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FRAMEWORK FOR INVESTIGATING ASBESTOS-CONTAMINATED COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION AND LIABILITY ACT SITES

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Executive Summary

This guidance presents a framework for investigating and characterizing the potential for human exposure from asbestos contamination in outdoor soil and indoor dust at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) removal and remedial sites. It also provides limited guidance to address asbestos containing material (ACM) and naturally occurring asbestos (NOA) that might be encountered at a site. This guidance is one piece of a broader intra- and inter-Agency effort to utilize recent developments regarding asbestos that applies current scientific information to better assess exposure and risk from asbestos (*e.g.*, Agency efforts to update cancer and non-cancer assessments for asbestos). This guidance supplements other U.S. Environmental Protection Agency (U.S. EPA) guidance concerning exposure and risk assessment (*e.g.*, Risk Assessment Guidance for Superfund [RAGS], U.S. EPA, 1989a), and is specific to assessment of sites contaminated with asbestos. This guidance is needed because there are several unique scientific and technical issues associated with the investigation of human exposure and risk from asbestos, and it is important for risk assessors and risk managers to understand these issues when addressing asbestos sites. This framework discusses specific strategies that are based on the best currently available science and recommends methods for characterizing exposure and risk from asbestos to inform risk-management.

Asbestos fibers in outdoor soil, indoor dust, or other source materials are inherently hazardous as they present a health threat when the asbestos is released from the source material into air where it can be inhaled. Once inhaled, asbestos fibers can increase the risk of developing lung cancer, mesothelioma, pleural diseases, pleural fibrosis, and asbestosis.

The relationship between the concentration of asbestos in a source material and the concentration of fibers in air that results when that source is disturbed is very complex and dependent on a wide range of variables. Research in this area indicates that the relationships between soil and/or dust levels of asbestos and measurements in air depend on many site-specific factors including meteorological conditions, soil type, soil moisture, and nature of contamination (*e.g.*, ACM vs. NOA).

This guidance emphasizes an empiric approach to site investigation and characterization. Specifically, a combination of samples from media (such as air and soil) are recommended to characterize exposures. Personal air sampling and stationary air monitors can be used to measure an individual's potential exposure to airborne asbestos fibers. Activity-based sampling (ABS), a standard method used by industrial hygienists to evaluate workplace exposures, is a personal air monitoring approach that can provide data for risk assessment and is recommended in this framework. ABS can be useful for assessment of asbestos-contaminated outdoor soil and indoor dust. In some cases, a new sampling technique known as the Fluidized Bed Asbestos Segregator (FBAS), may be useful at sites with asbestos contaminated soil.

The standard practice for indoor sampling to inform risk-based decisions at sites contaminated with asbestos is to combine short-term ABS with long-term stationary sampling. The ABS should be designed to evaluate short-term, high-intensity exposures. Based on agency experience, ABS with personal sampling (usually for time periods up to a few hours) can yield

the most representative estimate of short-term exposures that may occur during soil or dust disturbance activities. Stationary sampling is generally used (usually for a period of 8-24 hours) to characterize longer-term exposure. The combination of these sampling techniques can provide useful information to support risk-based decisions within a building.

The International Organization for Standardization (ISO) Method 10312 (ISO, 2019a) is the recommended method for asbestos air analysis under this decision framework. Once asbestos is detected, this analytical procedure can also be used to capture information concerning the specific mineralogy of asbestos fibers present, which can augment the exposure estimate.

Depending on its application, potential limitations of the ABS approach may include the representativeness of samples over an area of concern and the ability to generalize findings from a point in time and space to future exposures, other locations, others engaged in dissimilar activities, and differing environmental conditions. Site-specific data quality objectives (DQOs) and sampling plans should consider such issues prior to sample collection. Furthermore, cost of ABS and sample analysis, analytical sensitivity, and other site-specific factors should be considered in the planning process.

To assist with the complexities of the recommended exposure assessment for asbestos-contaminated sites, members of the Technical Review Workgroup (TRW) Asbestos Committee can provide technical assistance to site teams to develop optimal strategies for site investigation and characterization on a site-specific basis.

New information in the 2021 version of the framework includes:

- Specific recommendations for assessing indoor areas (Section 4)
- Use of the Fluidized Bed Asbestos Segregator to aid in characterizing asbestos in soils (Sections 4 and 5)
- Updates to soil analysis methods (Section 5)
- Various updated analytical method references for air and soil (Section 5)
- Quality control considerations for asbestos analysis (Section 6)
- Data management tools discussion (Section 6)
- Information from the 2014 Libby Amphibole Asbestos Integrated Risk Information System (IRIS) assessment (Section 7 and Appendix I)

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ACRONYMS[1]

ABS	Activity-based sampling
ACM	Asbestos containing material
AF	Adjustment factor
A_{GO}	Area of each grid opening
AHERA	Asbestos Hazard Emergency Response Act of 1986
ARAR	Applicable or relevant and appropriate requirements
ASHARA	Asbestos School Hazard Abatement Reauthorization Act
ASTM	American Society for Testing and Materials
AT	Averaging time
ATSDR	Agency for Toxic Substances and Disease Registry
ATV	All-terrain vehicle
BMC	Benchmark Concentration
BMCL	The lower confidence bound on a benchmark concentration (BMC).
BV DH FP	Bivariate dichotomous Hill model with a fixed plateau
CA	Concentration of asbestos in air
CAA	Clean Air Act
CARB 435	California Air Resources Board analytical method 435
CAS	Chemical Abstract Service
cc	Cubic centimeter
cc/m	Cubic centimeter per meter
CE10	Cumulative exposure to asbestos, lagged by 10 years
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm/s	Centimeters per second
CSM	Conceptual Site Model
DOT	Department of Transportation
DQO	Data quality objective
EBSD	Electron back scatter diffraction
ELCR	Excess lifetime cancer risk
ED	Exposure duration
EDXA	Energy dispersive x-ray analysis
EF	Exposure frequency
EFA	Effective filter area
ELCRs	Excess lifetime cancer risks
EPA	United States Environmental Protection Agency

[1] Definitions for some of these terms can be found in the Glossary in Appendix A.

EPC	Exposure point concentration
ERRPPB	Emergency Response, Removal, Preparedness and Prevention Branch
ERT	Environmental Response Team
ET	Exposure time
f/cc	Fibers per cubic centimeter
f/cm^2	Fibers per square centimeter
FBAS	Fluidized Bed Asbestos Segregator
FSP	Field Sampling Plan
GOs	Grid openings
HASP	Health and safety plan
HAZWOPER	Hazardous Waste Operations and Emergency Response
HQ	Hazard quotient
HRPO	Human Research Protocol Office
HSRRO	Human Subjects Research Review Official
Hz	hertz
ICs	Institutional controls
IDQTF	Intergovernmental Data Quality Task Force
I_M	Incidence of mesothelioma
IRIS	Integrated Risk Information System
ISM	Incremental Sampling Methodology
ISO	International Organization for Standardization
ISO 10312	International Organization for Standardization Method 10312
IUR	Inhalation unit risk
$IUR_{a,d}$	Inhalation unit risk at age of first exposure (a) and exposure duration (d)
kHz	kilohertz
K_L	Potency factor for lung cancer
K_M	Potency factor for mesothelioma
L	Liters
LAA	Libby Amphibole Asbestos
LOC	Level of concern
LOD	Limit of detection
LPT	Localized pleural thickening
MCE	Mixed cellulose ester
MCL	Maximum Contaminant Level
mm	millimeter
mm^2	Square millimeter
mm/s	Millimeters per second
MSHA	Mine Safety and Health Administration

NADES	National Asbestos Data Entry Spreadsheet
NAS	National Academy of Science
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NESHAP	National Emission Standards for Hazardous Air Pollutants
NFA	No further action
NFE	No further evaluation
NHEERL	National Health and Environmental Effects Research Laboratory
NIOSH	National Institute for Occupational Safety and Health
NOA	Naturally occurring asbestos
NVLAP	National Voluntary Laboratory Accreditation Program
OSC	On Scene Coordinator
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PCM	Phase contrast microscopy
PCMe	PCM-equivalent
PE	Performance Evaluation
PLM	Polarized light microscopy
PPE	Personal protective equipment
Q	A cubic function of exposure duration and time since first exposure
QAPP	Quality assurance project plan
RACM	Regulated Asbestos Containing Material
RAGS	Risk Assessment Guidance for Superfund
RfC	Reference concentration
RME	Reasonable maximum exposure
RI	Remedial Investigation
ROD	Record of Decision
RPM	Remedial Project Manager
RR	Relative risk of lung cancer
RRT	Regional Response Team
S	Analytical Sensitivity
s/cc	Structures per cubic centimeter.
s/cm^2	Structures per square centimeter
s/mm^2	Structures per square millimeter
SAED	Selected area electron diffraction
SAP	Sampling and analysis plan
SDWA	Safe Drinking Water Act
SEM	Scanning Electron Microscopy

SERAS	Scientific Engineering Response and Analytical Services
SHEM	Safety, Health and Environmental Manager
SOG	Standard operating guidelines
SOP	Standard operating procedure
SOW	Scope of Work
TEM	Transmission electron microscopy
TEI	Total exposure interval
TRW	Technical Review Workgroup
TSCA	Toxic Substances Control Act
TSFE	Time since first exposure
TSP	Total suspended particulate
TWA	Time weighted average
TWF	Time weighting factor
UCL	Upper confidence limit
UFP	Uniform Federal Policy
UR	Unit risk
U.S.	United States
USGS	U.S. Geological Survey

RECOMMENDED FRAMEWORK FOR INVESTIGATING ASBESTOS-CONTAMINATED CERCLA SITES

1.0 Scoping of Investigation

1.1 Introduction

1.1.1 Purpose of the Framework

This document provides technical and policy guidance to the U.S. Environmental Protection Agency (U.S. EPA) staff and others focused on site investigation, evaluation of exposures, and risk assessment supporting risk management decisions for asbestos contaminated Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites. This document is one piece of broader intra- and inter-Agency efforts to utilize recent information on asbestos so that current scientific information can be used to better assess exposure and risk from asbestos. The purpose of this document is to provide a flexible framework for investigating and evaluating asbestos contamination at removal and remedial sites consistent with the CERCLA process.[2] The recommended framework presented herein provides a process that supplements other U.S. EPA guidance concerning exposure and risk assessment (e.g.., U.S. EPA, 1989a), and is specific to assessment of sites contaminated with asbestos (see Figure 1). This document also provides remedial/removal managers, remedial project managers (RPMs), on-scene coordinators (OSCs), site assessors, and other decision makers with information to assist in the evaluation of asbestos risks at CERCLA sites It also provides information to the public and to the regulated community on how U.S. EPA intends to exercise its discretion in implementing its regulations at contaminated sites. It is important to understand, however, that the contents of this document do not have the force and effect of law and are not meant to bind the public in any way. This guidance is not intended to, and does not, create any right or benefit, substantive or procedural, enforceable at law or in equity by any party against the United States, its departments, agencies, or entities, its officers, employees, or agents, or any other person. Rather, the document is intended only to provide clarity to the public regarding existing requirements under the law or agency policies and suggests approaches that may be used at specific sites to assess exposures to asbestos and associated risk, as appropriate, given site-specific circumstances.

1.1.2 Support Removal Evaluations and Actions Under CERCLA

Removal site evaluations conducted under 40 Code of Federal Regulations (CFR) § 300.410 may include a removal preliminary site assessment and, if warranted, a removal site inspection. Information to support the removal evaluation may include but is not limited to: identification of source and nature of the release, evaluation by the U.S. EPA, the Agency for Toxic Substances and Disease Registry (ATSDR) or other agencies of the threat to public health, evaluation of the magnitude of the threat, determination of whether a removal action is required, and a determination of whether a nonfederal party is undertaking the appropriate response(s). A removal action pursuant to § 300.415 may be initiated by the lead agency if it decides, based on the preliminary assessment and consideration of eight factors listed in the National and Oil and

[2] Appendix B illustrates how the Asbestos Framework interacts with the CERCLA process through the removal program and the remedial program. The steps outlined in the Asbestos Framework are applicable during the evaluation of removal actions, during the hazard ranking and listing process and during the remedial investigation, feasibility study and record of decision process within the remedial program.

Hazardous Substances Pollution Contingency Plan (NCP), that there is a threat to public health, welfare or the environment. Generally, removal actions are initiated under the removal program and are routinely directed by On-Scene Coordinators (OSCs). In some cases, Remedial Project Managers (RPMs) may direct cleanup activities.

Removal sites often encounter asbestos-containing materials (ACM) as a contaminant located in soils or waste piles. ACM refers to any material containing 1% asbestos or greater. Common types of ACM encountered at CERCLA sites include pipe insulation, shingles, and cement (See appendix D for photographs of ACM). Frequently these sites are associated with building demolitions and redevelopments where ACM is discovered as improperly disposed materials or remnants present in soil from improper abatement procedures. Asbestos can also be found in soils due to human disturbance of geologic formations that contain unprocessed asbestos (naturally occurring asbestos [NOA]). Limited sampling and analysis (as discussed in Sections 4 and 5) is required to assess the presence of material at levels exceeding waste criteria or necessitating removal. If the removal site evaluation indicates that further investigation is required, the site may be addressed under §300.420.

In the Removal program, action memoranda (action memos) are used to document the selection and approval of the removal action for a site. Action memos describe the site history, current activities, and health and environmental threats; outline the action, cleanup levels (if applicable), and estimated costs; and document approval of the proposed action by the proper U. S. EPA Headquarters or Regional authority. When a proposed removal action is considered to be of national significance or precedent setting, the current U.S. EPA Action Memo Guidance (U.S. EPA, 2009c) requires Headquarters' concurrence, except in the case of an emergency response. The Action Memo Guidance identifies categories of removal actions that have been determined to be of national significance or precedent setting and it specifies procedures for requesting Headquarters' concurrence. Sites involving asbestos as the principal contaminant of concern are included as one of the categories and action memos for these sites require Headquarters' concurrence unless the action is considered an emergency response. Presently, U.S. EPA is reevaluating the removal action categories identified as nationally significant or precedent setting. Categories may be added and/or deleted in the future.

Additionally, the Action Memo Guidance includes as a nationally significant category releases identified in CERCLA Section 104(a)(3)(a) and (b). The CERCLA citations restrict removal or remedial actions, except in exceptional circumstances, in response to releases from (a) "a naturally occurring substance in its unaltered form, or altered solely through naturally occurring processes or phenomena, from a location where it is naturally found", and (b) "products which are part of the structure of, and result in exposure within, residential buildings or business or community structures." In the case of asbestos, these CERCLA response limitations may well prevent responses to naturally occurring asbestos and to damaged ACM contained within a building. If contemplating a removal action in these cases, Headquarters' consultation and concurrence is required and consultation with regional counsel is recommended. For guidance regarding response (b) above, see U.S. EPA (1993b).

1.1.3 Support Site Investigations and Remedial Actions Under CERCLA

Remedial site assessments and remedial investigations/feasibility studies conducted under 40 CFR § 300.420 and 430 generally address larger, more complex sites where there is widespread asbestos contamination in the environment. Remedial investigations (RIs) are designed to collect data necessary to adequately characterize the site for the purpose of developing and evaluating effective remedial alternatives. These investigations typically follow an ordered sequence of events beginning with development of a quality assurance project plan (QAPP), and then conducting field sampling, data analysis and risk assessment (human health and/or ecological) all included in a RI report. A community involvement plan assures that the community and stakeholders are kept informed and are involved in the decision-making process.

If unacceptable risks are present as defined in the statute, the feasibility study develops and evaluates appropriate remedial alternatives accounting for scope, characteristics, and complexity of the site problem. Remedial action objectives are developed to implement the chosen preferred alternative based on screening against U.S. EPA's nine criteria for remedy selection[3], which includes consideration of applicable or relevant and appropriate requirements (ARARs). This process leads to a Proposed Plan that is submitted for public comment and is finalized in a Record of Decision (ROD).

1.2 Site Planning/Investigation Process

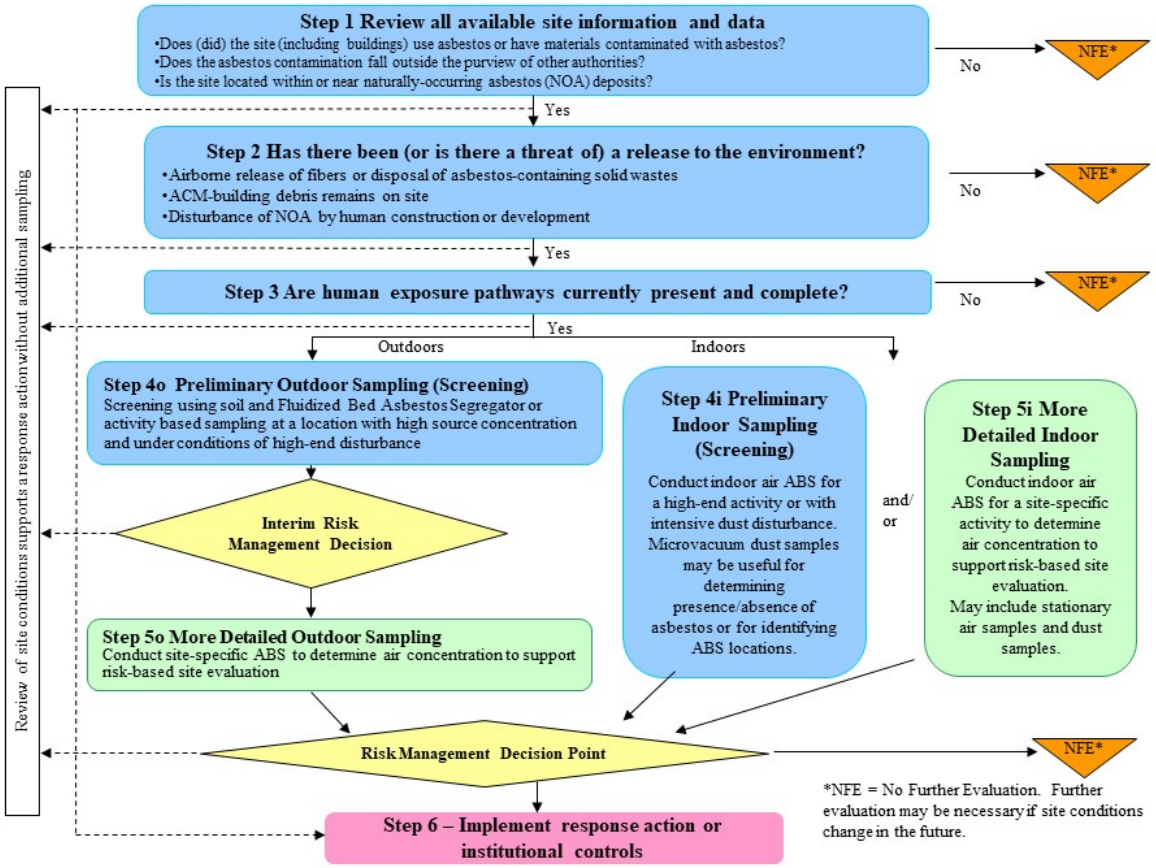
The investigation process outlined in this document follows the traditional RI process with some deviations due to the unique properties of asbestos/mineral fibers. Figure 1 presents a condensed outline of the investigation processes described in this document.

