs include general areas of the yard where human exposure likely to occur less frequently. Each 30-point composite included soil sampling points that were representative of and distributed equally throughout the entire NSUA or SUA.

All soil samples collected as part of the Indoor ABS program were sampled in accord with SOP CDM-LIBBY-05, and were prepared (dried, ground, sieved) and submitted for asbestos analysis by PLM. In addition, visual inspection data were collected and reported as described in Section 3.3 above.

5.2 Results Summary and Data Evaluation

Appendix E presents the detailed results for all samples collected as part of the Indoor ABS program. Table 5-2 summarizes the results for air, stratified by ABS property, sampling round, and disturbance scenario (active and passive).

[11] In Round 1, multiple composite dust samples (1 sample per floor) were collected at 14 of the 80 indoor ABS properties, rather than a single composite sample representative of all floors as specified in the Indoor ABS SAP. These samples were averaged to generate a value that is analogous to a physical composite across all floors. This issue was resolved in subsequent sampling rounds.

5.2.1 LA in Air as a Function of Disturbance Scenario and Season

Figure 5-2 presents the indoor ABS PCME LA air concentration data using a "box-and-whisker" format that characterizes the distribution of values observed. Note that indoor air concentration (the y-axis) is presented using a log-scale. Because samples with a concentration of zero cannot be plotted on a log-scale, for plotting purposes only they were assigned a value of 0.00001 s/cc, which is equal to the x-axis in the figure.

Inspection of Figure 5-2 reveals that air concentrations tended to be lower for the passive scenario compared to the active scenario. In addition, air concentrations in both scenarios showed seasonal variability, with the highest concentrations measured in the summer (Round 1) and the lowest concentrations in the winter (Round 3).

The observation that indoor air collected during active behaviors tends to contain more LA than air collected during passive behaviors is expected, and is consistent with the concept that active indoor behaviors tend to disturb LA structures that are present in or on reservoirs such as bare surfaces, carpets, or upholstery.

The reason that indoor air concentrations tend to be lower in winter than summer is not certain, but may be related to a decreased rate of track-in of contaminated soil from outdoor sources in winter than in summer, or to decreased aerial deposition of structures in indoor dust from outdoor ambient air, since this also tends to be lower in winter than in summer (EPA 2009). Other unknown factors may also be involved.

5.2.2 LA in Air as a Function of Post-Cleanup Property Category

As noted above, properties that were selected for evaluation in the Indoor ABS program were chosen based on a 4-category system for classifying the status of outdoor soil (see Section 5.1.1, above). During the ABS program, additional soil samples were collected, and some Category 4 properties were identified in which some LA was detectable by PLM. Based on this, Category 4 was re-defined as shown below:

Category	Did outdoor soil cleanup take place?	Post-cleanup Surface Soil		
		Visible		PLM
1	No	-	and	-
2		+	or	+
3	Yes	-	and	-
4		+	or	+

Visible: Visible vermiculite is present (+) or absent (-)
PLM: LA result is detect (+) or non-detect (-)

Figure 5-3 presents the indoor ABS PCME LA air concentration data stratified by the post-cleanup category assignments above. As seen, under active conditions, mean indoor air concentrations for post-cleanup properties in Category 1 (where no outdoor soil cleanup was performed and soil levels are non-detect) tended to be lower than properties in the other three categories. Under passive conditions, with the exception of Category 2 (which is influenced by a single high value), mean air concentrations tend to be generally similar across categories.

5.2.3 Correlation of LA in Indoor Air to LA in Indoor Dust

One potential use of the data from the Indoor ABS study was to determine if indoor air concentration values of LA can be correlated with (and predicted by) any measure of LA contamination in potential source media. One of these potential source media is indoor dust.

Table 5-3 presents the indoor dust data collected during the indoor ABS program. The results are summarized below:

Round	Dust Samples	Detect Samples	Total LA Structures	PCME LA Structures
1	96	1	1	0
2	80	8	9	3
3	80	1	4	0
4	80	0	0	0

As shown, both total LA and PCME LA were rarely detected in indoor dust. Of the 336 indoor dust samples collected, only 10 samples (< 3%) had detectable levels of total LA and only 3 samples had detectable PCME LA. Because of this very high rate of non-detects, the data are not adequate to support any meaningful effort to establish a quantitative relationship between LA in indoor air and indoor dust.

Although high levels of LA in dust were not expected (recall that all homes evaluated are post-cleanup), the very high non-detect rate in dust samples is somewhat unexpected, since the analytical sensitivity was set so that loadings of 20-30 s/cm^2 would usually be detected. In addition, the observation that active behaviors tend to increase the level of LA in indoor air (see Figure 5-2) strongly suggests that indoor dust is an important contributor to indoor air. One possible interpretation is that dust at levels below the analytical sensitivity are the main contributors to indoor air during active scenarios. An alternative interpretation is that the dust composite samples collected (typically including 10 templates derived from 4 accessible areas, 4 infrequently accessed areas, and 2 inaccessible areas) may not be representative of the main indoor reservoirs of LA.

5.2.4 Correlation of LA in Indoor Air to LA Levels in Outdoor Soil

Based on the expectation that LA contamination in outdoor soil might be a contributor to indoor dust and/or indoor air contamination, data on the levels of LA in outdoor soil at each indoor ABS property were collected using both PLM-VE and visible vermiculite inspection. This section investigates whether any relationship between outdoor soil and indoor air can be detected using these data. Table 5-4 presents soil PLM-VE results and visible vermiculite inspection data for SUAs and NSUAs for all indoor ABS properties.

5.2.4.1 Based on PLM-VE Data

Figure 5-4 presents the indoor ABS PCME LA air concentration data, stratified by disturbance scenario (active and passive), as a function of the PLM-VE values for SUA soil (Panel A) and for NSUA soil (Panel B). As seen in Panel A, the mean PCME LA air concentrations for both active and passive air samples tend to be somewhat higher for properties where the PLM-VE result for SUA soil was Bin B1 than for properties where the SUA result was Bin A. Results are less consistent for NSUA soil (Panel B). These results suggest that LA levels in soil that are detectable by PLM-VE are associated with increased levels of LA in indoor air, both for the active and the passive scenarios.