Investigations for asbestos sites include a review of site history, development of a QAPP, development of a sampling plan that includes data quality objectives (DQOs), development of a conceptual site model (CSM), and conducting field sampling event(s). Once the data are collected and analyzed, a risk assessment is performed to inform risk management and remedial decisions. The site may progress to a removal action and/or to a feasibility study leading to remedy selection, ROD, and remedial action(s). These steps are detailed in the following sections.

The first step in an asbestos site investigation is to review all existing information available at a site to determine whether asbestos may require evaluation (Figure 1, Step 1). The types of information that should be reviewed include information on historical use of the property, including past site operations, asbestos surveys, and/or the potential presence of geological asbestos deposits. The first step in an asbestos site investigation also includes determining whether other Federal or state regulatory programs may have authority over potential asbestos releases at the site.

[3] See Rules of Thumb for Superfund Remedy Selection. EPA 540/R/97-013, OSWER 9355.0-69 (U.S. EPA, 1997)

Figure 1. Asbestos Decision Framework for Outdoor and Indoor Environments



If a thorough review of available site data provides a clear indication that asbestos is not present, then no further action to address potential asbestos contamination is needed. If the available information indicates that asbestos is or may reasonably be expected to be present (and it is not being addressed by another authority), then all historical and current available information should be reviewed to determine if a release of asbestos to the environment has occurred or could occur due to human activities.

The use of ACM in buildings and the presence of NOA are two special situations that can affect U.S. EPA response actions.

Regarding ACM in buildings, CERCLA contains a qualified limitation on response authority for releases or a threat of release "from products which are part of the structure of, and result in exposure within, residential buildings or business or community structures" (U.S. EPA, 1993b).

Under the National Emission Standards for Hazardous Air Pollutants (NESHAP) (40 CFR part 61, Subpart M [NESHAP, 1984]; see Section 2.1.1), demolition and renovation activities in a "facility" (as defined in the rules) are regulated if the asbestos is regulated asbestos-containing material (RACM), present in sufficient quantity. Under the Clean Air Act (CAA) NESHAP, 40 C.F.R. § 61.141, "Regulated asbestos-containing material (RACM) means (a) Friable asbestos material, (b) Category I nonfriable ACM that has become friable, (c) Category I nonfriable ACM

that will be or has been subjected to sanding, grinding, cutting, or abrading, or (d) Category II nonfriable ACM that has a high probability of becoming or has become crumbled, pulverized, or reduced to powder by the forces expected to act on the material in the course of demolition or renovation operations regulated by this subpart." "Facility" means "any institutional, commercial, public, industrial, or residential structure, installation, or building (including any structure, installation, or building containing condominiums or individual dwelling units operated as a residential cooperative, but excluding residential buildings having four or fewer dwelling units); any ship; and any active or inactive waste disposal site. For purposes of this definition, any building, structure, or installation that contains a loft used as a dwelling is not considered a residential structure, installation, or building. Any structure, installation or building that was previously subject to this subpart is not excluded, regardless of its current use or function." See 40 C.F.R. 61.141.

Notice is required for all facility demolitions if RACM is present. If a building has been renovated, demolished or is destroyed (*e.g.*, by fire) and asbestos-containing debris is found to remain at the site, this should be considered a release of potential concern under CERCLA. This consideration is true even if the ACM is buried since it may be uncovered if the site is developed in the future (Appendix C).

Regarding NOA, Section 104(a)(3)(A) of CERCLA contains a qualified limitation on response authority for a release or a threat of release "of a naturally occurring substance in its unaltered form, or altered solely through naturally occurring processes, from a location where it is naturally found (CERCLA, 1980; U.S. EPA, 1993b)." This limitation does not affect U.S. EPA's authority to address a release or a threat of release of NOA that has been altered by anthropogenic activities. State and local authorities may be appropriate for NOA response and management, especially in locations where NOA is found to be widespread in native soils. U.S. EPA may respond if the NOA release constitutes a public health or environmental emergency, and no other person with the authority and capability to respond to the emergency will do so in a timely manner. U.S. EPA Headquarters must concur on the response plan.

If it is determined that there has been a release and a response is appropriate, then one may either proceed directly to a response action (Figure 1, Step 6) or evaluate if human exposure pathways are currently present and complete (Figure 1, Step 3). If there has not been a release, but there is a threat of release, then further evaluation should be performed under either the removal or remedial program, depending on the magnitude and/or severity of the potential future release.

2.0 Site Characterization

2.1 Asbestos and CERCLA Regulatory Authority

Asbestos is primarily a pulmonary toxicant that can be inhaled when asbestos contaminated soil and waste materials are disturbed. For asbestos, air data are needed to support risk management decisions and duration of exposure must be considered for risk calculations. The NCP (300.400[a]) authorizes the U.S. EPA to respond to releases of hazardous substances into the environment. Friable asbestos is a listed CERCLA hazardous substance under 40 C.F.R. § 302.4 (https://www.epa.gov/sites/production/files/2015-03/documents/list_of_lists.pdf). As a result,

nonfriable forms of asbestos could be subject to CERCLA if the substantial threat of release included activity rendering the asbestos friable.

Weathering and disturbance of material containing nonfriable forms of asbestos may result in the asbestos becoming friable over time. Unlike typical inorganic constituents in soil that have risk-based screening levels, U.S. EPA has not developed risk-based screening levels for asbestos fibers in soil or air due to several technical issues. The relationship between asbestos measured in soil/waste material and, if disturbed, air is complex and dependent on several factors (i.e., source concentration, fiber "releasability", soil type, moisture content and weather conditions as described in Section 4.3). Currently, there is no validated technique for modeling fiber "releasability" from the matrix of concern (e.g., soil, dust, ACM) to air across different locations. Therefore, we are challenged to make removal/remedial decisions based on the relationship between limited soil/waste concentrations and air concentrations for asbestos, rather than solely soil/waste concentrations for typical inorganic constituents (i.e., mg/kg soil versus fibers/cc). Another variant associated with asbestos relative to other contaminants is that once the mineral fiber is inhaled, it can remain in the respiratory system for long durations while continually eliciting a biological reaction.

Historically, asbestos has been addressed at U.S. EPA under CERCLA authority by reference to the term ACM as it is used in the National Emission Standard for Asbestos, which is found in Subpart M of the NESHAP, 40 CFR Part 61. Under the asbestos NESHAP, Category I and Category II nonfriable ACM are defined in part as certain products or materials containing >1% asbestos as analyzed by polarized light microscopy (PLM) (see 40 CFR 61.141 [NESHAP, 1984]). Office of Solid Waste and Emergency Response (OSWER) Directive 9345.4-05 (U.S. EPA, 2004; https://nepis.epa.gov/Exe/ZyPDF.cgi/90180500.PDF?Dockey=90180500.PDF) indicated that the NESHAP >1% definition may not be reliable for assessing potential human health hazards from asbestos-contaminated soils at CERCLA sites, and that a risk-based, site-specific action level generally is appropriate when evaluating response actions for asbestos at CERCLA sites.

Although the OSWER Directive (9345.4-05) is designed to help steer CERCLA asbestos investigations to a risk-based paradigm, it does not provide guidance for investigating and evaluating asbestos at CERCLA sites. The first Framework document (U.S. EPA, 2008) was written to provide this initial guidance. Furthermore, the OSWER directive does not address asbestos regulations that may constitute ARARs.

2.2 Mineralogy

Asbestos is a generic name applied to a variety of naturally occurring, fibrous silicate minerals. Detailed descriptions can be found at the following web sites:

- U.S. EPA site: https://www.epa.gov/asbestos
- U.S. Geological Survey (USGS) site: https://minerals.usgs.gov/minerals/pubs/commodity/asbestos/

The commercial use of asbestos is based on several useful properties such as thermal insulation, chemical and thermal stability, high tensile strength, and flexibility. Asbestos is divided into two mineral groups—serpentine and amphibole. Serpentine asbestos is a phyllosilicate and has a sheet or layered structure, whereas amphiboles are inosilicates and have a chain-like structure. The serpentine group contains a single asbestiform[4] variety (chrysotile[5]), while the amphibole group contains over 60 mineral varieties (Hawthorne et al., 2012). "Libby Amphibole Asbestos" (LAA) is comprised of several forms of amphiboles (or mineral fibers): winchite, richterite, tremolite, magnesio-riebeckite, magnesio-arfvedsonite, and edenite (84:11:6:1:1:1) (Meeker et al., 2003). U.S. EPA has developed separate toxicological values for assessing risk posed by general asbestos (see U.S. EPA 1988a) and LAA (see U.S. EPA 2014a).

Classification and nomenclature of amphibole forms of asbestos is complicated by the fact that there are over 60 known amphibole minerals with eight main subgroups of rock-forming minerals (Deer et al., 1997). The subgroups represent monovalent and divalent cation end-member compositions which contribute to mineral predominance within the subgroup (Leake et al., 1997). The most common amphibole subgroups include the following: magnesium- iron-manganese amphiboles (anthophyllite, amosite [cummingtonite-grunerite]) and calcium amphiboles (actinolite, tremolite, edenite), sodium-calcium amphiboles (richterite, winchite), and sodium amphiboles (crocidolite [riebeckite], arfvedsonite) (Hawthorne et al., 2012). This list is not intended to be comprehensive, because amphiboles exist in various mineralogical forms with the asbestiform habit as the one of most toxicological interest, thus other forms may be encountered at sites that may require consideration. Depending on the origin and physicochemical conditions of amphibole formation, multiple minerals can exist at a site as a solid solution series.

Friable asbestos is a CERCLA-listed hazardous substance (see 40 CFR 302.4-Designation of Hazardous Substances [U.S. EPA, 1989b]). Asbestos is also addressed by other U.S. EPA statutes and regulations (*i.e.*, AHERA [1986] under the Toxic Substances Control Act [TSCA] § 2642 [1976], Asbestos NESHAP [1984] under the Clean Air Act [CAA] § 101-131 [1970], Asbestos Maximum Contaminant Level [MCL] under the Safe Drinking Water Act [SDWA] § 300f [1974]) as well as other occupational regulations (*e.g.*, 29 CFR Parts 1910, 1915, and 1926). Issues regarding the regulatory definition of asbestos may be important at certain sites (especially those involving the amphibole group) and legal counsel should be consulted where this may raise an issue. The term "asbestos" has often been applied to the fibrous habit of six minerals that have been commonly used in commercial products:

1. chrysotile
2. crocidolite (riebeckite)
3. amosite (cummingtonite-grunerite)
4. anthophyllite
5. tremolite

[4] Refer to Appendix A (Glossary) for more information.
[5] There are three polytypes of chrysotile: clinochrysotile, orthochrysotile, and parachrysotile (Mellini, 2013).

6. actinolite.

This recommended framework is intended for CERCLA sites, and for purposes of this framework the term asbestos is intended to cover all mineral forms of asbestos that may be subject to CERCLA authority and are associated with health effects in humans.

It is important to recognize that these asbestiform minerals have been regulated chiefly because they have been preferentially mined for commercial applications or have been found as contaminants in commercially mined materials and recognized as asbestos. There are other forms of asbestiform minerals that are not on this list which may be subject to CERCLA authority as pollutants or contaminants should they pose a public health threat at a site. Further, it is well established that exposures to certain groups of mineral fibers not regulated under TSCA, NESHAP, or by the Occupational Safety and Health Administration (OSHA) can produce adverse health effects in humans (ATSDR, 2001; Carbone et al., 2004; Sullivan, 2007; Peipins, 2003; Larson et al., 2010a,b; Roccaro and Vagliasindi, 2009; Comba et al., 2003; Gianfagna and Oberti, 2001; Giuseppe et al., 2019; Hernandez, 2019).

This recommended framework is intended for CERCLA sites, and for purposes of this framework the term asbestos is intended to cover all mineral forms of asbestos that may be subject to CERCLA authority and are associated with health effects in humans. Caselaw confirms that CERCLA uses the broader Chemical Abstract Service (CAS) definition of asbestos and is not confined to the six commercial types regulated under the NESHAP regulation. See United States v. W.R. Grace, 504 F.3d 745, 754-57 (9th Cir. 2007).

Additionally, this recommended framework may be useful for site assessment of other elongate mineral particles where health effects similar to asbestos have been indicated (*e.g.*, erionite) (Emri et al., 2002; IARC, 2012; Van Gosen et al., 2013; Saint-Eidukat and Triplett, 2014). For more information on elongate mineral particles, see the National Institute for Occupational Safety and Health (NIOSH) Current Intelligence Bulletin: Asbestos Fibers and Other Elongate Mineral Particles: State of the Science and Roadmap for Research (https://www.cdc.gov/niosh/updates/upd-03-23-11.html).

2.3 Source of Contamination

Asbestos may be present at a site from one or more of the following sources:

- ACM or asbestos-contaminated sources. This includes the presence of manufactured products that intentionally included asbestos as an ingredient, but also includes products or processes that utilized materials in which asbestos is present as a contaminant (*e.g.*, vermiculite from the Libby mine). It may also include environmental media where asbestos-contaminated products or ACM were being transported to or from other locations for processing.
- ACM in on-site buildings. Asbestos was a common constituent in a wide variety of building materials in the past. As a result, the age of a structure may not be a reliable indicator of the presence of asbestos-containing materials. If the building is dilapidated or

demolition is required, or if remedial/removal work inside the building may impact potential ACM on site, then the presence of ACM should be evaluated to understand whether release of asbestos may be a consideration.

- Hazardous air emission standards addressed improperly under the authority of NESHAP. U.S. EPA established emission standards for hazardous air pollutants (including asbestos). Among the NESHAP regulations are work practices to minimize the release of asbestos fibers during activities involving processing, handling, and disposal of asbestos, including when a building that contains ACM is being demolished or renovated. If addressed properly under NESHAP, then CERCLA authority may not apply. However, if not addressed under NESHAP, then that release may be addressed under CERCLA authority.
- Presence of NOA. Asbestos occurs in natural mineral deposits at a number of locations around the country. Information on the presence of NOA deposits may be gained from numerous sources, including USGS, State geological offices, the Bureau of Land Management, the Department of the Interior, local agencies charged with cataloging or regulating NOA, or by consulting a properly trained and experienced geologist.

2.4 Characterization of Exposure and Risk

There are a number of special issues associated with the characterization and evaluation of asbestos exposures and risks which should be understood in order for risk managers to make informed site-specific management decisions.

When the exposure pathway is asbestos released to the air from disturbance of contaminated soil or dust, the primary concern is inhalation exposure. Inhalation exposure to asbestos increases the risk of both carcinogenic effects (*e.g.*, lung cancer, mesothelioma, laryngopharyngeal cancer, and possibly gastrointestinal tumors) and non-carcinogenic effects (*e.g.*, asbestosis, pleural disease such as localized pleural thickening) (U.S. EPA, 1986, 1988a, 2014a; Hodgson and Darnton, 2000; ATSDR, 2001; ATS, 2004).

Asbestos fibers occur in air as the result of the disturbance of some source material (*e.g.*, outdoor soil, indoor dust) by forces such as wind, weathering, or human activities. Thus, the key objectives during the investigation at any asbestos site generally are: (1) the identification of locations of asbestos contamination via source sampling, and (2) characterization of the levels of asbestos that may occur in air when the source is disturbed. The specific recommended approach emphasized here can then be used by risk assessors to estimate the level of human health exposure and subsequent risk attributable to the source, which in turn may be used by risk managers to determine whether use of a response action (source cleanup, institutional controls [ICs], etc.) may be appropriate in order to protect human health.

2.5 Conceptual Site Model (CSM)/Current, Future Land Use & Receptors

As part of the investigative process, a CSM should be developed to illustrate the potential for human exposures. The CSM describes the source of contamination, the release/transport mechanisms, exposure media, exposure routes, and the potentially exposed (current and future) populations. The CSM aids in developing sampling strategies for collecting the appropriate data to support an investigation report and a risk assessment. Typical exposure pathways for asbestos

include inhalation of asbestos fibers released from disturbed soil, disturbed settled dust, or ACM material that is disturbed during the remedial/removal action. As always, the evaluation of potential future risks should be based on an assessment of reasonably anticipated land use(s) (Appendix C).

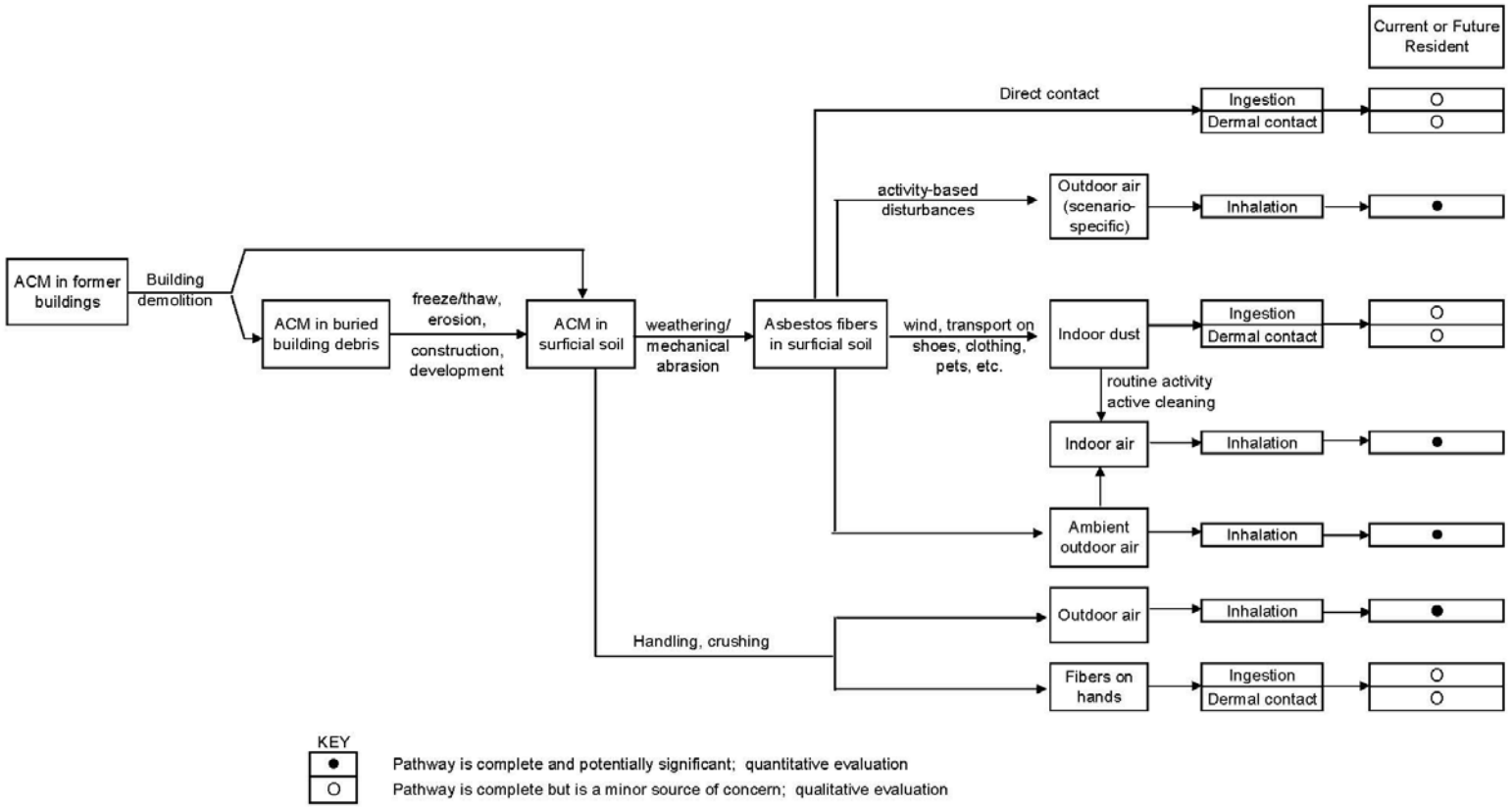
If a complete human exposure pathway does not exist and is not reasonably expected to occur in the future, typically no further evaluation of asbestos would be necessary. If it has been determined that a complete or potentially complete exposure pathway to contaminated outdoor soil or contaminated indoor dust exists under current conditions or may reasonably be expected to occur in the future, it may be appropriate either to undertake a response action or to proceed with further investigation of potential exposures at the site.

An example CSM is provided in Figure 2. This example illustrates the mechanics of developing a model for potential human exposures.

The first step in developing a sampling plan or approach (Section 3.1) is to review the potentially complete exposure pathway(s) identified in the CSM. As with other site assessments, there may be multiple pathways and distinct receptor populations to consider. This is especially important for certain types of asbestos (i.e., chrysotile and some amphiboles), as age at first exposure and duration of exposure will affect the risk estimate. Therefore, the exposure pathway, receptor (age), and exposure duration must be linked.

The primary goal of a sampling plan is to quantify breathing zone air concentrations associated with disturbance of contaminated media. One of the main objectives of this document is to establish the use of activity-based sampling (ABS) as the preferred approach for assessing asbestos exposure at CERCLA and other sites where personal activities in and around a site vary and a generalized sampling approach using fixed monitors would not adequately capture personal exposure in the breathing zone at the time of the activity. Once an exposure pathway of concern has been identified, sampling plans can be developed to characterize exposure for different activities.

Figure 2. Example Conceptual Site Model for Inhalation Exposures to Asbestos



Examples of pathways where ABS has been used to characterize human exposure at asbestos-contaminated sites in recent U.S. EPA risk assessments have included:

- Raking, gardening, weeding, and rototilling
- Children playing
- Organized sporting events (*e.g.*, baseball, soccer) in parks with asbestos-containing soil
- Walking, pushing a stroller, jogging, biking, and all-terrain vehicle (ATV) use
- Working among or near asbestos-contaminated media (such as would be experienced by tradespersons, commercial workers, and firefighters).

See Appendix F for photographs of various ABS scenarios.

3.0 Planning the Field Investigation

3.1 Workplan and QAPP

The field investigation workplan must include preparation of a Sampling and Analysis Plan (SAP). As described in 40 CFR 300.415(b)(4)(ii) and 300.430 (b)(8), the SAP consists of a field sampling plan and a quality assurance project plan. Current requirements for a quality assurance project plan, as described in the U.S. EPA and Uniform Federal Policy (UFP) references below, are inclusive of the field sampling plan elements (i.e., describes the number, type, and location of samples and the type of analyses), so the overarching planning document may be also be termed a quality assurance project plan (QAPP). Because every site has unique characteristics and challenges that must be addressed to adequately characterize exposure and risk (U.S. EPA, 1992), it is critical to prepare detailed site-specific SAPs/QAPPs to guide asbestos data collection activities although the extent of detail will depend on the complexity of the sampling effort (see U.S. EPA QA/R-5 Section 2.4.2 [U.S. EPA, 2001c] and UFP-QAPP Manual Section 1.2.5 discussions on graded approach [IDQTF, 2005]). SAPs/QAPPs previously prepared for sites with similar sampling needs can provide useful templates. Sampling program specifics, such as study designs, DQOs, quality assurance procedures, and analytical requirements, should be detailed in SAPs/QAPPs and may vary among sites. These plans should be prepared in accordance with existing Agency guidance including appropriate DQOs. For assistance in developing these documents, refer to the following:

- U.S. EPA Guidance for Quality Assurance Project Plans EPA QA/G-5 (EPA/240/R-02/009) (U.S. EPA, 2002a)
- U.S. EPA Requirements for Quality Assurance Project Plans EPA QA/R-5 (EPA/240/B-01/003) (U.S. EPA, 2001c)
- U.S. EPA Guidance on Systematic Planning Using the Data Quality Objectives Process EPA QA/G-4 (EPA/240/B-06/001) (U.S. EPA, 2006b)
- Intergovernmental Data Quality Task Force Uniform Federal Policy for Quality Assurance Project Plans: Evaluating, Assessing, and Documenting Environmental Data Collection and Use Programs - Part 1: UFP-QAPP Manual (IDQTF, 2005)
- Intergovernmental Data Quality Task Force Workbook for Uniform Federal Policy for Quality Assurance Project Plans – Part 2A (Revision 1): Optimized UFP-QAPP Worksheets (IDQTF, 2012).

Section 3.2 discusses DQOs in more detail. Section 4 of this document details methods and Standard Operating Procedures (SOPs) that should be followed when sampling for asbestos. The

SAP/QAPP should clearly identify any deviations from the procedures described in Section 4, as well as any specific field sampling methods and requirements that are needed at a site.

The Technical Review Workgroup (TRW) Asbestos Committee tools discussed in Section 6 can be used to facilitate the analytical services portion of decision planning. Members of the TRW Asbestos Committee are available to provide technical assistance during the development of the SAP/QAPP.

QAPPs or SAPs may be modified as necessary in consultation with the Quality Assurance manager, regional risk assessors, and risk managers to meet project-specific DQOs. Proper application of the DQO process will help maximize the probability that data collected will be adequate to support reliable risk assessments and risk management decisions, or to alert the risk manager when collection of adequate data may be cost prohibitive relative to the cost of a response action.

3.2 Data Considerations Including Data Needs & Data Quality Objectives (DQOs)

3.2.1 Applying the DQO Process

DQOs are statements that define the type, quality, quantity, purpose, and use of data to be collected. The design of an evaluation is closely tied to the DQOs, which serve as the basis for important decisions regarding key design features such as the number and location of samples to be collected and types of analyses to be performed. U.S. EPA has developed a seven-step process for establishing DQOs to help ensure that data collected during a field sampling program will be adequate to support reliable site-specific risk management decision-making (U.S. EPA, 2001c, 2006b). Table 1 links the DQO process to the framework process shown in Figure 1.

Table 1. Crosswalk between DQO and Framework Processes

DQO Process	Framework Process
Step 1. State the Problem.	Steps 1-3
Step 2. Identify the Goal of the Study.	Determine No Further Evaluation (NFE) or Step 6
Step 3. Identify Information Inputs.	Steps 3-5 are information inputs
Step 4. Define the Boundaries of the Study. Specify the target population & characteristics of interest, define spatial & temporal limits, scale of inference.	Step 3 (including CSM); Choose Outdoors and/or Indoors
Step 5. Develop the Analytic Approach. Define the parameter of interest, specify the type of inference, and develop the logic for drawing conclusions from findings.	Steps 4-5
Step 6. Specify Performance or Acceptance Criteria. Step 6A - Specify probability limits for false rejection and false acceptance decision errors or Step 6B - Develop performance criteria for new data being collected or acceptable criteria for existing data being considered for use.	Interim Risk Management Decision after 4o; Risk Management Decision Point after 5o and 4i/5i

DQO Process	Framework Process
Step 7. Develop the Plan for Obtaining Data. Select the resource-effective sampling and analysis plan that meets the performance criteria.	Iterative process throughout the flow chart; determine the information needed at each step to take a response without additional sampling

Decisions about the intended use of the data made in the DQO process inform the choice of sampling program design and analytical method. See Table 2.

Table 2. Asbestos Sampling and Analytical Approaches for CERCLA Data Categories

CERCLA Data Category	Framework Step	Sampling Approaches to Consider	Analytical Approaches to Consider
Screening Data	Step 4o/4i	Limited number of Soil, Bulk, Dust, Wipe, or Air (high-end disturbance conditions)	Soil Analysis or Fluidized Bed Asbestos Segregator (FBAS), Dust or ACM
Definitive Data	Step 5o/5i	ABS for Outdoors; ABS and Stationery for Indoors	Transmission Electron Microscopy (TEM) for Air
Screening Data with Definitive Confirmation	Step 4o/4i plus Step 5o/5i	Proceeds stepwise through approaches above	Proceeds stepwise through approaches above

3.2.2 Considering Air Action Levels in the DQO Process

Developing air action levels is a preliminary screening step intended to help evaluate if human exposure levels are likely to be below a level of concern (LOC) even under high-end exposure conditions (high-end exposure is used for this evaluation given the variations in releasability of asbestos fibers as discussed in Section 4.3). As such, air action levels must be considered in specifying DQOs for a site since the approximate concentration of a contaminant that would be of potential health concern to exposed humans can guide decisions about sample collection and analysis (*e.g.*, to determine the optimal sensitivity of the sample collection method desired for the risk evaluation). If exposures are judged to be below an asbestos air action level, then generally no further investigation would be needed under present site conditions.[6] If exposures from this high-end evaluation are of potential concern (*i.e.*, exceed the air action level), then a response action may be taken, or more detailed investigation may be appropriate to more accurately and completely characterize the magnitude of the exposure. For this purpose, the air action level is considered the LOC.

In brief, LOCs are typically determined by rearranging the risk equations discussed in Section 7 to compute the concentration of asbestos in air that corresponds to a specified risk level for a

[6] Site teams should also consider the possibility that subsurface asbestos can migrate upward due to soil weathering or frost heave. This is also a consideration for response actions that involve capping (geotextile barriers may be appropriate).

specified exposure scenario of concern (often a *de minimis* risk level). It is important to note that LOCs are typically used during more detailed sampling to establish analytical sensitivities required for site-specific ABS. For a site with multiple ABS scenarios, more than one LOC may be appropriate. See Section 7.5 for information related to calculating LOCs and Section 4.3.5 for further material regarding statistical considerations when applying an air action level to a site.

3.3 Health and Safety Considerations

U.S. EPA activities at CERCLA sites must comply with 40 CFR Part 300.150 of the NCP (NCP, 1994). This section focuses on requirements for worker health and safety. It requires compliance with OSHA health and safety regulations applicable to hazardous waste operations and emergency response, 29 CFR 1910.120 (OSHA, 1974).

For activities at CERCLA sites contaminated by asbestos, as stated in Part 300.150 (NCP, 1994), personnel must adhere to additional OSHA health and safety requirements beyond 1910.120. These requirements appear in the OSHA regulations at 29 CFR 1910.1001 and 29 CFR 1926.1101. Relevant to U.S. EPA CERCLA assessments and cleanups, the Asbestos in Construction Standard at 1926.1101 applies to physical handling of asbestos for the purpose of removal, containment, and disposal (OSHA, 1979). The Asbestos in General Industry Standard at 1910.1001 would apply to sampling and assessment activities (OSHA, 1974).

Important components of the OSHA regulations are those that apply to the personnel and exclusion zone/perimeter air sampling requirements found in 29 CFR Part 1910.1001(d). NIOSH Method 7400 (NIOSH, 2019) using Phase Contrast Microscopy (PCM) is required by OSHA for personnel monitoring and is generally used to determine personnel air fiber concentrations at CERCLA sites. However, PCM can only report total fiber concentrations, regardless of their nature and chemistry. Other fibers like refractory fibers, fiber wood and paper dust, mica dust and gypsum crystal fibers could be detected by PCM. Conversely, other fibers may be too long or heavy to be detected by PCM (e.g., hair, wool, glass insulation, cotton, plant fibers, man-made fibers).

NIOSH 7402 (NIOSH, 1994) is a Transmission Electron Microscopy (TEM) method designed to follow NIOSH 7400 PCM method if the user wishes to specifically identify asbestos fibers should NIOSH 7400 detect fibers that exceed OSHA's regulatory limits (time-weighted average [TWA] = 0.1 f/cc, 30-minute excursion limit – 1.0 f/cc). NIOSH 7402 clearly states it "is used to determine asbestos fibers in the optically visible range and is intended to complement the results obtained by PCM Method NIOSH 7400". When disturbed materials containing or suspected to contain asbestos are identified at CERCLA sites, project managers often arrange to have PCM filters with fiber detections or PCM filters exceeding a specific value reanalyzed using NIOSH 7402, particularly for those collected nearer to publicly accessible areas. Because it is a TEM method, it provides greater certainty in determining if workers and/or the nearby public might be exposed to airborne asbestos. The use of NIOSH 7402 adds time to the receipt of asbestos results, but the method is not uniquely expensive, and results can generally be received the next day. ISO 10312 (see Section 5.3) may also be used for perimeter sampling analysis.

The TRW asbestos committee can assist with guidance on air analytical methods to use during site activities to protect off-site receptors, including suggestions on the frequency of sampling, sampling locations, and when a sampling approach should be modified.

In addition to the OSHA asbestos regulations, and dependent on the CERCLA activities occurring at a site, regulations under NESHAP Section 112 of the CAA should be followed when possible. Also, dependent on the work activities and location, U.S. EPA recommends following the work practice regulations of the Asbestos School Hazard Abatement Reauthorization Act (ASHARA) of 1990 and AHERA (1986).

As of this writing, it is the Agency's position that the OSHA occupational health and safety requirements for asbestos at both 29 CFR 1910 and 1926 cannot be waived. The NCP states that all response actions will comply with 1910.120 and all applicable Federal and State Occupational Safety and Health (OSH) rules. The preamble to the 1990 NCP Final Rule states that OSH rules are not ARARs. OSHA standards for response action workers (i.e., Hazardous Waste Operations and Emergency Response [HAZWOPER]) must be met at every CERCLA site, and the more general OSHA standards will continue to be met where they apply.

CERCLA section 121(d)(2) defines potential ARARs as the standards, requirements, criteria or limitations under "any Federal environmental law." Because OSH rules are not environmental rules, the ARARs process cannot be used. The administrative and substantive portions of all applicable Federal and State OSH rules must be followed. Only the Secretary of OSHA can waive OSHA Rules. If assistance is needed with OSHA compliance during CERCLA Emergency Responses and/or Time Critical Removal Actions, the OSHA Regional Response Team (RRT) representative is available for consultation.

Understanding and interpreting how the OSHA, NESHAP, ASHARA, and AHERA work practice regulations pertain to U.S. EPA CERCLA activities has been an ongoing challenge. Standard Operating Guidelines (SOG) for Emergency Response, Removal, Preparedness and Prevention Branch (ERRPPB) Projects and Compliance with the Asbestos Rules and Regulations (SOG #T104; U.S. EPA, 2015b Version 2.0, available at https://response.epa.gov/hsmanualregion4) was prepared by U.S. EPA Region 4's Emergency Response Program. Although it is best interpreted by an industrial hygienist or similar occupational safety specialist experienced in asbestos work, the document serves as an aid for navigating the worker health and safety requirements.

3.4 Community Involvement

The Community Involvement Handbook (U.S. EPA, 2016a) provides guidance to U.S. EPA staff on how U.S. EPA typically plans and implements community involvement activities at CERCLA sites. This guidance document is intended to help promote consistent implementation of community involvement regulations, policies and practices. U.S. EPA project managers should follow regional policies regarding community involvement and confer with personnel staffing their region's community involvement program.

4.0 Sample Collection

Preplanning is an essential component of any CERCLA asbestos sampling effort. Development of robust DQOs is critical to adequately assessing risk and to making effective decisions. The CSM and the DQOs should be used to guide sample collection methods, sample processing needs, appropriate analytical methods, and to ensure that the number and locations of samples meet the DQOs established for the exposure unit. See Section 3.2. for additional information.

4.1 Soil and Sediment Samples

The exposures resulting from releases of asbestos contaminated sediments and soils can lead to elevated human health risks (Turci et al., 2016; Voulvoulis and Georges, 2015). Because of the potential risks to human health, it is important to be able to accurately detect and quantify the presence of asbestos in soils and sediments to inform risk management decisions. It should be the goal to collect and analyze samples that are as representative of the sampled areas as possible.

Accordingly, the TRW Asbestos Committee supports the use of incremental sampling methodology (ISM) for the collection and preparation of surface soil samples, as does the California Air Resources Board (CARB) Method 435 (ITRC, 2012; CalEPA, 1991, 2017). Because of the inherent heterogeneity of asbestos in soil, collecting 30 to 100 increments is recommended by the TRW Asbestos Committee if ISM is used to collect soil samples. Consideration should be given prior to beginning sampling on the proper selection of sampling tools, number of increments, size of decision units, and other site-specific sampling concerns. The potential for subsurface presence, upward migration or future land uses involving soil excavation determines if subsurface asbestos should also be considered. ISM is the TRW Asbestos Committee's sampling preference, but other sampling methods can be considered. Selection of site sampling methods will be site-specific and should be determined by the project team while developing the DQOs for the investigation

Careful consideration should also be given to whether sample processing steps should be conducted in the field or in the lab. The TRW Asbestos Committee also recommends, in keeping with OSWER Directive 9200.1-117FS (U.S. EPA, 2014b), careful processing of soils submitted for analysis to ensure that the integrity and representativeness of a sample is maintained from collection in the field through analysis in the laboratory (U.S. EPA, 2013). Rigorous and well considered sample processing is an integral part of ISM (ITRC, 2012). Concerning particle size, see American Society for Testing and Materials (ASTM) C702/C702M, Standard Practice for Reducing Samples of Aggregate to Testing Size (ASTM, 2011) for more information. See Section 5.1.1 that discusses some specific soil processing recommendations for the laboratory.