5.2.4.2 Based on Visual Vermiculite Data

Figure 5-5 presents the indoor ABS PCME LA air concentration data, stratified by disturbance scenario (active and passive), as a function of the detection frequency of visible vermiculite in SUA areas (Panel A) and NSUA areas (Panel B). As seen, there is a tendency for the mean indoor ABS PCME LA air concentration to be slightly higher when the detection frequency exceeds 10% than when the detection frequency is between 0 and 10%, including SUA soil (Panel A) and NSUA soil (Panel B).

Figure 5-6 is a similar plot, except that properties are stratified based on visible score rather than visible detection frequency. As seen, there is a tendency for the mean indoor ABS PCME LA air concentration to be slightly higher when the visible score exceeds 0.1 than when the score is below 0.1, including SUA soil (Panel A) and NSUA soil (Panel B).

These results are consistent with the hypothesis that contaminated outdoor soil serves as a source of LA in indoor air, although the transport pathway (direct track-in, deposition from outdoor air) cannot be determined.

Multivariate Semi-Quantitative Approach

One potential limitation of the correlations presented above is that they are based on a simple monovariate analysis (i.e., correlations are evaluated based on either SUA soil or NSUA soil individually). However, if LA contamination in outdoor soil is a contributor to indoor air contamination, it is likely that both SUA and NSUA soils will contribute. This potential for contribution likely differs for SUAs and NSUAs as determined by a number of factors, including area size, soil contamination levels, soil conditions (e.g., moisture, cover, particle size), and human use patterns.

Figure 5-7 presents a 3-dimensional graph that shows the mean PCME LA concentrations measured in ABS indoor air stratified based on the frequency that visible vermiculite was observed in NSUA and SUA soils. The visible detection frequency for each soil type is stratified into three bins: 0, >0 to 0.1, and >0.1. In this figure, Panel A presents mean air concentrations based on the active scenario and Panel B presents mean air concentrations based on the passive scenario.

Figure 5-8 presents a similar figure, except that mean PCME LA concentrations measured in ABS indoor air are stratified according to the visible vermiculite score rather than the detection frequency. As seen, in both cases there is a general tendency for the mean concentration of PCME LA in ABS air to increase as the detection frequency or visible vermiculite score in soil increases. This trend is present for both active and passive scenarios.

Multivariate Quantitative (Regression) Approach

As noted previously, one potential limitation to binning soils based on visible vermiculite inspection data is that the choice of bin-widths for use in graphing are arbitrary, and the appearance of a graph may be altered by choosing different bin widths. One way to minimize this is to evaluate the data using a regression approach.

In this approach, the concentration of PCME LA in indoor air is assumed to be influenced by SUA soil, non-SUA soil, and by other factors. The model is as follows:

$$C_a = b_0 + b_1 \cdot NSUA + b_2 \cdot SUA$$

where:

C_a = mean indoor air concentration
b_0 = air concentration from other non-soil sources
b_1 = soil to air factor for NSUAs
NSUA = soil metric for NSUA
b_2 = soil to air factor for SUAs
SUA = soil metric for SUA

This regression analysis was performed by minimization of square errors. Table 5-5 shows the best fit model parameters and the percent contribution of NSUA soils, SUA soils, and other sources to the mean indoor air concentration under active disturbance scenarios. As seen, sources other than soil (b_0) appear to be the largest contributor, with lower contributions for SUA soil and NSUA soil, respectively. This is true for both soil metrics (detection frequency and visible score).

5.3 Summary and Discussion

In this effort, the level of LA was measured in indoor air at 80 different post-cleanup properties at four different times of year (summer, fall, winter, spring). In each sampling round at each property, one air sample was collected that represented "passive" indoor activities, and another air sample was collected during "active" behaviors. This resulted in a total of 640 indoor ABS air samples collected. Each air sample was analyzed for LA using TEM.

The concentration of PCME LA observed in the indoor ABS air samples ranged from non-detect (usually < 0.0003 s/cc) to about 0.01 s/cc. On average, the concentration values associated with active behaviors were higher than for passive behaviors, supporting the concept that disturbance of an indoor source such as contaminated indoor dust is one contributing factor to indoor air levels of LA. Indoor air levels of PCME LA tended to be lowest during the winter and highest during the summer for both active and passive behaviors. The reason for this seasonal pattern is not certain, but might be related to a higher rate of transport of LA into the indoor environment in the summer, either through track-in of contaminated outdoor soil, and/or by deposition of LA in outdoor ambient air. Other unknown factors may also be involved.

Although composite dust samples were collected in each round at every property, it was not possible to establish a quantitative relationship between LA levels in indoor air and indoor dust because nearly all of the dust samples were non-detect (usually < 20 s/cm^2). However, a weak correlation could be detected between average indoor air levels of PCME LA and the level of LA in outdoor soil, using either PLM-VE or visible inspection to characterize the soil. The relation was clearer for SUA soil than for NSUA soil, although the pattern was usually similar for both. These results support the concept that outdoor soil is a source that contributes to indoor air contamination. However, regression analysis suggests that other sources besides outdoor soil may also be important.

6 Screening Level Risk Characterization

This section presents a preliminary characterization of the excess cancer risks associated with the levels of LA that have been observed in outdoor and indoor ABS air at post-cleanup properties. The purpose of this screening level assessment is to provide initial estimates of the range of risk estimates that may result during indoor and outdoor activities at post-cleanup properties in order to help provide a frame of reference for the ABS results.

These preliminary risk calculations are for *screening purposes only*, and are not intended to support final risk management decision-making at any specific locations. Final risk evaluations will be presented in the Human Health Risk Assessment for Libby OU4, and the results may be different than the screening level values presented here.

In addition, it is important to stress that most people who live or work in Libby may be exposed to LA by a number of different exposure pathways, and that risk management decision-making must consider the sum of the risks across all pathways, not just those evaluated in this report.

6.1 Risk Model

Inhalation exposure to asbestos increases the risk of both non-cancer effects (asbestosis, pleural changes) and cancer effects (lung cancer and mesothelioma) in humans (EPA 1986, ATSDR 2001). At present, no approved method is available for quantifying risks of non-cancer effects. Therefore, risks of non-cancer effects are not evaluated in this document. However, EPA has developed a method for estimating excess risk of death from cancer due to inhalation exposure to asbestos, as described in the following sections.