As noted earlier, releases of asbestos to air from disturbances of soil sources may vary widely as a function of many factors. Sampling design for soil and sediment should allow for the identification of asbestos and the selection of an area (determined by site information or professional judgment) for conducting ABS.

4.2 Indoor Dust Samples

Dust samples may be collected on solid, nonporous surfaces to identify areas where asbestos is present or absent. At this time, there is limited information available to correlate asbestos content in dust with human exposure to support risk-based decisions at CERCLA sites; however, dust information may be used to support risk management decisions when exterior high-level sources are present that result in high indoor dust levels (i.e., dust data alone may trigger removal actions such as indoor cleaning in some instances). Dust samples can be collected to provide a fiber loading per surface area in structures per square centimeter (s/cm^2). Two sample collection methods are available for dust: microvacuum and wipe sampling. The microvacuum approach (described below) is the most commonly used to support interior investigation and, in general, is the recommended method for sampling dust in indoor environments for asbestos.

4.2.1 Microvacuum method (ASTM D5755-09)

For indoor measurement of asbestos collected in dust samples, ASTM D5755-09(2014)e1, Standard Test Method for Microvacuum Sampling and Indirect Analysis of Dust by Transmission Electron Microscopy for Asbestos Structure Number Surface Loading (ASTM, 2014), commonly referred to as the micro-vacuum method, is used for general testing of non-airborne dust samples. It is used to assist in the evaluation of dust that may be found on solid surfaces in buildings such as ceilings, floor tiles, shelving, duct work, etc. The method provides an index of the concentration of asbestos structures in the dust per unit area sampled. Where a limited number of dust samples are available, the user should exercise caution in extrapolating those results to areas not sampled.

This method describes a technique in which a dust sample is collected by vacuuming a known surface area with a standard 25- or 37-millimeter (mm) air sampling cassette using a plastic tube attached to the inlet orifice of the cassette which acts as a nozzle. The ASTM method specifies use of an air velocity of 100 centimeters per second (cm/s), which is calculated based on an internal sampling tube diameter of 6.35 mm at a flow rate of 2 liters (L)/minute. The amount of suction used is very minimal and does not compare to what a normal household vacuum would create. Additionally, the area is “vacuumed” using tubing with an opening that is 6.35 mm (much smaller than a normal vacuum cleaner). Results are reported as the number of asbestos fibers per unit area (s/cm^2).

An alternative method for dust, such as ASTM D6480-19, Standard Test Method for Wipe Sampling of Surfaces, Indirect Preparation, and Analysis for Asbestos Structure Number Concentration by Transmission Electron Microscopy (ASTM, 2019), may be considered on a site-specific basis. For this method, a known area of a surface is wiped with a cloth material to collect a sample. Material from this wipe sample is transferred to an aqueous solution of known volume. An aliquot of this liquid is used to prepare a filter grid which is analyzed by TEM.

4.2.2 Considerations and Screening Procedures for Indoor Dust

Multiple lines of evidence normally should be evaluated to determine if indoor air sampling is necessary to ensure protectiveness of human health. When evaluating whether indoor sampling is

appropriate for a site, the project team (e.g., OSC/RPM, U.S. EPA risk assessor, ATSDR) generally should consider a number of factors, including the following:

- mechanism(s) by which asbestos may have entered and been distributed in a building,
- time elapsed since the asbestos release,
- severity of contamination found outside the building(s),
- potential presence of other (non-site related) types of asbestos that may be associated with building materials (e.g., flooring[7], insulation, or structural materials), and
- approaches to mitigate the possible disruption of the home occupants' daily routines as a result of the sampling event(s).

Asbestos concentrations in settled dust can be used for screening to inform risk management responses (such as early removal actions like cleanup activities) when high-level sources are present. Analogous to a situation where very high levels of asbestos are detected in residential soil and provide a basis for a cleanup action; the project team may decide in the planning phase of the indoor assessment that the presence of elevated concentrations of asbestos in indoor dust is sufficient for initiating a cleanup action. For example, asbestos-contaminated indoor dust samples having greater than 10,000 s/cm² (total fibers) were identified as generally above background by Millette and Hays (1994). Lower screening numbers for dust have also been used as the basis for site-specific cleanup: dust results greater than 5,000 s/cm² (total fibers) were considered sufficiently high to warrant a response action at indoor environments impacted by the World Trade Center collapse (U.S. EPA, 2003a, 2005b) and in Libby Montana (U.S. EPA, 2003b).

Because of limitations in predicting the release of asbestos fibers from settled dust, sampling of dust (such as microvac sampling) is not typically recommended as a stand-alone means of assessing indoor exposures to asbestos. Also, if a release has occurred, asbestos-contaminated dust concentrations less than the screening level generally require further evaluation (i.e., Step 4i air sampling) for risk characterization since there is insufficient information to conclude that levels below the screening level would not present a health concern if the dust is disturbed by occupants during routine activities. It is important to ensure that the number of samples meet the DQOs established for exposure unit. If this is a site where only dust sampling can be conducted (for whatever reason), the concentrations of concern should be discussed with the TRW Asbestos Committee.

4.3 Air and ABS Samples

In the past, a wide variety of different techniques were used to measure the amount of asbestos in air. Since about 1970, nearly all samples have been collected by drawing air through a filter that traps airborne particles on the filter. In general, such samples may be divided into two broad categories: (a) those using a fixed ("stationary") air sampling device, and (b) those where the sampling device is worn by a person ("personal monitor").

Studies at several sites have shown that, in cases where asbestos-contaminated source material is being actively disturbed by an individual, the personal air samples consistently yield higher and

[7] Carpeting can be difficult to clean and may act as a reservoir for asbestos.

more representative measurements of exposure than stationary air samples in the same vicinity (e.g., Doll and Peto, 1985; HEI, 1991; Lang et al., 2000; U.S. EPA, 2003c; Sakai et al., 2006). Both have advantages depending on the objective of the sampling (evaluation of personal exposure vs. characterization of ambient concentrations). Use of personal monitoring is consistent with National Academy of Sciences (NAS) recommendations concerning the assessment of personal exposures (NRC, 2004), and it is also necessary to comply with certain OSHA requirements.

Therefore, this framework recommends the collection of personal air samples during active source disturbance activities (such as ABS). Collection of this type of sample is essential in properly characterizing the levels of airborne asbestos exposure which may be expected to occur when a source material is disturbed. Recommended procedures for collection of ABS air samples are available in Scientific Engineering Response and Analytical Services (SERAS) SOP #2084 (SERAS, 2017) and "ERT Helpful Hints for Activity-Based Sampling for Asbestos in Air" (Appendix E). ABS may be employed to assess asbestos exposure in both outdoor and indoor environments. Stationary air monitors are used in the context of this framework to document site conditions around the perimeter of ABS activities and during removal actions. Stationary monitoring is also useful in assessing exposures of a person when the person is not actively engaged in a source disturbance activity (e.g., sitting on a couch watching television indoors, inhalation of outdoor ambient air).

U.S. EPA recommends the use of 0.8 µm MCE filters for most CERCLA air sampling applications.

A sample of air is collected using a pump to draw a specified volume (i.e., flow rate multiplied by collection time) of air across a filter, typically a mixed cellulose ester (MCE) filter, held in a cassette to collect airborne asbestos fibers. When the sampling is complete the sample cassette which, is sent to the laboratory for analysis. **U.S. EPA is recommending the use of 0.8 micrometer (µm) MCE filters for most CERCLA applications** (0.8 µm filters are specified for NIOSH PCM Method 7400 [NIOSH, 1994a, 2019] and may be used for the NIOSH TEM method 7402 [NIOSH, 1994b]). This recommendation is made after consultation with NIOSH and other asbestos experts as to their applicability (see Vallero et al., 2009). The use of 0.8 µm filters is also consistent with ISO 10312 when measuring structures longer than 5 µm.

One potential limitation to the ABS approach is the uncertainty associated with extrapolation to unsampled areas or under different activity conditions. The concentration of asbestos that occurs in air when a particular source is disturbed by some specified activity is likely to depend on several factors, including the amount of asbestos that is present in the source at that location, the "releasability" of the asbestos from the matrix (e.g., soil, dust, ACM), and the environmental conditions (e.g., soil type, moisture content, weather conditions, and other local factors). Spatial representativeness of an ABS sampled area to a larger area requires consideration of several factors, e.g., site or facility historical operations, depth and details of asbestos waste disposal, soil characteristics, uniformity of soil cover, uniformity of fiber distribution depending on asbestos source, and other factors that would affect extrapolation from one area to another. Subsections 4.3.1 to 4.3.5 discuss these issues in greater detail.

Furthermore, it is important to recognize that the releasability of asbestos at a location may change over time. For example, under present site conditions, asbestos in outdoor soil might exist primarily as large particles (i.e., large "chunks" of ACM or large lumps), which will tend to have low releasability of respirable asbestos fibers. Over time, however, these large non-respirable materials may become broken down by weathering and/or by mechanical forces (including the disturbance associated with a vigorous activity), thereby increasing the fraction of the material that exists as readily releasable fibers without altering the amount of asbestos that is present (see Appendix F with photos). Thus, in cases where data suggest that a substantial fraction of the asbestos present in soil exists in a poorly releasable form, it may be appropriate to interpret the results of ABS measurements to reflect current, but not necessarily future, site conditions (Appendix C). In cases where asbestos contamination is present in subsurface media, surface ABS efforts may have limited utility to predict potential future risks if that contamination were to be exposed.

At present, there is no established and validated technique for modeling or adjusting for differences in "releasability" of asbestos across different locations. U.S. EPA is continuing to evaluate relationships between asbestos concentrations in soil and air. The Fluidized Bed Asbestos Segregator soil preparation method (FBAS; Januch et al., 2013) has been developed and published as U.S. EPA Other Test Method 42 (OTM-42) – Sampling and Sample Preparation and Operation of a Fluidized Asbestos Bed Segregator (U.S. EPA, 2018a). (Other Test Methods are test methods which have not yet been subject to the Federal rulemaking process.) This method is a valuable tool for use in conjunction with field-based ABS (see Section 5.1 for more information) to address this issue.

4.3.1 Considerations for ABS Sampling

When preparing a sampling plan and considering a strategy for ABS sampling at individual sites, site teams should consider the following questions in establishing the data quality objectives to be addressed by the plan:

- *Is ABS necessary?*
  There may be sufficient information available to reach a risk management decision point without the need for collecting ABS data and conducting a risk assessment. For example, the presence of visible ACM on the ground or elevated concentrations of asbestos in soil samples are usually enough to indicate the need for action at a site. ABS may be most useful for decision making when the need for risk management actions is unclear and/or if air concentration data is needed to evaluate various exposure scenarios in a risk assessment. ABS may also be useful to document that site actions have reduced potential human health risks to acceptable levels.

- *If ABS sampling is needed, what type(s) of ABS activities should be employed?*
  Consideration of current use and potential future uses of the property should be incorporated into decision making for sampling. Determine which modeled ABS activities may be most protective for evaluating current and potential exposures. Where

possible, seek public input on ABS activities from the community. Determine if trespasser scenarios may be appropriate for some ABS sampling activities.

- *Do different areas of the site require different modeled ABS activities?*
  Consider if there are different property use scenarios for different parts of the property or if contaminant release differed across the property (including subsurface asbestos that could potentially migrate or be exposed at the surface in the future). Given the above, how many ABS samples should be collected during any one ABS event or activity?

- *How many repetitions of ABS sampling should be collected over a specified time period?*
  Consider weather conditions, changes in soil moisture, community concerns, etc. Consider which data points will be used to assess risk.

When conducting an ABS soil disturbance sampling activity, a key consideration should be whether the activity can be safely conducted. The proximity of individuals who may be potentially exposed to airborne asbestos during the sampling activity should be considered. Perimeter monitoring and/or sampling should be conducted during ABS to document potential releases. If ABS cannot be safely conducted due to the proximity of unprotected people to the sample area, alternatives, such as use of the FBAS, should be considered as part of a detailed weight-of-evidence approach that would meet the data quality objectives of the project.

Because practitioners may be unfamiliar with ABS sampling, assistance can be sought from U.S. EPA-Environmental Response Team (ERT) personnel and members of the TRW Asbestos Committee, if needed. See Section 4.3.5 for additional information on statistical considerations. Prior to undertaking ABS, which may be time and resource intensive, RPMs and OSCs should carefully weigh whether multiple lines of evidence exist that could allow a decision that no further evaluation is necessary.

Additional information on ABS activities, including description, duration, and sampling considerations is available in the SOP (SERAS, 2017) and "ERT Helpful Hints for Activity-Based Sampling for Asbestos in Air" (Appendix E). The disturbance scenario should be performed when environmental conditions are favorable to allow evaluation of maximum releasability and airborne exposure concentrations (*e.g.*, the soil is dry, and the wind is relatively calm for the location). The potential for frost heaving and other weathering conditions that can bring asbestos to the surface should also be considered.

4.3.2 Considerations for Outdoor Air Sampling

Area Selection

When selecting areas for ABS, consideration should be given to the potential for off-site migration of contaminants and possible exposure of the public. While conducting ABS, to the degree practical, particulate migration off-site should be minimized, and constraints or mitigation protocols established to eliminate public exposure. These constraints/mitigation protocols may include conducting the ABS in remote areas of the site, building a containment structure, etc. Air sampling should be conducted to document the airborne concentration of asbestos at the site perimeter during activities.

Flow Rate Considerations

When selecting flow rate, a balance is needed between the volume needed to meet analytical requirements versus the potential for filter overload. Examples of the minimum number of grid openings required for various volumes to achieve the desired analytical sensitivity and limit of detection are provided in Table 1 of ISO (2019a). During most ABS activities, participants may be fitted with two sampling pumps or samplers may be collocated to sample a high and low volume of air to increase the likelihood of at least one of the two samples being analyzed using the direct analytical method (ISO Method 10312; ISO, 2019a) without overloading. Ideally, when performing ABS, a volume of 560 L should be collected for the low-flow samples, and the targeted high volume is typically up to 1,200 L. For stationary perimeter monitors, a volume up to 4,000 L should be collected for the high-flow samples, since these samples are not typically constrained by overload considerations. For example, ABS conducted for two hours at a flow rate of 10.0 L/minute will produce a 1,200 L sample. However, for activities that generate a large quantity of dust (i.e., particulates), sample flow rates may need to be reduced accordingly to avoid overloading the filters. For example, sampling pump flow rates between 1.0 and 3.0 L/minute were found to be most effective at one site for monitoring for asbestos while riding ATVs on dusty soils while high soil moisture and reduced particulate generation at another site permitted a 5.0 L/minute flow rate.

High flow rates may result in sampling errors including filter damage due to failure of its physical support associated with increased pressure drop, leakage of air around the filter mount so that the filter is bypassed or damage to the asbestos structures (breakup of bundles and clusters) due to increased impact velocities (ISO Method 10312; ISO, 2019a). High flow rates can also tear the filters during initial pump startup due to the shock load placed on the filter when the pump is first started.

Sampling larger volumes of air and analyzing greater areas of the filter media can, theoretically, lower the limit of detection indefinitely. In practice, the total non-asbestos suspended particulate (TSP) concentration limits the volume of air that can be filtered as TSP can obscure asbestos fibers. ISO Method 10312 states that the direct analytical method cannot be used if the general particulate loading exceeds approximately 25% coverage of the collection filter (2019a). See Section 4.3.5 for statistical and analytical sensitivity considerations.

Meteorology

It is recommended that an onsite, portable, meteorological station be established. If possible, sample after two to three days of dry weather and when wind conditions are representative for the climatology of the location based on month and time of day. Historical hourly wind speed and wind direction data should be analyzed before mobilization. Wind speed, wind direction, temperature, and station pressure should be recorded on the meteorological station data logger and real-time data should be available for review on the station display panel. Alternatively, a nearby representative meteorological station may be used to acquire the necessary data.

Real-time Particulate Monitoring

For removal actions that have significant potential to cause releases of asbestos to the environment, it is recommended that real time perimeter particulate monitoring (DustTrak DRX, or similar) co-located with concurrent asbestos perimeter air sampling is set up daily through the course of the removal action. The particulate monitoring system can be connected to U.S. EPA's VIPER system[8], so that the field team receives instantaneous notification if a particulate action level has been exceeded. ATSDR and State Health departments can assist in establishing perimeter action levels for particulates (these can be applied as instantaneous exceedances, or exceedances sustained over 1 or 5 minutes, rather than using 8- or 24-hour average values as particulate action levels). If a particulate action level is exceeded, the situation should be investigated, work stopped if needed, and additional dust control measures, such as wetting surfaces, should be employed.

4.3.3 Considerations for Indoor Air Sampling

Exposures during different types of activities would likely result in different exposure levels. Indoor sampling to support a risk-based site evaluation should represent exposures across a range of activities expected in the building, to include short-term dust disturbing activities (e.g., for residences this may include sweeping, dusting, vacuuming) as well as some longer-term quiescent or passive activities (such as watching TV, sleeping, or cooking). In practice, these exposures should be considered together to provide a more representative estimate of long-term exposure levels for residents. Given that indoor sampling at someone's residence may result in an inconvenience to the property owner or occupants, it is likely that there would be only one opportunity for sample collection. Further, if the goal is to obtain information about likely exposures occurring at the site a more detailed sampling plan may be more appropriate than screening level sampling (see Figure 1). See Section 4.3.4 if potential site concerns require gathering information from or about human subjects.

Both the dust load and the asbestos content of the dust will contribute to the asbestos fibers available for release during disturbance. Thus, the most conservative ABS sample representing the high-end of the exposure range would be a high energy activity, which results in high suspended dust, in an area with a high dust load which contains asbestos. The location that is likely to have asbestos-contaminated dust at the high end of the concentration range may be determined by site information (e.g., microvac dust or wipe sampling) and/or professional judgment (e.g., high-traffic areas, dust collection reservoirs, areas that are not regularly cleaned).

Data from stationary air sampling in an occupied building may not necessarily be equivalent to ABS using breathing zone measurements of exposure. Therefore, the general recommendation and preferred approach for indoor sampling to support decisions within buildings is to use ABS with personal samplers to assess short-term exposure in combination with long-term stationary sampling to assess quiescent, long-term exposure.