The basic equation used to estimate excess lifetime cancer risk is (EPA 2008b):

$$\text{Risk} = \text{EPC} \cdot \text{TWF} \cdot \text{IUR}_{a,d}$$

where:

Risk = Probability of developing cancer as a consequence of the asbestos exposure being evaluated
EPC = Exposure Point Concentration of asbestos in inhaled air (PCM or PCME s/cc)
TWF = Time Weighting Factor to account for less than continuous exposure (unitless)
$\text{IUR}_{a,d}$ = Inhalation Unit Risk $(\text{PCM s/cc})^{-1}$ based on continuous exposure beginning at age “a” and continuing for duration “d” years

The level of cancer risk that is of concern is a matter of personal, community, and regulatory judgment. In general, EPA considers excess cancer risks that are below about 1E-06 to be so small as to be negligible, and risks above 1E-04 to be sufficiently large that some sort of remediation is desirable. Excess cancer risks that range between 1E-04 and 1E-06 are generally considered to be acceptable (EPA 1991), although this is evaluated on a case-by-case basis, and EPA may determine that risks lower than 1E-04 are not sufficiently protective and warrant remedial action. Note that risk management decisions generally consider the sum of all the risks contributed by differing exposure scenarios into account, rather than simply evaluating each one independently.

6.2 Inputs to the Equation

6.2.1 Exposure Point Concentration (EPC)

An exposure point is a location where exposure and risk are to be evaluated, and an exposure point concentration (EPC) is an estimate of the long-term average concentration of PCME LA in air at that location.

In this screening level assessment, an exposure point is taken to be a residence. That is, the exposures that are being evaluated include the outdoor and indoor activities that occur at a person's home. This strategy is based on the concept that most area residents are likely to have a majority of their soil-related and indoor exposures at their own homes. To the extent that some individuals may have outdoor or indoor exposures at other locations, this needs to be evaluated separately and the risks combined, as appropriate.

6.2.1.1 EPC for Outdoor Air

For outdoor exposures during soil disturbance activities, the EPC is the average of the ABS air concentrations, combining across activity (mowing, raking, and digging) and across time (Round 1 and Round 2). This is because the goal is to estimate the average concentration over many years of various types of outdoor activities.

There are two alternative strategies for estimating the outdoor air EPC for a particular location. The first is to use only the ABS air data from that location. The second approach is to combine the ABS data from all locations that have the same or similar levels of soil contamination. In this screening level assessment, the second approach is used. This is based on the expectation that the many random variables that influence release of LA from soil to air will tend to average out over time, and that it is soil level alone, rather than any other attribute of a property, that will determine the long term average concentration in ABS air.

6.2.1.2 EPC for Indoor Air

For indoor air, two EPC values are needed. The first is the long-term average concentration of LA in indoor air during passive behaviors, and the second is the long-term average concentration in indoor air during active behaviors.

As above, two strategies are available for estimating the EPCs for indoor air at a location. The first is to use the data from that location alone, and the second is to combine data from all locations that are judged to be similar. In this case, because no relation could be established between indoor air and indoor dust, there is no reliable basis for defining residences that are "similar" based on indoor dust. Although only weak associations were detected between indoor air and outdoor soil, ABS data from all properties that have the same or similar levels of soil contamination were combined. All calculations of EPCs for indoor air were averaged over time (Rounds 1 to 4).

6.2.1.3 Concentration Units of the EPC

As noted above, all indoor and outdoor ABS air samples were analyzed for LA using TEM. However, the risk model described above requires that asbestos concentration to be expressed in terms of PCM fibers, referred to as PCME (EPA 2008b). In accord with the PCM method (NIOSH 7400), a PCME structure is defined as a structure with length > 5 um, width ≥ 0.25 um, and an aspect ratio (length:width) ≥ 3:1. The EPC is expressed as PCME LA s/cc.

6.2.1.4 Uncertainty in the EPC

Ideally, the EPC used in the risk calculations for each exposure location would be the true average concentration value of PCME LA structures, averaged across the exposure duration "d". However, the true average concentration at a location can only be approximated from a finite set of measurements, and the observed sample mean might be either higher or lower than the true mean. In order to minimize the chances of underestimating the true level of exposure and risk, EPA generally recommends that risk calculations be based on the 95% upper confidence limit (95UCL) of the sample mean (EPA 1992), and has developed a software application (ProUCL) to assist with the calculation of UCL values (EPA 2007c). However, the equations and functions in ProUCL were not designed to work well for asbestos data sets, and application of ProUCL to asbestos data sets may not yield reliable results.

Because the 95UCL cannot presently be calculated with confidence, risk calculations presented in this report utilize the sample mean only. Consequently, the risk estimates presented here are uncertain, and true risks may be either higher or lower than presented. However, it is not possible to estimate the potential magnitude of the under- or over-estimation.

6.2.2 Time-Weighting Factor (TWF)

The value of TWF ranges from zero to one, and describes the average fraction of full time that exposure occurs in the time interval being evaluated. The general equation is (EPA 2008b):

$$TWF = ET/24 \cdot EF/365$$

where:

ET = Average exposure time (hrs/day) on days when exposure is occurring
EF = Average exposure frequency (days/year) in years when exposure is occurring

For example, if a person were exposed to asbestos 10 hours per day for 200 days per year, the value of TWF would be:

$$TWF = 10/24 \cdot 200/365 = 0.228$$

Not all individuals within a group will have equal values for ET and EF. To account for this variability in exposure between different individuals, EPA focuses on individuals who have central tendency exposures (CTE) and on those who have reasonable maximum exposures (RME).

At present, no site-specific data are available on the activity patterns of residents of Libby, so screening-level exposure parameters were selected based on information in EPA's Exposure Factors Handbook (EPA 1997) and on professional judgment.

Relevant data items available from EPA (1997) for estimating exposure times (ET) are summarized below:

- Hrs/day at residence = 16.4 (CTE) to 23.3 (RME) *(page 5-17)*
- Hrs/day spent house cleaning = 1.3 (CTE) to 5.6 (RME) *(Table 15-71)*
- Hrs/day doing yard work = 2.5 (CTE) to 7.8 (RME) *(Table 15-92)*

Indoor activities are conservatively assumed to occur with an exposure frequency (EF) of 365 days/year. Data on the frequency of outdoor yard care activities were not located, but EPA (1992) recommends assuming about 1-2 days per week during warm weather. In Libby, assuming outdoor yard work is likely to occur mainly between May and September (about 20 weeks per year), the total number of days/year spend doing yard work is estimated to be about 20 to 40.

Based on these data, the parameters selected for use in this screening assessment are as summarized below:

Source	CTE			RME		
	ET	EF	TWF	ET	EF	TWF
Indoor Passive	15	365	0.625	17.5	365	0.729
Indoor Active	1.3	365	0.054	5	365	0.208
Outdoor Active	2	20	0.005	7.7	40	0.035
Total hrs/day	16.4			23.3		

6.2.3 Inhalation Unit Risk (IURa,d)

Values of IURa,d for a wide range of values for "a" (age at first exposure) and "d" (exposure duration) are given in EPA (2008b). This document also gives an equation for computing IURa,d for any combination of "a" and "d" that are not included in EPA (2008b). At present, no site-specific data exist to estimate values of "a" and "d" for exposure of area residents. In the absence of data, conservative values were assumed, as follows:

Receptor	a	d	IURa,d
CTE	0	30	0.17
RME	0	50	0.21

6.3 Results

6.3.1 Outdoor Exposures During Soil Disturbance Activities

Figure 6-1 presents the distribution of screening level estimated excess cancer risk values for each of the 75 outdoor ABS areas. In this assessment, the EPC (PCME s/cc) for each outdoor ABS area was calculated as the mean of the six outdoor ABS air samples (3 scenarios x 2 rounds) available for the area. As seen, for a CTE receptor, most of the areas are below the upper end of EPA's acceptable risk range (1E-04), but about 10% of the properties equal or exceed the risk range. For an RME receptor, about 40% of the areas exceed 1E-04. These results suggest that excess cancer risks may remain within a range of potential concern at some post-cleanup properties. However, this conclusion is not certain, for several reasons, including:

1. Exposure and risk at a property depends on the yard-wide average concentration. In most cases, the ABS study areas do not represent a yard-wide average concentration at a property, but only a sub-area of a property. Consequently, the distribution of risks at ABS areas is not equivalent to the distribution of risks at the 62 properties where outdoor ABS samples were collected.

2. At each ABS area, the risk calculations are based on the mean of six outdoor ABS samples. Because of the high variability between samples, six samples may not provide an accurate estimate of the true long-term average concentration. In general, it would be expected that, if additional samples had been collected at each location, the width of the distribution of means would tend to narrow, which would tend to decrease the number of ABS areas that exceed a risk level of 1E-04.

Other potential uncertainties in these risk estimates are described in detail in Section 6.4 below. However, despite these considerations, it seems likely that at least some post-cleanup locations may exceed EPA's risk range if repeated outdoor soil disturbance activities occur.

A key question is whether or not such properties can be reliably recognized without having to perform multiple ABS activities at each property. The traditional approach for doing this is to establish a relationship between the concentration of contaminant in the source material (soil) and the level of risk that exists due to exposure to that source material (via soil disturbance scenarios that result in inhalation exposure of LA).

Table 6-1 presents screening level excess cancer risk estimates for CTE and RME residential exposure to outdoor air during soil disturbance scenarios, evaluated using a range of alternative strategies for estimating the relationship between PCME LA in ABS air and LA in the soil. As seen, the results depend somewhat on the method used to evaluate the relationship between soil and outdoor ABS air. However, taken together, the results suggest that risks to residents from typical (CTE) soil disturbance activities may be in the range of about 7E-06 to 7E-05 at locations where soils are at the low end of the contamination range (including clean fill), and may range from about 9E-05 to 5E-04 for locations where soils are near the high end of the range that may remain at some post-cleanup properties. Likewise, risks to residents from high end (RME) soil disturbance activities may be in the range of about 6E-05 to 7E-04 at locations where soil are at the low end of the contamination range (including clean fill), and may range from about 8E-04 to 4E-03 for locations where soils are near the high end of the range that may remain at some post-cleanup properties.

These results suggest that excess cancer risks to residents may remain at or above the high end of EPA's risk range at properties where residual soil contamination remains, as determined by PLM-VE analysis and/or by inspection for visible vermiculite.

6.3.2 Indoor Exposures

Figure 6-2 presents the distribution of screening level estimated excess cancer risk values for residents at each of the 80 post-cleanup properties where indoor ABS air data were collected in all four sampling rounds. In this assessment, the EPC (PCME s/cc) for each activity level (active, passive) at each property was calculated as the mean of the four indoor ABS air samples for that activity at that property. Risks were calculated using the active and passive exposure parameters described above, and then risks were summed across active and passive behaviors to yield the total risk.

As seen, risks from indoor exposure are within EPA's acceptable risk range (1E-06 to 1E-04) for both CTE and RME receptors at more than 95% of the properties evaluated. This suggests that risks from indoor air are likely to be of relatively low concern at most post-cleanup properties. However, risks approach or exceed the upper end of the risk range (5E-05 to 4E-04) at about 5% of the properties.

As noted above, a weak relationship appears to exist between indoor air levels and the level of LA in outdoor soil. Table 6-2 presents screening level excess cancer risk estimates for CTE and RME residential exposure to indoor air during active and passive behavior activities, evaluated using several alternative strategies for estimating the relationship between PCME LA in indoor ABS air and LA in outdoor soil.

As seen, in all approaches the combined risks (active plus passive) to residents from typical (CTE) indoor activities appear to be about 6E-06 at locations where soil are at the low end of the contamination range (including clean fill), but may range up to about 6E-05 for locations where soils are near the higher end of the range that may remain at some post-cleanup properties. For an RME receptor, risks at low soil locations are about 2E-05, ranging up to 1E-04 at higher soil locations.

6.3.3 Combined Exposures

Most residents are likely to be exposed to LA both indoors and outdoors during soil disturbance activities. Figure 6-3 displays the distribution of total risks (outdoor, indoor active, indoor passive) at 38 properties where both outdoor and indoor ABS data are available. As seen, nearly all properties are within EPA's risk range for CTE receptors, and about 25% of the locations exceed the upper end of the risk range for RME receptors. These total risks are determined mainly by the contribution of the outdoor soil disturbance pathway, although indoor exposures (both active and passive) contribute to the total. Average contributions across the 38 properties are summarized below:

Receptor	Outdoor Active	Indoor Passive	Indoor Active
CTE	65%	15%	20%
RME	75%	9%	17%

As noted previously, a property-specific assessment of potential risks based on measured ABS results is not feasible at Libby, where there are more than 4,000 properties, due to both time and cost considerations. Therefore, it is expected that risk managers will tend to rely upon an extrapolation of ABS results between areas of similar LA contamination in soil to make cleanup decisions.