[8] VIPER is a wireless network-based communications system designed to enable real time transmission of data from field sensors to a local computer, remote computer, or enterprise server also providing data management, analysis, and visualization. https://response.epa.gov/site/site_profile.aspx?site_id=5033

Stationary air monitoring equipment has the capability to collect longer-duration samples (approximately 8-24 hours), and samples with a higher volume than personal samplers to achieve an improved analytical sensitivity. Thus, stationary samplers may be useful to help characterize longer term exposure during and after ABS sampling or exposure during relatively quiescent activities (e.g., watching television or sleeping). They may also be used to determine risk under quiescent conditions (which may be useful for screening, since unacceptable airborne asbestos levels during quiescent periods can be used to support risk management actions). Stationary air sampling alone (i.e., without dust disturbance) has limited ability to quantitatively assess higher exposures expected due to occupant activity in the building. Therefore, it is generally recommended that ABS be used in addition to stationary sampling to inform risk-based site decisions.

There may be instances where stationary air sampling with dust disturbance could be used as a surrogate for ABS and the resulting data could be used to assess risk. For example, where it is impractical to conduct ABS or where the building owner or occupants will not allow ABS, the Agency has used other methods of dust disturbance with short- and long-term air sampling (e.g., vacuum cleaners, oscillating fans, leaf blowers). Although these methods do provide some indication of the releasability of fibers, airborne fiber levels measured after these surrogate dust disturbance methods are not generally used to quantitatively inform risk estimates.

There may be instances where this is the only exposure information available to support site decisions. In those instances, consideration should be given to the following: (1) exposures due to actual human activity may be higher or lower than estimated by these surrogate methods, and (2) air sampling with no dust disturbance may underestimate the potential indoor exposures. These should be included as uncertainties in the risk assessment where appropriate.

4.3.4 Considerations for Human Subjects

U.S. EPA workers and contractors with potential airborne exposure to asbestos should have appropriate training and use appropriate personal protective equipment (PPE), consistent with a properly developed health and safety plan (HASP) that follows U.S. EPA policies and OSHA regulations (for more information, see response.epa.gov). An appropriate QAPP/SAP will be followed as required.

In most cases, it will not be necessary for the project team to consult with U.S. EPA's Human Subjects Research Review Official (HSRRO) or Regional equivalent prior to sampling. This type of sampling does not constitute human subjects research, because it is usually being conducted for exposure assessment purposes in support of U.S. EPA's public health/remediation mission.[9] However, this should be clearly stated in the sampling DQOs and should the plan change to include information from or about human subjects, including conducting surveys or interviews with residents for research purposes beyond typical public health/remediation activities, the plan must be submitted to the HSRRO for review and approval, consistent with 40 CFR 26 and U.S. EPA Policy Order 1000.17 Change A (U.S. EPA, 2016b). The project team should contact the

[9] Personal correspondence between Andrea Kirk (U.S. EPA OSRTI Science Policy Branch) and Dan Nelson (Human Research Protocol Office [HRPO], National Health and Environmental Effects Research Laboratory [NHEERL]). August 29, 2019.

HSRRO by phone or email if questions exist on whether aspects of the ABS sampling project constitute human subjects' research.

Determination of whether residents should be present during sampling will depend on the type of sampling being conducted. If the sampling objective is to assess exposure conditions using ABS to actively disperse asbestos fibers, residents should not be present during the sampling events to avoid the potential for exposures that would not otherwise occur but for the sampling event. However, in cases where ABS methods cannot be applied and the sampling objective is to assess exposure levels under passive conditions, then it may be appropriate to allow residents to remain during the sampling period. Regardless of the sampling methods, owners/residents should not be asked to wear personal air samplers to assess exposure.

In the case of occupied buildings, advance discussions with the owner/resident are recommended to explain the sampling process. Also, post-sampling communication is recommended to explain the results. If the asbestos concentrations are found to be elevated, the actions that U.S. EPA intends to take and/or that the owner/resident can take to reduce exposure to asbestos in dust should also be communicated so that the owner/resident has a clear understanding of the implications of sampling.

4.3.5 Statistical and Analytical Sensitivity Considerations

As noted in Section 3.2.1, air action levels, or LOCs, can impact decisions related to sample collection and analysis. That is, they aid in determining the optimal sensitivity of the sample collection method desired for risk evaluation. Choosing target risk levels to use when computing LOCs is a risk management decision and should be consistent with CERCLA and the NCP. In general, it is expected that the value will fall within the risk range of 1E-4 to 1E-6. However, the choice of target risk level may be influenced by sampling and analytical constraints, as discussed below and in SERAS (2017).

In general, flow rates used during sampling are tailored to meet site-specific needs. The LOC calculated for a site can be used to establish the analytical limit of detection (LOD) requirements, which must be determined prior to sample collection. The LOD should be at or below the LOC. The LOD is the upper 95% confidence limit of the Poisson distribution for a count of zero structures. In the absence of background contamination, the LOD is 2.99 times the analytical sensitivity. The sensitivity (S) is defined as the concentration corresponding to the detection of one structure in the analysis. See Section 11 of ISO 10312 (ISO, 2019a)[10]. The LOD is equivalent to a reporting level and expresses the uncertainty around the sensitivity level for non-detects. For a direct preparation, the analytical sensitivity for a sample is determined by the volume of air drawn through the filter, the active area of the filter, the number of grid openings (GOs) analyzed by a microscopist, and the area of each GO analyzed as follows (additional detail is provided in Section 7):

[10] Before collecting any samples, consult with regional risk assessors and/or the TRW asbestos committee in the early stages of project planning in order to determine the required analytical sensitivity.

$$S = EFA \div [GOs \bullet A_{GO} \bullet V \bullet 1000] \quad \text{(Eq. 1)}$$

where:

S	=	Analytical sensitivity (1 structure/cubic centimeter [cc])
EFA	=	Effective filter area (square millimeter [mm^2])
GOs	=	Number of grid openings evaluated
A_{GO}	=	Area of each grid opening (mm^2)
V	=	Volume (L)
1000	=	Unit conversion factor (cc/L)

$$LOD = 2.99 \bullet S \quad \text{(Eq. 2)}$$

Sample volume and the number of grid openings analyzed can be controlled during sample collection and analysis. However, there may be several practical constraints on each of these parameters. For example, the volume of air collected is given as the product of pump flow rate (L/minute) and collection time (minutes). Most personal sampling pumps have a maximum flow rate in the range of 3 to5 L/minute (some specialty pumps can achieve 10 L/min), and the maximum sampling time for a personal air sample associated with ABS is usually about 2 to 4 hours. At some sites, much lower flow rates may be needed to avoid overloading a filter depending on activity and site conditions. In general, the flow rate for sample collection should not exceed the point where the filter surface contains more than 25% particulate. Thus, the volume for personal air samples typically ranges from 200 to 600L, but generally no more than 1200 to 2400 L. In theory, the number of grid openings can be any number, but the time and cost of analysis is directly related to the number of grid openings analyzed. A grid opening calculator is available from the TRW Asbestos Committee to assist in determining the number of grid openings that must be counted for a user-defined LOD and user-defined air volume. The calculator can be downloaded from https://response.epa.gov/asbestosdatamgmt.

Example Scenario:

For a site-specific ABS Activity, clearing brush with brush hog, how many grid openings would the laboratory need to count using typical flow rates and sampling durations for a one-acre area to meet an air action level of 0.003 structures/cc?

As noted earlier, sampling design must balance sufficient loading and representativeness with overloading with dust. Brush hogging may be dusty, and overloading can be an issue with this type of ABS activity. The needed sensitivity is 0.001 structures/cc (S = LOD/2.99 = 0.003/2.99). Typically, 2 to 3 hours will achieve the needed sensitivity. Two pumps are typically recommended, one high flow at 4 to 5 L/minute and one low flow at 1.5 to 3 L/minute. For sites where filter overload may be a concern, see Appendix E for more information on using on-site PCM analysis to gauge potential filter overload. The number of grid openings that need to be counted is inversely proportional to both the flow rate and the sampling duration. The number of grid openings needed for an example scenario can be calculated as follows:

$GOs = N \bullet EFA \div (A_{GO} \bullet V \bullet S)$
where:
GOs = grid openings to be counted (determined by inputs)
N = the number of structures counted; N=1 at the sensitivity level
EFA = Effective filter area (385 mm^2 for a standard 25 mm cassette)
A_{GO} = Area of grid opening (laboratory-specific or estimate using 0.01 mm^2)
V = Volume in Liters (calculated from pump flow rate • sampling duration)

Example 1: High Volume Sample Analyzed
Assumptions: Sampling occurs at 5 L/minute flow rate for 3 hours (180 minutes)
GOs = 1 structure • 385 mm^2 /(0.01 mm^2 • 5 L/min • 180 min • 0.001 structures/cc • 1000 cc/L)
GOs = 43 grid openings

Example 2: High Volume Sample Overloaded - Low Volume Sample Analyzed
Assumptions: Sampling occurs at 2 L/minute flow rate for 3 hours (180 minutes)
GOs = 1 structure • 385 mm^2/(0.01 mm^2 • 2 L/min • 180 min • 0.001 structures/cc • 1000 cc/L)
GOs = 107 grid openings

5.0 Laboratory Analysis

Similar to other contaminant analyses, asbestos analysis requires determination of laboratory capability to meet project criteria during the planning phase and assessment of laboratory success in meeting the project criteria during the data evaluation phase. However, unlike many other contaminant analyses, the analytical approaches discussed in this document may be unfamiliar to some laboratories. These recommended approaches differ somewhat from non-CERCLA regulatory program approaches used for many years, focusing on exposure assessment rather than strict regulatory compliance. So, the project team may need more scrutiny of the laboratory portion of the project for asbestos than is needed for other site contaminants. See Section 6.1.1 for Quality Control Considerations.

Characterization of potential human exposure to asbestos generally involves analytical testing using current methodologies that afford: (1) accurate identification of fibrous material present in sample media, (2) accurate and precise quantitative results, (3) reproducibility among multiple testing laboratories, (4) flexibility, (5) consensus acceptance of the method among asbestos professionals, and (6) cost effectiveness. Keeping these six parameters in mind, U.S. EPA has reviewed the extensive number of published and in-house asbestos analytical methods and selected what are believed to be the most appropriate methods to use for investigating CERCLA sites that may be contaminated with asbestos. Each of U.S. EPA's recommended analytical methods for soil, dust, and air are summarized below. Analysis of asbestos in aqueous media is not addressed in this section because ingestion of asbestos via drinking water has not historically been considered an important exposure route at CERCLA sites when compared to inhalation. However, the SDWA includes a method for analyzing asbestos in drinking water if it is determined that asbestos in drinking water is a complete exposure pathway at a site. The release of asbestos to the air is thought to be the primary and most harmful route of exposure at CERCLA sites. The methods detailed below are for CERCLA investigations; their applicability to natural or man-made disasters should be evaluated on a case-by-case basis.

5.1 Soil

5.1.1 Soil Preparation

Many commercial laboratories have experience with analyzing bulk sample building material by PLM, but not with soil analysis by PLM or other methods. Soil presents analytical challenges relative to bulk building materials due to the matrix and to the relatively low levels of asbestos present. In addition to those steps taken in the field (e.g., ISM), preliminary work conducted by U.S. EPA laboratories and others recommend the use of 3-D shaker mixers (such as TURBULA®) for quick and homogenous mixing of asbestos in heterogeneous soil matrices with differing particle size fractions and weights. Regardless of the method selected, the laboratory should have appropriate equipment for soil sample preparation to ensure the sample matrix is amenable to analysis. A gravimetric reduction technique, such as thermal ashing, may be used optionally to remove interferences, such as organic material. The gravimetric reduction procedure is found in EPA/600/R-93/116 (U.S. EPA, 1993a). Gravimetric reduction can alter the asbestos fibers in the sample. (Rouxhet et al., 1972; McCrone, 1987; Deer et al., 1992; Jeyaratnam and West, 1994; Getman and Webber, 2008). As discussed in EPA/600/R-93/116 Sections 2.3.2 (Interferences) and 2.4.5.2.3 (Ashing), laboratories must use caution and account for any expected changes in making asbestos identifications (U.S. EPA, 1993a). The FBAS details a soil preparation method that is unique from the other soil methods in that it creates a filter sample for analysis (U.S. EPA, 2018a).

5.1.2 Soil Analysis

The asbestos content of soil is usually low compared to bulk asbestos-containing materials, so the fraction of particles that are asbestos is small, and accurate quantification is very difficult. Thus, the results from these methods should generally be interpreted semi-quantitatively during initial phases of a site assessment. These methods, however, do allow for initial findings that a release has occurred and comparison among samples that may allow grouping samples into similar levels for the purpose of selecting locations for ABS sampling or extrapolating ABS results from one area to other locations.

Air analysis is needed for quantitative risk assessment calculations, since toxicity values are not available for soil.

Soil methods may fail to identify levels of asbestos that produce air asbestos concentrations that are potentially of concern. Sampling at multiple sites has shown that even when soils are non-detect by PLM (<0.25%), concentrations of asbestos in the air via ABS may result in unacceptable health risks. Since soil results are used for screening and information on the performance of soil methods is limited, this section provides a summary of possible soil methods instead of a recommended method. Three commercially available method options for soil analysis are: EPA/600/R-93/116 (U.S. EPA, 1993a), CARB 435 (CalEPA, 1991), and ASTM D7521-16, Standard Test Method for Determination of Asbestos in Soil (ASTM International, 2016). Alternatively, soil samples may be processed through U.S. EPA method OTM-42 using the FBAS to create filter samples for analysis using air methods. (For FBAS, see also the air methods discussion in 5.3.) In some situations, a

combination of tools may be appropriate. For example, a set of samples may initially be analyzed by CARB 435 followed by further analysis using FBAS for trace or non-detect samples.

5.1.2.1 EPA/600/R-93/116 (U.S. EPA, 1993a)

EPA/600/R-93/116 (U.S. EPA, 1993a) is a bulk building material analysis method that includes stereoscopic examination and PLM as mandatory techniques. Other techniques such as powder x-ray diffraction and analytical electron microscopy are used optionally to resolve qualitative and/or quantitative uncertainties. See Table 1-1, Simplified Flowchart for Analysis of Bulk Materials, in EPA/600/R-93/116 (U.S. EPA, 1993a) for an overview of the available techniques.

Suspected asbestos-containing building materials visible in the soil can be picked out for stereoscopic microscopic examination as a first step prior to sample preparation. Since this method was developed for suspected asbestos-containing building materials, it does not include preparation steps specific to soil. Soil analysis will benefit from milling of the sample after stereoscopic examination and from use of the optional electron microscopy step when samples are non-detect using the mandatory techniques. Laboratories may vary significantly in sample preparation processes use and in their use of the optional analytical techniques. When using this method, any specific requirements for soil should be communicated to the laboratory. When reporting data, the laboratories should also thoroughly document the preparation processes and analytical techniques that were used. This method defines asbestiform as having a mean aspect ratio of 20:1 to 100:1 for fibers longer than 5 µm, but also includes a reference to >10:1 aspect ratio. Laboratory analysts may vary in their use of the aspect ratio criterion for identifying asbestos. The detection limit may vary according to the techniques used. While it may be as low as 0.25% based on a PLM 400-point count, in practice the target reporting limit is usually 1%. If the optional electron microscopy step is used, the sensitivity would be determined as discussed in Section 5.3.1. The document can be found at https://nepis.epa.gov/.

5.1.2.2 CARB 435

CARB 435 (M435; CalEPA, 1991) is a method developed for the analysis of asbestos fibers in serpentine rock aggregate. CARB also developed the Implementation Guidance Document, Air Resources Board Test Method 435, Determination of Asbestos Content of Serpentine Aggregate, Field Sampling and Laboratory Practices to accompany the method. The original method remains in this implementation guidance document under Appendix A. The Implementation Guidance Document describes best practices for sample processing in the laboratory, for microscopic analysis, and for quality control (CalEPA, 2017). The document can be found at https://ww3.arb.ca.gov/toxics/asbestos/tm435/tm435.htm.

5.1.2.3 ASTM D7521-16

ASTM D7521-16, Standard Test Method for Determination of Asbestos in Soil (ASTM, 2016), is based on differential sieving of soil rather than grinding and homogenization of soil. In this method, soils are dried and sieved into coarse, medium, and fine fractions. The method also provides for wet sieving of soil as an alternative method. Particles >19 mm are removed and analyzed separately from the method.

The three particle size fractions are each analyzed by stereomicroscopy and PLM. Total results are calculated using a formula that weights the contribution of each fraction. If the PLM results are non-detect, then the fine fraction may be subject to further analysis by TEM. If other lines of evidence support the presence of asbestos, but PLM results are non-detect, the TEM step may provide positive detections that would support proceeding to an air analysis step. The PLM detection limit of this method as weight percent is the weight of the fine fraction multiplied by 0.25%. The TEM sensitivity is calculated based on sample-specific inputs as shown in Section 13.1.2.2 of the method. The document can be found at https://www.astm.org/Standards/D7521.htm.

Fluidized Bed Asbestos Segregator (FBAS)

The FBAS is a sample preparation method/instrument that utilizes air elutriation to concentrate light, aerodynamic asbestos structures from heavier matrix particles and deposit these structures onto an air filter which can be analyzed by TEM or other appropriate microscopic technique(s). The results of multiple performance evaluation (PE) studies have shown an approximately linear relationship between the nominal concentration of asbestos in soil PE standards and the mean reported concentration of asbestos for replicate filters prepared by FBAS (Januch et al., 2013). Method detection limits achieved in these studies, which ranged from 0.002% to 0.005% asbestos in soil by weight, are approximately 100 times lower than the detection limits that are possible with other current analytical methods that are typically utilized for soil and other solid media. It should also be noted that the FBAS has also been successfully used for determination of other elongated mineral particles such as erionite (Farcas et al., 2017; Berry et al., 2019).

U.S. EPA OTM-42[11] details how samples are typically prepared for processing in the FBAS by drying in a laboratory oven at 60 degrees Celsius (°C) for 12 hours, followed by sieving through a #20 mesh (850 µm) U.S. standard testing sieve (U.S. EPA, 2018a). An aliquot of the sieved sample is combined with 20/30 mesh laboratory-grade sand (Ottawa or equivalent), placed inside a glass vessel that is conical on both ends, and mounted vertically on the FBAS. Typically, 1 to 3 grams of sample are combined with 17-19 grams of sand to equal a total weight of 20 grams. A vacuum pump is used to draw air through the sample/sand mixture inside the glass vessel. When the pressure drop through the solid particles equals the weight of the particles, they begin to circulate and act as a fluid. For the FBAS, this occurs at an air flow rate of approximately 16 to 20 L/minute. A mechanical vibration device is used to limit buildup of larger particles on the sloped inner surface of the glass vessel. The vibration velocity is approximately 15 millimeters per second (mm/s) at a frequency of 10 hertz (Hz) to 1 kilohertz (kHz).