6.4 Uncertainties in Risk Estimates

There are a number of sources of uncertainty in the risk calculations presented in this report. The most important of these include:

- <u>Uncertainty in true long-term average LA concentrations in air.</u> As discussed above, there is usually high variability in measured ABS air concentrations, and this results in uncertainty in the true long-term average concentration. Use of the sample mean concentration for use in risk calculations may either underestimate or overestimate the true risk. However, EPA has not yet developed a statistical method for characterizing the magnitude of the uncertainty in the mean concentration.

- <u>Uncertainty arising from use of an indirect preparation technique.</u> During TEM analysis of the ABS personal air samples, the analytical laboratories noted that a majority of the air filters were significantly overloaded with particulates. As a result, these samples were analyzed using an indirect preparation method after ashing. For chrysotile asbestos, indirect preparation often tends to increase structure counts due to dispersion of bundles and clusters (Hwang and Wang 1983; 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).

  The expectation that indirect preparation is a minor source of uncertainty in estimates of LA concentration is supported by a Libby-specific study conducted in 2005. This study compared the results for 31 samples analyzed for LA using both direct and indirect preparation methods (EPA 2007e). Figure 6-4 presents the paired results from this study. As shown in Panel A, some samples were statistically lower, some were not statistically different, and some were statistically higher when analyzed by an indirect method compared to a direct method. Although the difference was 10-15 fold in a few samples, these samples tended to be from areas outside of OU4 (i.e., from Rainy Creek Road). For the subset of samples from OU4 (see Panel B), the difference between the two results was minor (i.e., the average indirect to direct ratio was about 1.2).

This relative insensitivity in LA concentration estimates to preparation method is likely due to the fact that complex structures (bundles, clusters, etc.) that might be subject to dispersal during an indirect preparation are generally minor in most Libby air samples. Table 6-3 shows the frequency that different LA structure types were observed in outdoor ABS air samples by analysis preparation method. As shown, in direct preparation analyses, more than 90% of all structures recorded were free fibers or a single fiber protruding from a matrix (shaded grey in the table), and bundles and clusters are not common.

Based on these considerations, it is concluded that analysis of samples for LA using an indirect preparation method is a relatively minor source of uncertainty. EPA is in the process of conducting two Libby-specific studies to evaluate the potential effects of indirect preparation methods on ABS air samples. Results from these studies will inform uncertainty evaluations in future risk assessment reports.

- Uncertainty in the relationship between LA in air and LA in soil. As discussed in Section 4, the concentration of PCME LA in ABS air tends to increase as the level of LA contamination is soil increases, but development of reliable quantitative or semi-quantitative models to predict mean air concentrations from measured soil levels is not straightforward. For this reason, the calculations presented in this screening assessment utilize several alternative means of relating air levels to soil levels, and the variation in results between methods provides one measure of the uncertainty associated with the soil to air transfer pathway.

- Uncertainty in outdoor exposure patterns. To the extent that there may be significant differences in exposure between different outdoor disturbance activities, and accepting that some individuals may engage in one activity more than others, there is uncertainty in risk estimates derived using the average concentration across all outdoor ABS activities. Thus, risk calculations for any given individual may be either higher or lower, but the magnitude and direction of any differences is not known.

- Uncertainty in Libby-specific human exposure patterns. Risk calculations require knowledge of the duration, frequency, and age at which exposure occurs. As noted above, no data on human exposure parameters are available that are specific to the residents of Libby, so the values used in this screening assessment were selected using professional judgment, incorporating information that is available from studies in other locations. The values used in the risk calculations may be either higher or lower than the true Libby-specific values, but the magnitude and direction of any differences is unknown.

- Uncertainty in the cancer exposure-response relationship. Available data from studies in both animals and humans suggest that the risk of cancer from inhalation exposure to asbestos may depend in part on the type of asbestos (chrysotile vs. amphibole) and on the dimensions (length and width) of the inhaled fibers. Evaluations performed to date suggest that amphibole asbestos is somewhat more potent than chrysotile (e.g., Hodgson and Darnton 2000; Berman and Crump 2008a,b), although quantification of the difference remains difficult. Because the current EPA method for estimating cancer risk does not differentiate between the mineral forms, the potency estimates based on the current EPA method are uncertain, and may be somewhat low for use at a site such as Libby where exposure is to amphibole asbestos only. Development of site-specific unit risk factors is being addressed as part of the Libby Action Plan. It is also important to note that the current EPA method for estimating cancer risk is based on the best estimate of the cancer potency factors for lung cancer and mesothelioma, and that the true value of the potency factors might be up to 10-times higher or lower than the best estimates (EPA 1986). Consequently, true risks might be up to 10-times higher or lower than the values reported here.

- Lack of an approved method for assessing non-cancer risks. As noted above, EPA has not yet developed national guidance for evaluating the risk of non-cancer effects from inhalation exposure to asbestos. However, numerous studies of former workers and area residents provide strong evidence that exposure to LA results in an increased incidence of non-cancer adverse effects, and that these effects occur in some individuals who appear to have had only low exposure. It is not presently known whether exposure levels that protect against cancer risk will also protect against non-cancer risk from asbestos.

- Uncertainty associated with cumulative exposures. As noted above, most people who live or work in Libby may be exposed to LA by a number of different pathways. Because this screening level assessment evaluates only some of these pathways, the risk estimates presented here are likely to underestimate the total risks to some people. However, until risk assessments are completed for all potentially significant exposure pathways, the magnitude of the risks cannot be reliably estimated.

Because of these uncertainties, all screening level risk estimates for exposure to asbestos presented here should be considered to be uncertain, and actual risks may be either higher or lower than estimated.

6.5 Conclusions

One of the main objectives of the ABS program was to determine if residual human health risks are acceptable at post-cleanup properties in Libby. Based on the data currently available, it appears that residual risks from indoor exposures at post-cleanup properties are likely to be within EPA's acceptable risk range, but that some post-cleanup locations may remain where excess cancer risks from repeated outdoor soil disturbances could approach or exceed the upper end of EPA's acceptable risk range. Identifying these properties is not simple. However, it appears that if outdoor soil does not contain a level of LA that is detectable by PLM-VE, and if vermiculite is not detectable by visible inspection, then risks are likely to be within EPA's acceptable risk range. If soil contains detectable levels of LA by PLM-VE and/or if the soil contains visible vermiculite, risks tend to be somewhat higher. However, because of the high variability in ABS air values and the multiple sources of uncertainty in the process of estimating cancer risks, the boundary between acceptable and unacceptable is difficult to define with confidence.

7 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).

7.1 Audits

7.1.1 Field Audits

Field audits are conducted to evaluate field personnel in their day-to-day activities and ensure all processes and procedures are performed in accord with the applicable field guidance documents (or approved Libby Field Office [LFO] modification forms) to make certain that samples collected are correct and consistent. All aspects of data documentation and sample collection, as well as sample handling, custody, and shipping are evaluated. If any issues are identified, field personnel are notified and retrained as appropriate.

A field audit was performed on October 10, 2007, to evaluate field procedures for air and dust samples collected as part of the ABS program. The auditor concluded that the field personnel were very effective and efficient at implementing sampling and reporting ABS program requirements and commended the field personnel and staff for their efforts in maintaining an effective field program and their persistent focus on detail and quality (Updike 2007).

7.1.2 Laboratory Audits

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 the Summer/Fall of 2008 to evaluate all of the Libby laboratories. No critical deficiencies were noted during the laboratory audits that would be expected to impact data quality.

7.2 Modifications

During a large-scale sampling program, such as the ABS program, deviations from the original SAP may occur and/or it may be necessary to modify procedures identified in the original SAP to optimize sample collection. At the Libby Site, all field and laboratory modifications are recorded in site-specific modification forms. These forms provide a standardized format for tracking procedural changes in sample collection and analysis and allow project managers to assess potential impacts on the quality of the data being collected.

During the ABS program, a number of field and laboratory modifications were created that document changes from sample collection and analysis methodology specified in the Indoor and

Outdoor ABS SAPs (EPA 2007a,b). In addition, a number of laboratory modifications were created that apply to the analysis of samples from the ABS program. Copies of all modification forms are provided in Appendix F.

Table 7-1 summarizes the modifications that are applicable to the ABS program and notes the impact of each on the quality and usability of the data. As indicated, most of the modifications are not expected to have an impact on data quality or usability. Modifications which may have influenced analytical preparation techniques for air samples or the achieved analytical sensitivities could have potential impacts on data quality and interpretation. These potential impacts are discussed in more detail in the data adequacy evaluation (Section 7.5) below.

7.3 Data Verification

The Libby2DB has 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 Libby2DB 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, 100% of all samples and analytical results underwent a detailed verification. In brief, verification involves comparing the data for a sample in the Libby2DB to information on the original hard copy FSDS form and on the original hard copy analytical bench sheets for that sample. Any omissions or apparent errors identified during the verification were submitted to the field teams and/or analytical laboratories for resolution and rectification in the Libby2DB and in the hard copy documentation.

FSDS Review. Hard copy FSDS forms were reviewed for a total of 1,839 ABS samples as part of the data verification effort. Appendix G presents a summary of the findings of the FSDS review for the ABS program. In general, most of the critical issues identified were important for the purposes of sample tracking (e.g., scenario description, high volume/low volume pump type), but would not have influenced the quantitative analytical results reported for the sample. The critical error rate based on a review of the FSDS forms was about 3%.

TEM Review. A total of 1,427 TEM analyses were reviewed as part of the data verification effort. Appendix G presents a summary of the findings of the TEM data verification for the ABS program. In general, the laboratories showed a decrease in the error frequency as the ABS program progressed (20% error rate in Round 1 compared to 1-3% error rate in Rounds 2 through 4). However, it is important to note that not all errors identified were critical in nature (i.e., critical errors are those that would influence the quantitative results). Almost half of all TEM recording issues were due to the analyst incorrectly or inconsistently applying Libby

Laboratory Modification #LB-000066[12], which would not be deemed a critical error for the purposes of this report.

PLM Review. A total of 412 PLM analyses were reviewed as part of the data verification effort. The data verification only identified a single error in the reported PLM-VE bin for one soil sample (error rate of <0.1%).

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 Libby2DB [provided in Appendix A and B]) generated for this report reflect corrected data.

7.4 Quality Control Sample Summary

A number of Quality Control (QC) samples were collected as part of the ABS program 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. A detailed evaluation of these QC samples is provided in Appendix H. Based on the results of the QC evaluation, it is concluded that:

- Inadvertent contamination of air, dust, or soil field samples with LA is not of significant concern, either in the field or the laboratory.
- Transmission electron microscopy (TEM) precision is generally good, as indicated by high agreement rates between field samples and field duplicates (dust only), between original and re-preparation analyses, and between original and recount analyses (i.e., samples where the same grid openings are evaluated twice).
- Polarized light microscopy (PLM) precision is generally good, as indicated by high concordance rates between field samples and matched field duplicates, preparation splits, laboratory duplicates, and interlabs.
- PLM accuracy is also good, as indicated by the concordance rates when analyzing performance evaluation samples.

7.5 Data Adequacy Evaluation

A comparison of the data collected with the data quality objectives summarized in the Indoor and Outdoor ABS SAPs (EPA 2007a,b) is presented below.

[12] This modification requires TEM analysts to note information on the levels (presence/absence) of the sodium and potassium peaks observed in the EDS spectrum for the recorded LA structure in the EDD comment field.

7.5.1 Outdoor ABS

7.5.1.1 Spatial and Temporal Representativeness

The goal of the outdoor ABS program was to evaluate 15 sampling locations for each of 5 soil category types (N total = 75 outdoor ABS locations), encompassing the range of types and levels of residual sources that may remain at post-cleanup locations, and providing a reasonable spatial representation of OU4. Target and actual numbers of ABS locations are summarized below.

Soil Category	Number of Outdoor ABS Locations	
	Target	Actual
1	15	15
2	15	15
3	15	15
4	15	14
5	15	16
Total	75	75

As seen, the number of outdoor ABS locations sampled met the specified goal for nearly all soil categories, and achieved the target total number of locations (N=75). Inspection of the map of outdoor ABS locations (see Figure 4-1) shows that the selected locations were spread throughout Libby and are generally representative of OU4. All 75 outdoor ABS locations were evaluated in both summer and spring, which are the two seasons where soil disturbance activities are likely to be highest. Based on this, the outdoor ABS data collected are deemed to be spatially and temporally representative.