Small particles that are elutriated from the sample are drawn through an isokinetic splitter situated on the top end of the glass vessel. The splitter segregates 1/80th of the air flow that is then drawn through a 25-millimeter (mm) MCE filter with a pore size of 0.8 µm at approximately 200 cubic centimeters per minute (cc/m). Air is drawn across the filter for approximately 3 minutes. Initially, the air filters are examined with a phase contrast microscope to determine if the particle loading on the filter is optimal for TEM examination (target is about 15 to 25% coverage). If not, the sample to sand ratio in the mixture is adjusted either upward or

[11] https://www.epa.gov/sites/production/files/2018-08/documents/otm_42_sampling_sample_preparation_and_operation_of_fluidized_bed_asbestos_segregator.pdf

downward until optimal loading is achieved. Then, the air filter is typically analyzed by TEM for asbestos in basic accordance with the recording rules specified in ISO 10312 (ISO, 2019a). The results of analysis are typically expressed as asbestos structures per gram of soil.

The level of fiber detection for PLM is approximately 0.25% in soil which may not be adequately low to ensure that asbestos concentrations in samples below the detection limit are protective of human health. The FBAS methodology provides significantly greater sensitivity for detection of asbestos fibers in soils and solid matrices than PLM or other commonly used analytical methods for solid media (Januch et al., 2013). Attempts to correlate the airborne concentrations of asbestos fibers resulting from ABS activities with the FBAS soil concentrations have been limited and require further research (Wroble et al, 2017; Wroble et al., 2020). However, the limited results obtained to date illustrate that fiber releasability from soil is a complex problem. The TRW can be consulted for assistance with application of the FBAS method and interpretation of the data produced.

The air elutriation process in the FBAS soil preparation method is far more rigorous in terms of releasing fibers from soil than most common ABS exposure scenarios such as mowing or raking. As such, FBAS has been used to define background concentrations of mineral fibers at the Libby Asbestos Superfund site where PLM (CARB 435) could not detect the presence of fibers (U.S. EPA, 2018c). It has also been used to evaluate borrow soil sources for the North Ridge Estates site, direct ABS sampling locations at the Spokane Expansion Plant and properties adjacent to the expansion plant and to provide needed data for delineation of contaminated areas and decision making at the Davidson site in North Carolina.

Soil samples undergoing the FBAS preparation method should be collected in a way that is representative of site conditions and current and future exposures (including subsurface soils, if appropriate). The TRW recommends incremental sampling as a soil sampling method that is well suited to this task (ITRC, 2012). Soil processing, subsampling, and sample volume reduction steps should also follow rigorous protocols to maintain sample representativeness from collection through analysis.

The FBAS method may be used to screen sites and target ABS activities based on the low-level detection limits and the reproducibility of the method. The method has also been used as part of a weight-of-evidence approach for asbestos delineation and decision-making at sites where collecting ABS samples presented unique challenges. At these sites, FBAS data were used along with site-specific knowledge regarding soil data from other methods, visual inspection for the presence/absence of ACM, community air sampling data, and other relevant information. FBAS also provides a unique opportunity to evaluate subsurface soils that may be contaminated with asbestos since ABS methods cannot be conducted below grade. Given its relative sensitivity versus other soil sampling methods, it may also prove useful for delineation of an area that may need soil excavation and/or confirmation sampling to establish that the soil excavation or clean-up is complete.

Because of the low-level detection capability of the FBAS preparation method, it likely has the greatest utility where there is concern about low-level residual soil contamination and where sensitive populations are likely to contact asbestos contaminated soils. Since FBAS is a relatively

new technique for assessing asbestos in soil, specific members of the TRW Asbestos Committee can provide guidance on its application and use. As of this writing, there is limited availability of laboratories equipped to perform the method. FBAS instruments are located in the Region 10 environmental laboratory in Port Orchard, WA; Region 8 laboratory in Denver, CO; U.S. EPA's ERT in Edison, NJ; and one is available via a commercial lab. Efforts are underway by U.S. EPA and others to expand the commercial availability of the method.

See Table 3 for considerations in selecting a method.

Table 3. Pros and Cons of Soil Analytical Methods

Method	Pros	Cons	When to Use	Cost[a]
EPA/600/R-93/116 with Milling (U.S.EPA, 1993a)	• Entire sample is represented under the coverslip • Non-proprietary U.S. EPA method and widely used • TEM component may detect fibers missed by PLM	• Milling information is not detailed, so process may vary by laboratory • Milling may alter fiber dimensions • Milling requires thorough cleaning of equipment between samples (potential cross-contamination) • TEM is optional	• Samples have visible ACM in the soil and/or suspected source of asbestos is ACM	$$$
CARB 435 (CalEPA, 1991)	• Entire sample is represented under the coverslip • Inexpensive and non-proprietary State method • Milling information is detailed in an extensive implementation guidance, mitigating concerns that milling may alter fiber dimensions	• Success depends on laboratory skill in sample preparation • Milling requires thorough cleaning of equipment between samples (potential cross-contamination) • Does not include TEM - may miss fibers that could be detected by TEM	• Samples have expected asbestos content between 0.25% and 10%	$
ASTM 7521 Sieve Method (ATSM, 2016)	• Soil preparation is simplified; sieving approach eliminates milling concerns	• Uncertain quantification of the original sample; >19 mm fraction, weighted total of PLM point count	• Samples have expected asbestos content at trace levels	$$

Method	Pros	Cons	When to Use	Cost[a]
	• Particle size fractions may be easier to analyze • TEM component may detect fibers missed by PLM	and visual area estimation, and TEM results are reported separately • TEM is optional and only applied to the fine fraction		
U.S. EPA OTM 42 - Fluidized Bed Asbestos Segregator	• Increased sensitivity than other soil methods • Provides a measure of "releasability" of asbestos from soil • More reproducible than ABS • Can be used to evaluate subsurface data where ABS is not possible	• Limited availability of analysis • Units don't allow for direct comparison to screening values • Correlation between soil data and air data uncertain	• When there is concern regarding potential for residual low-level contamination and susceptible populations may be present • Characterizing borrow material	$$$$

[a] Cost estimates are relative to other methods in the table.

5.2 Settled Dust

As discussed in Section 4.2, dust samples may be collected on solid, nonporous surfaces to identify areas where asbestos is present or absent. Similar to the use of soil methods when screening an outdoor setting, dust methods should also be interpreted semi-quantitatively during initial phases of a site assessment when screening an indoor setting. Dust results may be a useful tool for quickly determining whether an asbestos release has occurred indoors. Dust analysis is essentially an indirect TEM analysis, and the TEM discussion in Section 5.3 below applies. Dust samples are often taken preferentially in areas believed to be most contaminated and may not be intended to be representative of an entire decision unit. Even if collected at random locations, dust samples represent a smaller sampling area than ABS samples. So, extrapolating dust results across a broader decision unit such as a room may significantly overestimate or underestimate exposure.

Since the dust methods discussed in Section 4.2 reference counting rules described in AHERA, the dust results represent a different set of fibers than the PCM-equivalent (PCMe) count of corresponding air samples. The AHERA method defines a fiber as "a structure greater than or equal to 0.5 µm in length with an aspect ratio (length to width) of 5:1 or greater and having substantially parallel sides." Fibers that are too short to be included in the PCMe air count will be

counted in the dust results. Correlation of dust and PCMe air results will be particularly difficult for chrysotile since chrysotile tends to have more short fibers than amphiboles. Additionally, fibers that meet the PCMe aspect ratio of 3:1 or greater may not meet AHERA aspect ratio of 5:1 or greater. As in AHERA, only primary structures are recorded.

The dust methods also involve indirect preparation of filters for analysis. For chrysotile asbestos, indirect preparation often tends to substantially increase structure counts as compared to direct preparation (as much 1,000 times larger) due to dispersion of bundles and clusters (Chesson and Hatfield, 1990; Kauffer et al. 1996; Hwang and Wang, 1983; HEI, 1991; Breysse and Steele, 1991). For amphibole asbestos, the effects of indirect preparation are generally much smaller (Bishop et al., 1978; Sahle and Laszlo, 1996). For example, Libby-specific studies on the effect of indirect preparation on reported LAA air concentrations show that indirect preparation usually increased reported PCMe LAA air concentrations, but these concentrations were within a factor of about 2 to 4 compared to direct preparation LAA (Goldade and O'Brien, 2014).

When the asbestos content of dust is low (e.g., <100 fibers per square centimeter [f/cm^2] for dust), the fraction of particles that are asbestos is small, and accurate quantification is very difficult. Thus, the results from dust sampling methods should generally be interpreted semi-quantitatively.

5.3 Air

TEM is preferred to PCM for characterization of environmental exposures to inform decisions at CERCLA sites.

As noted above, asbestos is not a single chemical entity, but includes fibers that may differ with respect to mineral type and particle sizes. There is generally consensus among asbestos researchers that both mineral type (serpentine, amphibole) and fiber dimensions (length, width, and aerodynamic diameter) are likely to influence the toxicity of asbestos fibers (ATSDR, 2001). The vast majority of past studies examining the health effects caused by asbestos exposure measure asbestos levels using PCM measurements (Chesson et al., 1990; Verma and Clark, 1995; U.S. EPA, 2015a; Dodson et al., 2013; Lockey et al., 1984; Pairon et al., 2014; Rohs et al., 2008; Benson et al., 2015). For risk calculations, the inhalation unit risk (IUR) for asbestos was derived for PCM measurements of air filter samples, and the Integrated Risk Information System (IRIS) includes a statement that the IUR should not be applied directly to any other analytical techniques. However, the IRIS summary also acknowledges that use of PCM alone in environments which may contain other fibers may not be adequate (U.S. EPA, 1988a). Because PCM cannot distinguish asbestos from other fibers, TEM methods for counting PCMe structures have been designed so that fiber counts made with the two techniques would be approximately equal (Lynch et al., 1970; Marconi et al., 1984; Dement and Wallingford,1990). U.S. EPA has also observed comparable PCM and PCMe results in site-specific risk assessments including the Sumas Mountain Human Health Risk Assessment (HHRA), North Ridge Estates HHRA, and Libby Asbestos Superfund Site HHRA (U.S. EPA, 2011; 2009b; 2015a). The advantage of the PCMe method is that TEM can be used to definitively identify various asbestos fiber types. U.S. EPA recognizes there is some uncertainty associated with using PCMe fiber counts to calculate risk with the IUR, but the amount of uncertainty is thought to be relatively small compared to other sources. Alternatively,

the use of PCM in environments where other mineral or organic fibers are present is likely to contribute a much larger source of uncertainty. **Thus, TEM is preferred to PCM for characterization of environmental exposures to inform decisions at CERCLA sites.**

5.3.1 ISO 10312 (TRW Asbestos Committee Recommended Method)

ISO Method 10312, *Ambient air – Determination of asbestos fibres – Direct-transfer Transmission electron microscopy method* (ISO, 2019a) is the recommended method for air analysis under the decision framework. (It should be noted that, while ISO 10312 uses the same instrument as the AHERA method referenced in 40 CFR Part 763, the two methods differ in the size range of structures counted and how the structures are counted.)

Note that the use of ISO Method 10312, Annex E is recommended to count asbestos fibers with a width range between 0.20 µm and 3.0 µm inclusive, length >5 µm, and aspect ratio ≥ 3:1. For CERCLA purposes, bundles meeting the size criteria will also be counted.

Low magnification (i.e., 5,000x magnification) analysis is recommended to permit more rapid identification and counting. This analytical approach may result in a considerable reduction in analytical time and cost compared to high magnification (~20,000x magnification), or, for the same time and cost, a more representative (i.e., larger), portion of the sample may be analyzed. The PCMe size range for counting is recommended to mimic the size fraction of fibers that would be detected if the sample were being run under PCM. Section 12.6.6 and Annex E of ISO 10312 describe counting of PCM equivalent fibers, or PCMe using low magnification of ≥5,000x (ISO, 2019a). Under this scheme, the analyst is to count fibers that are longer than 5 µm in length, have a defined width range between 0.2 µm and 3.0 µm, and aspect ratios of ≥ 3:1. For CERCLA purposes, it is recommended that both fibers and bundles meeting the PCMe size criteria be counted, including fibers and bundles that are found within a disperse matrix or disperse cluster of any size. (ISO 10312, Section 12.6.6 and Annex E, also describes the counting of all asbestos fibers and bundles longer than 5 µm in length at 10,000x magnification. This count based only on length is not needed for CERCLA purposes.)

In summary, the recommended approach for CERCLA sites using the ISO 10312 method is as follows:

- Low magnification of 5,000X
- PCMe size criteria as follows: Length >5 µm, Width ≥0.2 µm and ≤3.0 µm[12] inclusive, and Aspect Ratio ≥3:1
- Count the following structure types: F, B, CF, CB, MF, and MB (using structure descriptions in ISO 10312, Annex C).

Since the structures to be counted differ from ISO 10312, Annex E, clear instruction to the laboratory is needed in addition to the method reference. A mini-statement of work (mini-SOW)

[12] For most CERCLA sites, the recommended thickness is ≤3. For some sites, including the Libby Asbestos Superfund Site, there is no upper limit on thickness.

is available from the TRW Asbestos Committee to assist with communicating method requirements and quality control considerations to potential laboratories.

The TRW Asbestos Committee further suggests that a subset of samples representing the full range of concentration levels also be analyzed using high magnification counting the full fiber size distribution. Particularly for chrysotile, where short fibers are common, the high magnification analysis may provide a more complete picture of the suspected release.

Alternatives to the recommended method may be considered on a site-specific basis. The recommended ISO 10312 TEM low magnification PCMe method (ISO, 2019a) may not be appropriate for responses to natural disasters or other emergencies due to resource limitations and time constraints.

5.3.1.1 Sensitivity

When planning for TEM analysis, the data user must specify the analytical sensitivity and associated LOD. The sensitivity level for most CERCLA data is determined by method and instrumentation. However, for Asbestos analysis by TEM, it is dependent on the area of the filter counted by the analyst. The data user must specify the sensitivity level needed for each sample set prior to analysis. The sensitivity level is determined from the site-specific risk assessment level of concern as discussed in more detail in Section 4.3.5.

While results of an analysis can be reported as asbestos structures found per square mm (s/mm^2) of an effective filter media or as asbestos structures per cubic centimeter (s/cc) of air sampled, the more common units for risk assessment are s/cc. The LOD is set using s/cc.

The formula for s/mm^2 is:

$$\text{N structures/ GOs Counted} \bullet \text{GO Area} \qquad \text{(Eq. 3)}$$

The formula for (s/cc) is:

$$\text{N structures} \bullet \text{EFA/ GOs Counted} \bullet \text{GO Area} \bullet \text{F-factor} \bullet \text{Air Volume} \bullet 1000 \qquad \text{(Eq. 4)}$$

where:

GO = Grid Opening
EFA = effective filter area (385 mm^2 is the effective area of a 25 mm sample filter)
F-factor = computed by entering prep inputs if indirectly prepared or 1 if directly prepared
Air Volume = volume sampled in L

5.3.1.2 Summary of the Method

A very small portion of the filter is used to prepare grids for analysis. Since TEM results are calculated by extrapolating the count from this portion to the entire sample, uniform distribution of fibers onto the sample filter is important. The ISO 10312 method requires the laboratory to examine the grids and to qualify results if anomalies in fiber distribution are detected. The

laboratory should also calibrate their etching process to ensure that grids are optimal for reading, often described as an “orange peel” texture.

In addition to the visual detection of asbestos structures by the TEM analyst, the instrument has two identification tools which are then used for confirmation. The use of electron diffraction or selected area electron diffraction (SAED) to examine the unique diffraction pattern of the structure and the use of energy dispersive X-ray analysis (EDXA) to determine the chemical make-up of the fiber being analyzed are detailed in the analytical methods. Based on decisions made in the QAPP, the laboratory should receive instructions that specify how frequently the laboratory will capture the documentation of electron diffraction patterns and EDXA results for inclusion in the data package. Additionally, some data users may want a sketch or photograph of the structure to document the visual observation. If not specified up front, it may be considerably more difficult to capture or locate this documentation after the analysis has already been completed, as it may not have been stored by the laboratory.

5.3.2 ISO 13794

In the course of preparing grids for ISO 10312 analysis, the laboratory may discover that the filter(s) collected for a given location are overloaded above 25%. If the sample includes filters from cassettes with two different volumes and the higher volume filter is overloaded, the laboratory should generally first attempt direct preparation of the corresponding lower volume filter. If there is no lower volume filter or if it is also overloaded, it is not possible to proceed with direct analysis by ISO 10312 (ISO, 2019a). Instead, it may be possible to prepare the grids for analysis using the indirect preparation procedures found in ISO Method 13794, *Ambient air – Determination of asbestos fibres – Indirect-transfer transmission electron microscopy method* (ISO, 2019b). It is suggested that laboratories be instructed to contact the client when encountering overloaded filters before proceeding with indirect preparation and analysis. Additional cost is involved in continuing to this alternate procedure, and as discussed in Section 5.2, indirect analytical results could result in a higher fiber count and may not be comparable to direct analytical results. The use of indirect analytical results should be considered on a site-by-site basis and may be useful for decision making, but direct analytical results are preferred where feasible. An alternative approach to proceeding with indirect preparation is cancellation of analysis for overloaded sample filters. New samples would then be re-collected with field modifications such as shortened collection time or lower pump rate.

5.3.3 ISO 14966

An additional tool for air samples which require better visualization of the asbestos structure surface is Scanning Electron Microscopy (SEM) using ISO 14966: *Ambient air – Determination of numerical concentration of inorganic fibrous particles – Scanning electron microscopy method* (ISO, 2019c). This method may be used as a supplement to TEM.

SEM will provide more detailed information on surface topography and morphology. As with TEM, EDXA is used to determine the elemental composition of the structures. While SAED is not used in the SEM method to determine crystal structure, the SEM method can be supplemented with the use of Electron Back Scatter Diffraction (EBSD) to determine crystal structure (Bandli and Gunter, 2012, 2013).