7.5.1.2 Air Samples

Sample Completeness

Completeness is defined as the fraction of samples that were planned that were successfully collected and analyzed. As described above, three different disturbance scenarios were evaluated at each outdoor ABS location – mowing, raking, and digging. During each disturbance scenario, the individual performing the activity wore two personal air monitors (high volume and low volume) to collect air samples for asbestos analysis. The high volume sample was analyzed in preference to the low volume sample (the low volume sample was analyzed only if the high volume sample was damaged or lost). The target number of personal air samples for the outdoor ABS program was 450 samples (75 ABS locations x 3 scenarios x 2 rounds). All of these samples were successfully collected and analyzed (i.e., 100% completeness). There was only one case where the high volume sample was damaged and the low volume sample was analyzed instead.

Sample Duration

As specified in the Outdoor ABS SAP, each soil disturbance activities was planned to span a 2-hour time interval. This time was selected to help ensure that samples captured a sufficiently long sampling interval that the sample would be a reliable measure of the long term mean concentration during an ABS activity, and would not be unduly influenced by short-term (minute to minute) spikes and dips in the concentration.

However, in Round 1 the laboratories reported that a high number of filters were overloaded and would require indirect preparation. In an attempt to reduce the number of overloaded samples, the sample collection protocol was modified (see Outdoor ABS SAP Mod 1 in Appendix F) to stop the sample collection if the filter became overloaded (based on a visual inspection in the field). This modification was in effect between August 16-24, 2007.

Shortening sampling duration is not expected to have a significant effect on data quality unless sampling durations become so short that sample results may be dominated by short term fluctuations. In this event, the chief effect that would be expected is increased variability in the samples, which in turn tends to increase uncertainty in the mean concentration. It is not known how short the duration would need to be before this becomes a concern, but it seems unlikely that it would be an important factor for samples that are 30 minutes or longer. As shown in Figure 7-1, 399 out of 450 samples (89%) had a sample duration of 30 minutes or more, while 34 had a duration of 15-30 minutes and 17 had a duration of less than 15 minutes. Thus, the fraction of samples in the dataset that might tend to have limited temporal representativeness is small. In addition, the short duration samples tended to span all ABS activity scenarios and all outdoor ABS area categories (as shown in the tables below the graph), which shows that a systematic bias is not expected. Therefore, the overall effect of the short duration samples on data quality is not likely to be significant.

Analytical Sensitivity

As specified in the Outdoor ABS SAP, the target analytical sensitivity for all outdoor air samples was 0.001 cc^{-1}. In the SAP, it was assumed that this sensitivity could be achieved by counting 30 grid openings (GOs) (assuming the target air volume was achieved and direct preparation was possible). However, as discussed above, in some instances the total air volume achieved was less than the target and some samples needed to be prepared indirectly due to filter overloading. Based on this, the TEM analysis stopping rules were modified (see Outdoor ABS SAP Mod 1 in Appendix F) to allow the TEM analysis to stop (even if the target sensitivity was not achieved) if either 50 LA structures were recorded or if 100 GOs were examined.

Figure 7-2 summarizes the analytical sensitivities achieved for all outdoor ABS air samples. As seen, about 50% of all samples achieved the target sensitivity of 0.001 cc^{-1}. When samples did not achieve the target sensitivity, the TEM analysis was stopped based on GOs examined in 184 samples (41%) and based on LA structure count in 38 samples (8%).

Halting a TEM analysis prior to achieving the target analytical sensitivity is likely to have little impact on uncertainty in the reported air concentration in cases where the number of LA structures counted is above 10-20 structures. Figure 7-3 summarizes the total number of LA structures recorded for outdoor ABS air samples where the target analytical sensitivity was not achieved because the analysis was halted based on the 100 GO stopping rule. As seen, 113 of these samples (25% of the total) have fewer than 10 LA structures recorded, and 76 samples (17%) have fewer than 5 LA structures recorded.

The consequence of this is that the concentration estimates for samples with low count due to stopping before the target sensitivity is achieved will have somewhat higher uncertainty than would have been achieved if the samples had been analyzed until the analytical sensitivity was achieved. The magnitude of the effect can be assessed by noting that the expected coefficient of variation (CV = standard deviation / mean) around a count of N is equal to $1/N^{0.5}$. For example, a sample with a count of 5 has an expected CV of 44%, while a sample with a count of 20 has an expected CV of 22%. Note that the effect of low count is to increase uncertainty, but no bias is introduced. Because the frequency of samples with low count (e.g., < 5) that did not achieve target sensitivities is relatively low (17%), it is expected that the overall impact of this modification on data quality is not significant.

7.5.1.3 Soil Samples

Sample Completeness

Based on the Outdoor ABS SAP, for each outdoor ABS location, a 30-point soil composite sample was to be collected in both Round 1 and Round 2 for PLM analysis. In addition, visual inspection for vermiculite was to be performed at each of the 30 inspection points in both Rounds 1 and 2. In Round 2, a 2-point soil composite sample was also collected which was representative of the sub-areas where the digging scenario occurred. Based on this, the target number of soil PLM-VE samples and visible inspection surveys for the outdoor ABS program was 225 (75 ABS locations x 3 samples).

The outdoor ABS program was able to collect and perform PLM analyses for all of the target number of soil samples (i.e., 100% completeness). Completeness was also high for visible inspection, with only one case in Round 1 where the visual vermiculite inspection results were not recorded for the 30-point composite. This single omission is not expected to limit or bias the data evaluation.

7.5.2 Indoor ABS

7.5.2.1 Spatial and Temporal Representativeness

The goal of the indoor ABS program was to evaluate 20 properties for each of 4 post-cleanup types (N total = 80 indoor ABS properties), encompassing the range of types and levels of residual sources that may remain at post-cleanup locations, and providing a reasonable spatial representation of OU4. Target and actual numbers of ABS locations are summarized below.