5.3.4 NIOSH 7400

PCM is used where specified by regulation for purposes such as personal air sampling and perimeter monitoring in occupational environments as well as for prevention of filter overload (see discussion in Section 3.3). PCM method NIOSH 7400 (NIOSH, 1994a) may also be used for limited screening of the site, such as where there is great uncertainty about the location of the contamination. If PCM analysis is chosen for decision making at a CERCLA site beyond a screening step, the TRW Asbestos Committee should be consulted. Only a portion of the filter should be used for the NIOSH methods, with the remainder of the filter being archived by the laboratory for possible later re-analysis by ISO 10312. Thus, for screening, many samples can be taken from a large area for the cost-effective PCM analysis, and a subset of samples could then be confirmed by the more definitive ISO 10312 method (TEM). It is anticipated that the PCM-based screening approach will be the exception rather than the rule for most asbestos CERCLA sites. Because TEM provides more defensible data, it is the preferred analytical method for characterization of environmental exposures.

Table 4. Air Analytical Methods for Site Characterization

Method	Pros	Cons	When to Use
TEM ISO 10312	• Identifies and counts only asbestos fibers • Provides full fiber size distribution for possible later use	• More expensive method for sampling asbestos • No options for on-site analysis	• Recommended method
TEM ISO 13794	• Identifies and counts only asbestos fibers • Can be used on overloaded filters • Provides full fiber size distribution for possible later use	• More expensive method for asbestos analysis • No options for on-site analysis • Indirect analysis method can alter concentration levels; data may not accurately reflect site conditions and may not be comparable to direct analysis data	• Backup method; used only when the laboratory determines filters are too overloaded with particulate for ISO 10312
SEM ISO 14966	• Provides better visualization of the asbestos structure surface	• Does not include selected area electron diffraction	• When TEM is inconclusive and better visualization

Method	Pros	Cons	When to Use
	• Can be supplemented with the use of Electron Back Scatter Diffraction (EBSD)	(SAED) as an identification tool	of the structures is needed
PCM (NIOSH 7400)	• Least expensive method for sampling for asbestos • relatively quick • able to perform analysis on-site if needed	• Does not distinguish between asbestos and non-asbestos fibers • Does not provide full fiber size distribution	• Screening only

6.0 Data Management

The TRW Asbestos Committee has developed and maintains tools to facilitate collection of analytical data of known and documented quality for site decision-making. These tools include mini-SOW templates, National Asbestos Data Entry Spreadsheets (NADES), and Validation Process Guidelines for Asbestos Data Review. The editable versions of the mini-SOWs and NADES templates are found at https://response.epa.gov/asbestosdatamgmt. The validation guidelines are found at https://www.epa.gov/superfund/asbestos-superfund-sites-technical-resources. The use of the mini-SOW templates is discussed further in Section 6.1. The use of the NADES tools is discussed further in Section 6.2. The use of the validation documents is discussed further in Section 6.3.

6.1 Obtaining Analytical Services using Mini-SOW Templates

The success of the analytical data collection effort depends not only on the capabilities of the laboratory selected but also on a clear understanding of project requirements. Members of the TRW Asbestos Committee are available to provide technical assistance in using the tools discussed in this section.

6.1.1 Assessing Laboratory Capability

Tools for assessing laboratory capability include accreditations, pre-award requirements, on-site audits, and performance evaluation samples.

Many commercial laboratories participate in the National Voluntary Laboratory Accreditation Program for Asbestos Fiber Analyses (NVLAP) or other reputable accreditation programs. While accreditation is a positive consideration in assessing laboratory capability, accreditation is method-specific and current accreditation programs do not cover the methods and modifications recommended in this document. So, additional effort is needed to ensure laboratory capability relative to specific project requirements. In particular, some soil methods prescribe specific preparation methods prior to analysis. It may be useful to communicate with the laboratory

throughout the planning and analysis process to ensure that the processing steps of the methods are understood, followed, and documented.

Pre-award requirements suggested in the mini-SOW template include:

- Copy of accreditation certificate and certificate scope,
- Copy of the most recent laboratory audit findings and the laboratory's response to the findings (corrective action),
- Brief statement describing experience with the method(s) being requested (including control charts or results for inter-laboratory analyses which have been conducted within the preceding 12 months),
- Copy of the current laboratory Quality Management Plan, which is usually known as the Quality Manual (Statement of Work should specify the criteria that will be used to evaluate it), and
- Identification of potential conflicts of interest within the last 5 years.

When establishing the data quality objectives that inform the SAP, the soil processing steps performed by the laboratory should be given the same level of consideration that is given to the collection of the samples. Some analytical methods have prescribed soil processing methods that some asbestos laboratories may have limited experience performing. Project teams should review the processing required by the various methods and discuss the processing requirements prior to submitting the samples for analysis. If using incremental sampling methods to collect soils samples, the soil volume may need to be reduced through systematic subsampling methods that should be described in detail in the SAP/QAPP and coordinated with the analytical laboratory.

An on-site evaluation of the proposed laboratory to assess their overall quality system, capabilities relative to the specific work, and an understanding of method requirements (inclusive of modifications) is recommended. During the planning phase, the project team may determine through communication with the TRW Asbestos Committee or with the proposed laboratory that a recent U.S. EPA on-site audit report is already available such that follow up on any pending corrective actions is all that is needed. If no recent U.S. EPA on-site audit has been performed, the TRW Asbestos Committee will recommend appropriate resources that may be available to conduct the audit.

While PE samples, also known as blind spikes, are often used for CERCLA data assessment, efforts to use PE samples for asbestos analysis have been problematic. For air samples, the loading process may produce samples of uncertain and/or uneven level, samples requiring more rigorous preparation than the associated field samples, and samples at a much higher level than the associated field samples. Additionally, asbestos performance evaluation samples may be lacking statistical databases of past results from multiple laboratories that are normally used to establish acceptable PE recovery ranges. For soil samples, PE samples have been used successfully to assess comparability between laboratories. If blind spikes are used for air or soil, the quantitative results should be interpreted with caution, since the PE sample outcome may not reflect directly on the quality of the field sample results.

6.1.2 Communicating Project Requirements

The mini-SOW templates provide language for solicitation and contracting of commercial laboratories. The templates are suitable to be used directly by U.S. EPA, by U.S. EPA contractors when subcontracting, and/or by private entities. Mini-SOWs are available for air analysis by TEM and for soil analysis by PLM. Mini-SOWs incorporate the recommended analytical method and suggested modifications, along with detailed data package requirements to allow for later data validation. EPA-540-R-08-005, Guidance for Labeling Externally Validated Laboratory Analytical Data for Superfund Use (U.S. EPA, 2009c), provides an overview of options for different stages or levels of data validation. The mini-SOW templates include the supporting documentation for the highest stage deliverable, but the templates can be edited by the user to the desired stage. Note that the guidance is not specific to asbestos, so commonly incorporated criteria for other contaminants may not be applicable to asbestos analysis.

The mini-SOW templates are not ready for solicitation as downloaded. The templates contain fill-in items that must be completed by the project team prior to solicitation. These include project-specific information and the selection of options. Option choices are not equivalent with regard to method or cost, so the project team (not the laboratories) must select the appropriate options in the templates prior to providing the mini-SOW to the potential laboratories.

6.2 Electronic Data Management using NADES Reporting Tools

NADES tools were developed in a spreadsheet format to provide analytical laboratories with formatted and exportable electronic data deliverables for asbestos analysis and are generally recommended for use at U.S. EPA CERCLA sites. The NADES were originally developed by Region 8 and later adopted and modified for national use by the TRW Asbestos Committee. NADES are available for air or dust analysis by TEM, fluidized bed sample analysis by TEM, soil analysis by PLM, and air analysis by PCM. The two TEM NADES templates provide an efficient way to organize the structures counted into the size bin(s) of interest for decision-making. The TEM NADES results calculations default to two size bins: Total and PCMe. An additional size bin of project-specific interest may be entered in the User Defined Binning Rules. Solicitations should include appropriate NADES template(s) attached to the mini-SOW(s), if the NADES tools will be used.

The NADES PCM and NADES PLM templates are ready to attach to the SOW without project-specific edits. The two NADES TEM templates contain fill-in project-specific items in two worksheets that are populated prior to analysis: (1) Stopping Recording Rules is populated for all projects, and (2) User-Defined Binning Rules sheet is optional. It is recommended that the project team populate these sheets before providing them to the laboratory.

The Stopping Rules portion is usually populated with the sensitivity requirement for the project as determined according to Section 4.3.5. The sensitivity determines the minimum structure count needed for each sample. Projects may optionally also populate a “maximum area examined” where the area is the filter area being counted. This stopping rule can be used to capture the minimum 10 grid opening requirement that should be used regardless of sensitivity needed using 10 * GO area for the individual laboratory. When higher level samples are anticipated, it is helpful to also include a stopping rule based on structures observed (ex. 100

structures). NADES will then alert the analyst during entry when a stopping rule has been met. The Recording Rules portion can be used to narrow laboratory effort to the range of interest result. The User-Defined sheet may be optionally populated prior to analysis. Unlike the Stopping Recording Rules, the User-Defined sheet is used to calculate results in the NADES report.

The NADES spreadsheets include capability to export data in Comma Separated Values (.csv) format files so they can be imported to Scribe or other data management tools. The TEM NADES spreadsheets (Air and FBAS) include a check for uniform loading of fibers on the grids and report sample results with associated confidence intervals around each result. The representativeness of the results relative to the sample and the confidence intervals may be important when results are close to the site-specific air action levels.

6.3 Validation Process Guidelines for Asbestos Data Review

As with other analytical services, accreditation provides some assurance that the laboratory has a functioning quality system but does not eliminate the need for data review of individual data packages. After analysis is complete, a thorough assessment of the data received is recommended relative to the requirements. Two guideline documents for asbestos data review were developed through the Technical Review Workgroup: U.S. EPA TEM Validation Process Guidelines (U.S. EPA, 2016c) and U.S. EPA PLM Validation Process Guidelines (U.S. EPA, 2016d). These two documents are found at https://www.epa.gov/superfund/asbestos-superfund-sites-technical-resources. These documents are not intended to establish specific contract compliance, but definitive guidance is provided where performance should be fully under a laboratory's control (e.g., blanks, calibration standards, instrument performance checks), while general guidance is provided for evaluating subjective data that is affected by the site conditions.

For any procurement mechanism, it is expected that deviations and modifications, whether intentional and approved or unavoidable, will be documented thoroughly in the data package. The deviations will be considered during the data review process alongside other identified quality issues. The procurement mechanism will influence whether and when deviations and modifications are accepted. When U.S. EPA is contracting directly, foreseeable questions or concerns must be raised by the laboratory to the Contracting Officer during the solicitation period so that answers or changes are shared with all possible offerors. Similarly, if unforeseen issues arise during sample analysis, these should be identified by the laboratory to the Contracting Officer for further direction. In addition to providing data usability information for site decision-making, the data review process helps inform data package acceptance and invoice approval.

Staff assigned to perform asbestos data review should have specific experience with asbestos analyses, since the laboratory quality control tools differ significantly from those used for typical CERCLA chemical analyses. Individual U.S. EPA Regions may not have capability for asbestos data validation available through their usual resources. Data review resources should be considered and selected during the planning process in consultation with the TRW Asbestos Committee, so that task order development and funding of the data review resource can occur prior to data receipt.

7.0 Risk

Calculation of excess lifetime cancer risk (ELCR) and non-cancer hazard can be used to determine whether airborne concentrations of asbestos are associated with unacceptable risks to human receptors at a given site. Although ingestion of asbestos can contribute to an increased cancer risk, the risk from oral exposure is generally believed to be small compared to the risk and hazard from inhalation exposure, and U.S. EPA has not established a dose-response relationship for the oral exposure route. Consequently, calculations of cancer risk and non-cancer hazard from asbestos exposure are currently based solely on inhalation exposures. As previously stated in Section 2, asbestiform fibers, once inhaled and deposited in the lung, are biodurable and remain in the lung for long periods of time over which they continue to elicit biological activity (Addison and McConnell, 2008). Mineral fibers have been identified in human biopsy and surgical tissues that have resided in the body for over 50 years (Dodson et al., 2013). Fibers including tremolite, anthophyllite, chrysotile, and asbestiform amphibole fibers associated with LAA have been identified in lung and lymph biopsy tissues (Dodson et al., 2008, 2013; Black et al., 2017 & Suzuki, 2005). Based on the long fiber residence times, risk estimates for mineral fibers reflect cumulative dose and time from first exposure as risk determinants.

Two IRIS Toxicological Reviews are available to provide toxicity information for quantitative risk assessment of asbestos. The IRIS profile for asbestos published in 1986 provides an IUR value for evaluating cancer risk (U.S. EPA, 1986). The second asbestos IRIS Toxicological Review was developed for a specific class of asbestiform minerals that comprise LAA (U.S. EPA, 2014a). The 2014 Toxicity Profile provides an IUR and a non-cancer reference concentration (RfC). The IURs for general asbestos and LAA differ and are applied differently. Therefore, the methods for assessing cancer risks associated with general asbestos and LAA are discussed separately in Sections 7.2.1 and 7.2.2. The methods for assessing non-cancer health effects associated with LAA are presented in Section 7.3.

The following sections are primarily geared toward risk assessors, although the general concepts presented should also be understood by site managers. Several example scenarios are included. These scenarios are appropriate for a wide variety of sites and could be used at some sites without modification. Generally, however, exposures should be determined from activity-based sampling conducted during actual activities that occur or are likely to occur at the site in question. Footnote 7 of Risk Assessment Guidance for Superfund (RAGS) Part F (U.S. EPA, 2009a) states: “if a site contains asbestos contamination, risk assessors should contact U.S. EPA’s Technical Review Workgroup for Metals and Asbestos for assistance.” Sections 7.1 through 7.3 of this document are intended to provide that assistance in calculating cancer risk and non-cancer hazard for those sites.

7.1 Determination of Pathway Specific Exposure Point Concentrations (EPCs)

At this stage, it is assumed that exposure pathways and receptors of potential concern were previously identified and considered when developing the sampling plan for the site (as discussed in Section 2.5). Once the presence of asbestos has been established through sampling, the next step in evaluating risk involves quantifying exposure to those receptors by first generating exposure point concentrations (EPCs).

It is suggested that calculated EPCs be based on the simple mean of ABS sample results, using a value of zero to evaluate sample results that are "non-detect".

EPCs for each activity of potential concern can be determined from the results of sampling and analysis to estimate airborne fiber concentrations at the site. As discussed in Section 4, ABS should be used for assessing risk from exposures associated with disturbance of asbestos-contaminated soils. Assessment of ambient air exposure concentrations during quiescent activities (those that do not involve active soil disturbance) should be assessed by air monitoring with stationary samplers. Ideally, selection of the sampling approach will be determined by the nature of the activity being assessed. Once a set of measurements is collected to represent the exposure level for the scenario being evaluated, the EPC that would normally be used is the 95% upper confidence limit (UCL) on the mean of all the relevant and representative measurements. While methods for computing the UCL are well-established for non-asbestos analytes using U.S. EPA's ProUCL software, computing the UCL of a set of asbestos measurements is more complicated because variability in the observed mean is contributed from two sources (authentic inter-sample variation and random Poisson counting variation), and methods for estimating the UCL for asbestos are not yet established. Thus, until methods are developed and approved by U.S. EPA, **it is suggested that EPC calculations be based on the simple mean of the data** accompanied by a clear statement that this value is an uncertain estimate of the true mean and that actual risks might be either higher or lower. For analytes other than asbestos, U.S. EPA generally recommends that, when computing the mean of a set of samples, "non-detects" (i.e., samples whose concentration is below the detection limit of the analytical instrument) be evaluated by assigning a surrogate value of ½ the quantitation level (U.S. EPA, 1989a). By analogy, it is sometimes supposed that "non-detects" for asbestos (i.e., samples where the observed count is zero) should be evaluated by assigning a value equal to ½ the LOD. However, the LOD in microscopic analyses is not analogous to a quantitation limit in chemistry analysis and use of ½ the LOD or even ½ the sensitivity as a surrogate for asbestos non-detects may lead to a substantial overestimate of the true mean of a group of samples, especially those primarily comprised of non-detect results (see example scenarios below). Rather, **the mean of a set of microscopy sample results is computed by treating "non-detects" as a zero**. This approach for computing the average of multiple sample results derived using microscopic counting methods has been reviewed and validated by U.S. EPA as part of the rulemaking process for microbial contamination in drinking water (U.S. EPA, 1999). Taking site-specific characteristics into consideration, risk estimates based on other EPCs (*e.g.*, maximum and minimum in addition to the central tendency) may be used to illustrate the range of risks and associated uncertainties (example discussions of uncertainty are available, https://www.epa.gov/superfund/asbestos-superfund-sites-cleanup-examples).

Toxicity values discussed in Sections 7.2 and 7.3 were developed using PCM data and are thus reported in units of f/cc. It is recommended that that air concentrations reported in units of s/cc be compared to toxicity values reported in units of f/cc.

Depending on the type of analysis that is performed, air concentrations can be reported in units of fibers per cubic centimeter (f/cc) or structures per cubic centimeter (s/cc). PCM results are reported in f/cc and ISO 10312 TEM (including PCMe) is reported in s/cc. ISO 10312 TEM is generally the recommended method for air analysis under the decision framework. Because the toxicity values discussed in Sections 7.2 and 7.3 were developed using PCM data and are thus reported in units of f/cc, **it is recommended that air concentrations reported in units of s/cc be compared to toxicity values reported in units of f/cc**.

Computing the Concentration in Air for an Individual Sample

The analytical result for an individual asbestos air sample is reported in terms of the number of asbestos structures observed divided by the volume of air that passed through the portion of the filter that was examined:

$$CA = N / V \qquad \text{(Eq. 5)}$$

where:

CA	=	Concentration in air (s/cc or f/cc)
N	=	Number of fibers observed during the analysis (s or f)
V	=	Volume of air that passed through the area of filter examined (cc)

For convenience, 1/V is referred to as sensitivity (S), and the equation for computing concentration is often written as:

$$CA = N \bullet S \qquad \text{(Eq. 6)}$$

Computing the Asbestos EPC for an Activity or Decision Unit (DU)

An asbestos EPC for an activity or DU is generated by taking the simple mean of all individual asbestos sample concentrations (CA) within a DU:

$$EPC = \frac{CA_1 + CA_2 \ldots + CA_n}{n} \qquad \text{(Eq. 7)}$$

Example Scenarios:

Example 1 - Calculating an EPC with lower concentrations of detected results and many non-detect samples:
Consider the case where the true EPC of the decision unit is 0.001 s/cc, the sensitivity is 0.010 s/cc, and the LOD is 0.030 s/cc.