Category	Number of Outdoor ABS Locations	
	Target	Actual
1	20	19
2	20	21
3	20	20
4	20	20
Total	80	80

As seen, the number of indoor ABS properties sampled met or exceeded the specified goal for nearly all soil categories, and met the target total number of locations (N=80). Inspection of the map of indoor ABS properties (see Figure 5-1) shows that the selected properties were spread throughout Libby and are generally representative of OU4. All indoor ABS properties were evaluated in all four sampling rounds[13] (i.e., data are representative of each season). Based on this, the indoor ABS data collected are deemed to be spatially and temporally representative.

7.5.2.2 Air Samples

Sample Completeness

Two different scenarios were evaluated at each indoor ABS property – during active and passive behaviors. During each scenario, the individual performing the activity wore two personal air monitors (high volume and low volume) to collect air samples for asbestos analysis. The high volume sample was analyzed in preference to the low volume sample (the low volume sample was analyzed only if the high volume sample was damaged or lost). The target number of personal air samples for the indoor ABS program was 640 samples (80 ABS locations x 2 scenarios x 4 rounds). Nearly all of these samples were successfully collected and analyzed (i.e., >99% completeness). There were only two samples where the where the high volume sample was damaged; in one instance, the low volume sample was analyzed instead, in the other, the low volume sample was also damaged and no analysis could be performed.

Sample Duration

As specified in the Indoor ABS SAP, each scenario was planned to span a 4-hour time interval. This time was selected to help ensure that samples captured a sufficiently long sampling interval that the sample would be a reliable measure of the long term mean concentration during the ABS activity, and would not be unduly influenced by short-term (minute to minute) spikes and dips in the concentration.

Shortening sampling duration is not expected to have a significant effect on data quality unless sampling durations become so short that sample results may be dominated by short term fluctuations. In this event, the chief effect that would be expected is increased variability in the samples, which in turn tends to increase uncertainty in the mean concentration. It is not known

[13] Property 628 Avenue B was identified as a backup property for Category 2. This property was only sampled in Round 1 (summer) and is not included in the summary table.

how short the duration would need to be before this becomes a concern, but it seems unlikely that it would be an important factor for samples that are 1 hour or longer. As shown in Figure 7-4, only 4 samples had sample durations of less than 3 hours. Thus, the fraction of samples in the data that might tend to have limited temporal representativeness is small, and the overall effect on data quality is not likely to be significant.

Analytical Sensitivity

As specified in the Indoor ABS SAP, the target analytical sensitivity for all indoor air samples was 0.0002 cc^{-1}. In the SAP, it was assumed that this sensitivity could be achieved by counting about 80 GOs (assuming the target air volume was achieved and direct preparation was possible). However, as discussed above, in some instances the total air volume achieved was less than the target and some samples needed to be prepared indirectly due to filter overloading. Based on this, the TEM analysis stopping rules were modified (see Libby Laboratory Modification #LB-000079 in Appendix F) to allow the TEM analysis to stop, even if the target sensitivity was not achieved, if either 50 LA structures were recorded or if 100 GOs were examined.

Figure 7-5 summarizes the analytical sensitivities achieved for all indoor ABS air samples. As seen, about 85% of all samples achieved the target sensitivity of 0.0002 cc^{-1}. When samples did not achieve the target sensitivity, the TEM analysis was stopped based on GOs examined for all but 2 samples.

Halting a TEM analysis prior to achieving the target analytical sensitivity is likely to have little impact on uncertainty in the reported air concentration in cases where the number of LA structures counted is above 10-20 structures. Figure 7-6 summarizes the total number of LA structures recorded for indoor ABS air samples where the target analytical sensitivity was not achieved because the analysis was halted based on the 100 GO stopping rule. As seen, 89 of these samples (89% of the total) have fewer than 10 LA structures recorded, and 72 samples (72%) have fewer than 5 LA structures recorded.

The consequence of this is that the concentration estimates for these samples have somewhat higher uncertainty than would have been achieved if the samples had been analyzed until the analytical sensitivity was achieved. However, it is not expected that this modification leads to any bias in the data, and this only impacts less than 15% of all indoor ABS samples (those that did not achieve the target sensitivity and had a low structure count), so the overall impact on data quality is not expected to be significant.

7.5.2.3 Dust Samples

Sample Completeness

According to the Indoor ABS SAP, for each indoor ABS property, a single 10-point composite indoor dust sample was to be collected during each round of sampling which was representative of 4 accessible areas, 4 infrequently accessed areas, and 2 inaccessible areas within the rooms where the ABS activities were performed. The target number of dust samples was 320 (80 properties x 4 rounds).

The actual number of dust samples (N=336) collected was higher than the target. This is because in Round 1 multiple composite dust samples (1 sample per floor) were collected at 14 of the indoor ABS properties, rather than a single composite sample representative of all floors. These samples were averaged to generate a value that is analogous to a physical composite across all floors. This issue was resolved in subsequent sampling rounds.

There are only two cases where dust samples are not available for all rounds from all properties. Property 628 Avenue B was only sampled in Round 1, and the dust sample from Round 1 was lost for property 105 West Oak Street.

Analytical Sensitivity

As specified in the Indoor ABS SAP, the target analytical sensitivity for all indoor dust samples was 20 cm^{-2}. With one exception, all dust samples achieved the target analytical sensitivity. The sensitivity achieved for the one sample that did not meet the target was 27 cm^{-2}.

7.5.2.4 Soil Samples

Sample Completeness

Based on the Indoor ABS SAP, for each ABS property, two 30-point soil composite samples were to be collected in Round 1 for PLM analysis – one from an SUA and one from a NSUA. In addition, visual inspection for vermiculite was to be performed at each of the 30 inspection points for both samples. Based on this, the target number of soil PLM samples and visible inspection surveys for the indoor ABS program was 160 (80 ABS locations x 2 samples).

The indoor ABS program was able to collect and perform PLM analyses and visible vermiculite inspection data for all of the target number of soil samples (i.e., 100% completeness).

(Note: A number of soil samples were collected, as part of the initial property selection procedure for the Indoor ABS program, for properties that were not ultimately selected for indoor ABS. These data are not presented in this report.)

7.5.3 Data Adequacy Conclusions

Based on the data adequacy assessment presented above it is concluded that the data generated during the OU4 ABS programs meet the DQOs stated in the respective SAPs and results are adequate to support the data evaluations presented in this report.

7.6 Data Quality Conclusions

Taken together, these results indicate that TEM and PLM data collected at the Libby site as part of the OU4 ABS program are representative, of acceptable quality, and considered to be reliable and appropriate for use without qualification.

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