If 10 samples from the decision unit were analyzed, the expected result would be that 9 of the 10 analyses would yield a count of zero, and one of the samples would yield a count of 1, which would correspond to a concentration estimate of 0.010 s/cc (10-times the truth) using equation 6 above. When averaged, the resulting EPC is 0.001 s/cc, which is the expected value. If ½ the LOD were to be assigned to the 9 non-detects, the resulting average (i.e., EPC) would be 0.0145 s/cc, over ten times higher than the true value. If ½ the sensitivity was to be assigned to the 9 non-detects, the resulting EPC would be 0.0055 s/cc, nearly six-times higher than the true value.

Example 2 – Calculating an EPC with higher detected results and fewer non-detect samples:

Consider the case where the true EPC of the decision unit is 0.040 s/cc, the sensitivity is 0.010 s/cc and the LOD is 0.030 s/cc.

10 samples from the decision unit were analyzed yielding 6 samples with a count of zero, and 4 samples yielding a count of 10, which would correspond to individual sample concentration estimates of 0.10 s/cc (2.5-times the truth) using equation 6 above for the four samples with detected structures. When averaged, the resulting EPC is 0.04 s/cc, which is the expected value. If one-half of the LOD were to be assigned to the 6 non-detects, the resulting average (i.e., EPC) would be 0.049 s/cc, approximately 25% higher than the true value. If one-half the sensitivity was assigned to the 6 non-detects, the resulting EPC would be 0.043 s/cc, approximately 8% higher than the true value.

For sites where relatively large sets of ABS data are available for the same exposure population (e.g., ABS from a single DU over time, multiple DUs that make up a larger exposure area, etc.), it may be useful to pool the data to arrive at a weighted average to develop a more robust EPC. Additional information on pooling data to establish an EPC can be found in Appendix G.

7.2 Cancer Risk Assessment

The general equation for estimating cancer risk from inhalation of both general asbestos and LAA from a specified exposure scenario is obtained from combining equations 6 and 11 from RAGS Part F (U.S. EPA, 2009a). This equation is generally applicable for calculating risk, it is not specific to asbestos.

IURs were developed using PCM data and are thus reported in units of f/cc. It is recommended that that air concentrations reported in units of s/cc be compared to toxicity values reported in units of f/cc.

$$ELCR = IUR \bullet (CA \bullet ET \bullet EF \bullet ED)/AT \quad \text{(Eq. 8)}$$

where:

ELCR = Excess Lifetime Cancer Risk, the risk of developing cancer as a consequence of the site-related exposure scenario
IUR = Inhalation Unit Risk $(f/cc)^{-1}$
CA = Asbestos Concentration in Air (*i.e.*, the EPC [s/cc or f/cc])
ET = Exposure Time (hours/day)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (years)
AT = Averaging Time (lifetime in years x 365 days/year x 24 hours/day)

Substituting the numerical values from the definition of AT in the above equation and using the lifetime equal to 70 years, gives the following equation. This equation is generally applicable for calculating risk, it is not specific to asbestos.

$$ELCR = IUR \bullet CA \bullet ET/24 \bullet EF/365 \bullet ED/70 \quad \text{(Eq. 9)}$$

In cases where a receptor is exposed by more than one exposure scenario, the total risk to the individual is computed by calculating the risk for each scenario separately and then summing across scenarios:

$$ELCR_{total} = \sum ELRC(i) \quad \text{(Eq. 10)}$$

This section discusses how the general equations included above are modified to evaluate cancer risks associated with asbestos. Also discussed are the two alternative approaches that U.S. EPA has developed for determining the IUR needed to quantify excess lifetime cancer risk from a specified exposure scenario. The alternative that is appropriate for a given site depends upon the form of asbestos present as determined by the analytical data and site history.

7.2.1 IRIS approach for General Asbestos

U.S. EPA developed a method for quantification of cancer risks from inhalation exposure to asbestos in 1986 (U.S. EPA, 1986). This method was based on fitting exposure-response models for lung cancer and/or mesothelioma to data from 14 different epidemiological studies available at that time. These studies included nine where exposure was mainly to chrysotile (although two of these studies also had low level exposure to amosite and/or crocidolite), one study where exposure was mainly to amosite, and four studies where exposure was to a mixture of chrysotile and amosite and/or crocidolite. Because all of these asbestos forms are regulated, this IUR is taken to apply to any of the regulated forms of asbestos (chrysotile, amosite, crocidolite, tremolite, anthophyllite, and actinolite) and could also apply to nonregulated forms such as winchite, richterite, and asbestiform amphiboles that meet the PCMe dimensional criteria, etc.

7.2.1.1 General Asbestos IUR

U.S. EPA (1986) selected a relative risk model to quantify the relation between exposure and risk for lung cancer, while, an absolute risk model was selected for mesothelioma, as follows.

Lung cancer: $RR = \alpha (1 + CE10 \bullet K_L)$ (Eq. 11)

Mesothelioma: $I_M = Q \bullet C \bullet K_M$ (Eq. 12)

where:

RR	=	relative risk of lung cancer
α	=	relative risk of lung cancer in the absence of asbestos exposure
CE10	=	cumulative exposure to asbestos (f/cc-yrs), lagged by 10 years
I_M	=	incidence of mesothelioma (cases per person year)
Q	=	a cubic function of exposure duration and time since first exposure ($years^3$)
C	=	the concentration of asbestos (f/cc)
K_L	=	potency factor for lung cancer
K_M	=	potency factor for mesothelioma

It is important to note that the potency factors (K_L and K_M) derived from the modeling are not analogous to cancer slope factors or IURs. Rather, in order to derive estimates of the excess lifetime risk of cancer to an exposed individual, it is necessary to implement a life-table approach, as detailed in U.S. EPA (1986). In brief, given some specified level of exposure to an asbestos mixture of specified composition, risks of dying from asbestos induced lung cancer or mesothelioma are computed for each year of life, and these risks are combined with the probability of death from other causes to yield an estimate of the lifetime total probability of dying from the asbestos exposure. The mesothelioma risk model is additive and there is an assumption that there is no background risk of mesothelioma in the absence of exposure to asbestos. Thus, the data required to compute excess lifetime risk for a specified scenario include the concentration level of asbestos, the potency factor, the age at first exposure, the duration of exposure, and age-specific death rates for all-cause and lung cancer in unexposed people.

Because of this, the IUR value for total risk (lung cancer plus mesothelioma) is not a constant but depends on duration of exposure and age of first exposure. Consequently, it is best to annotate an IRIS-method IUR value with subscripts ($IUR_{a,d}$) to identify the specific applicable values of age at first exposure ($_a$) and exposure duration ($_d$). **The IUR value presented in IRIS (0.23 $[f/cc]^{-1}$) is based on continuous exposure for a lifetime (*i.e.*, a = 0, d = 70).** Appendix H, Table H-4, provides $IUR_{a,d}$ values for a range of ages at first exposure and exposure duration.

7.2.1.2 Time-Weighting Factors (TWF) for Less-Than-Lifetime General Asbestos Exposure (IRIS)

To accommodate less-than-lifetime exposures, Time Weighting Factors (TWFs) need to be considered. TWFs are used to determine the proportion of time (*e.g.*, hours per day, days per year) over which specific exposure activities may occur. To incorporate TWFs into risk evaluation, the basic RAGS Part F (U.S. EPA, 2009a) equation requires modification. This is achieved by omitting the ED/70 term from the basic equation in Section 7.2 (Eq. 6). This is because the exposure duration may be accounted for in the derivation of the IUR term by considering age at first exposure ($_a$) and the duration of exposure ($_d$) in deriving an exposure specific adjusted IUR (shown here as the $IUR_{a,d}$). The final cancer risk equation for general asbestos is below.

$$ELCR = IUR_{a,d} \bullet CA \bullet TWF \quad \text{(Eq. 13)}$$

Where:

$$TWF = ET/24 \bullet EF/365 \quad \text{(Eq. 14)}$$

In accordance with RAGS, Volume I (RAGS, Section 6.4.1, U.S. EPA, 1989a), the exposure frequency and duration assumptions made in developing TWFs should represent reasonable maximum exposure (RME) scenarios.

Table 5 provides Exposure Time (ET) and Exposure Frequency (EF) values for several different exposure scenarios that might be of concern at a CERCLA site. Table 6 provides $IUR_{a,d}$ values for these example exposure scenarios.

Table 5. Factors for Example Exposure Scenarios

Exposure scenario	ET, hours per day	EF, days per year
Continuous Lifetime	24	365
Baseline Residential[†]	24	350
Gardening, Adult	10	50
Recreational, Adult	1	156
Recreational, Child	2	350

[†] If the resident also exercises and gardens, then the exposure time and exposure frequency for the baseline residential scenario should be adjusted downward accordingly.

Table 6. Inhalation Unit Risk ($IUR_{a,d}$) Values for Example Exposure Scenarios

Exposure scenario	Age at first exposure (years)	Exposure duration (years)	$IUR_{a,d}$ $(f/cc)^{-1}$
Continuous Lifetime	0	70	0.23
Baseline Residential	0	26	0.16
Gardening, Adult	20	26	0.070
Recreational, Adult	20	24	0.068
Recreational, Child	1	5	0.045

All values in Table 6 are taken from Appendix H, Table H-4, interpolating between exposure durations as appropriate.

Example Calculations: General Asbestos (IRIS)

The following examples illustrate how TWF (*i.e.*, ET and EF) and $IUR_{a,d}$ values are used in conjunction with ABS air monitoring data to estimate ELCRs for various exposure scenarios. These examples are not intended to be prescriptive or to cover all exposure scenarios.

Example 1: Recreational Exposure – Adult

In this scenario, an adult receptor is exposed to asbestos only while running or walking in a contaminated recreational area (*e.g.*, a park) and is assumed to have no residential asbestos exposure. Under an RME scenario, the adult is assumed to run/walk one hour per day, 156 days per year over a 24-year period from ages 20 to 44 years old. The airborne asbestos concentration in the breathing zone measured during ABS was 0.04 s/cc.

CA = 0.04 s/cc

$IUR_{20,\ 24} = 0.068\ (f/cc)^{-1}$ (Table 6)

TWF= 1 hour/24 hours • 156 days/365 days = 0.018 (Table 5)

ELCR = $0.068\ (f/cc)^{-1} \bullet 0.04$ s/cc • $0.018 = 4.8 \times 10^{-5}$

Example 2: Recreational Exposure – Child

In this scenario, a child receptor is exposed to asbestos only while playing in the dirt in a recreational area (*e.g.*, a park) and is assumed to have no residential asbestos exposure. Under an RME scenario, the child is assumed to play two hours per day, 350 days per year over a five-year period from ages one to six years old. The airborne asbestos concentration in the breathing zone measured during ABS was 0.02 s/cc.

CA = 0.02 s/cc

$IUR_{1,5} = 0.045\ (f/cc)^{-1}$ (Table 6)

TWF = 2 hours/24 hours • 350 days/365 days = 0.080 (Table 5)

ELCR = $0.045\ (f/cc)^{-1} \bullet 0.02$ s/cc • $0.080 = 7.2 \times 10^{-5}$

Example 3: Combined Residential Ambient Air Exposure and Gardening Exposure – Adult

In this scenario, an adult receptor is exposed due to disturbance of asbestos-contaminated soil while gardening and to asbestos in ambient air during quiescent activities. Under a residential RME scenario, the period of exposure is assumed to be 26 years, starting at age 20. The

gardening scenario is assumed to be 10 hours per day, 50 days per year. Similarly, RME exposure to asbestos in ambient air is assumed to occur at all times that gardening is not occurring (14 hours per day for 50 days per year and 24 hours per day for 300 days per year). The asbestos concentration in the breathing zone while gardening during ABS was 0.02 s/cc. The ambient air concentration measured in the community by stationary air monitors was 0.0007 f/cc.

Gardening Exposure Scenario:

CA = 0.02 s/cc

$IUR_{20,26} = 0.070\ (f/cc)^{-1}$ (Table 6)

TWF = 10 hours/24 hours • 50 days/365 days = 0.057 (Table 5)

$ELCR_{gardening} = 0.070\ (f/cc)^{-1} \bullet 0.02\ s/cc \bullet 0.057 = 8.0 \times 10^{-5}$

Ambient air exposure on days when gardening occurs:

CA = 0.0007 s/cc

$IUR_{20,26} = 0.070\ (f/cc)^{-1}$ (Table 6)

TWF = 14 hours/24 hours • 50 days/365 days = 0.080 (Table 5)

$ELCR_{ambient\ air\ on\ gardening\ days} = 0.070\ (f/cc)^{-1} \bullet 0.0007\ s/cc \bullet 0.080 = 3.9 \times 10^{-6}$

Ambient air exposure on days when gardening does not occur:

CA = 0.0007 s/cc

$IUR_{20,26} = 0.070\ (f/cc)^{-1}$ (see Table 6)

TWF = 24 hours/24 hours • 300 days/365 days = 0.822 (Table 5)

$ELCR_{ambient\ air\ on\ non\text{-}gardening\ days} = 0.070\ (f/cc)^{-1} \bullet 0.0007\ s/cc \bullet 0.822 = 4.0 \times 10^{-5}$

Total ELCR is then the sum of the three scenario-specific values to complete 24 hours/day and 365 days/year for the combined exposure scenario:

$ELCR_{total} = 8.0 \times 10^{-5} + 3.9 \times 10^{-6} + 4.0 \times 10^{-5} = 1.2 \times 10^{-4}$

7.2.1.3 Uncertainties in Cancer Risk Estimates for General Asbestos (IRIS)

In accordance with standard U.S. EPA risk assessment guidance (U.S. EPA, 1989a, 2000a), important sources of uncertainty in cancer risk estimates should be discussed in the uncertainty section of the risk assessment.

In the case of cancer risk estimates derived using the U.S. EPA (1986) method, there are several areas of uncertainty that should be included in this discussion. First, the IUR was developed using data from multiple studies that included a number of differing forms of asbestos, including chrysotile, amosite, and crocidolite. Consequently, the IUR may not account for any potential differences in potency between different mineral forms. Second, in all cases exposure was expressed in terms of PCM f/cc, so the IUR does not account for any potential differences in potency as a function of differing distributions of fiber width/length. In addition, in a number of the studies the exposure estimates were based on measurements of dust in air, and conversion of these measurements to PCM f/cc is often uncertain. A study by NIOSH indicates that for chrysotile exposed textile workers, shorter fibers better correspond to the risk of asbestosis than longer fibers (Hein et al., 2007). Longer, thinner, fibers may be better associated with lung cancer. However, these findings do not define a limit to toxicity based on fiber dimension. There are a number of studies which support the view that shorter fibers cause disease (Hein et al., 2007; Dodson, 2003).

Additional areas of uncertainty in the use of the dose-response assessment, not specific to asbestos (*i.e.*, they also pertain to other pollutants), may also be appropriate to discuss in the uncertainty characterization section of the risk assessment. These uncertainties may include differences between the study on which the dose-response assessment is based relative to the exposure circumstances being assessed, and recognition of assumptions inherent in methods employed to derive a continuous exposure toxicity value from exposure-response data involving discontinuous exposures (U.S. EPA, 1994). These uncertainties may also include differences with regard to the exposed population (*e.g.*, workers vs. general population), the magnitude of exposure (*e.g.*, generally higher study levels than those being assessed), and duration and frequency of exposure (*e.g.*, 20-30 years of five to six 8- to 10-hour days per week vs. alternate exposure scenarios). See Appendix H, Derivation of Cancer Unit Risk Values for Continuous and Less-Than-Lifetime Inhalation Exposure to Asbestos, for more information.

7.2.2 Libby Amphibole Asbestos (LAA)

U.S. EPA has completed an assessment of the exposure-response relationship for cancer effects (lung cancer and mesothelioma) and non-cancer effects (localized pleural thickening [LPT]) in humans exposed to a particular type of asbestos referred to as Libby Amphibole Asbestos (LAA). The assessment was posted on the IRIS database in 2014 (U.S. EPA, 2014a). LAA consists of a mixture of winchite (84%), richterite (11%), tremolite (6%), edenite (trace), magnesio-arfvedsonite (trace), and magnesio-riebeckite (trace), which was identified in the Rainy Creek complex near Libby, MT (Meeker et al., 2003).

The following sections summarize the derivation of the IUR for LAA and the recommended method for calculation of the cancer risk for LAA. This IUR applies to sites contaminated with LAA. The recommended approach for calculation of non-cancer hazard is in Section 7.3.2.

7.2.2.1 Inhalation IUR (LAA)

The exposure-response models for cancer were developed using epidemiological studies of mortality from lung cancer or mesothelioma in a cohort of workers who were exposed to LAA in and/or near the vermiculite mine and mill in Libby, Montana as reported by McDonald et al. (1986), Amandus et al. (1987), Amandus and Wheeler (1987), and Sullivan (2007).

The Libby mine began operations about 1935 and continued until 1990. PCM-based measurements of asbestos in air were collected at multiple locations in and around the mine and mill beginning about 1967 and extending to 1982. To estimate worker exposures that occurred before that time, long-time plant employees were interviewed to obtain information on relative exposure intensities as well as known changes in operations over the years, and this information was used to back-extrapolate exposure concentrations from post-1967 measurements (Amandus et al., 1987). To limit the uncertainty due to the back-extrapolation of early exposure intensities, U.S. EPA selected a sub-cohort of 880 workers who were hired in 1960 or after for use in the exposure-response modeling (U.S. EPA, 2014a).

The quantitative exposure-response relationship for lung cancer mortality was evaluated using the Cox proportional hazards model.

$$\lambda(t|Z) = \lambda_0(\mathrm{t})\exp\,(\beta^T z) \qquad \text{(Eq. 15)}$$

Where β is the vector of regression coefficients, $\lambda_0(t)$ denotes the baseline hazard function, and t denotes transposition of the vector (U.S. EPA, 2014a).

Lung cancer and mesothelioma mortality was evaluated using a wide variety of alternative exposure metrics to determine which metrics yielded the best fit of the data. These included cumulative exposures lagged by 0 to 20 years and residence time weighted cumulative exposures, with and without the effects of various rates of fiber clearance from the lung (U.S. EPA, 2014a).

Ultimately, the exposure metrics identified as providing the best fit were as follows.

Lung cancer: Cumulative exposure (f/cc-years) lagged by 10 years, with a 10-year half-life for fiber clearance
Mesothelioma: Cumulative exposure (f/cc-years) lagged by 10 years, with a 5-year half-life for fiber clearance

Based on these exposure metrics, the potency values for LAA derived from the selected models were used to calculate IUR values using a life table method (U.S. EPA, 2014a). The resulting values are below.

IUR (lung cancer) = 0.068 $(f/cc)^{-1}$
IUR (mesothelioma) = 0.122 $(f/cc)^{-1}$

The IUR for the occurrence of either lung cancer or mesothelioma was estimated by finding the upper bound on the sum of the IUR values, assuming that the uncertainty around each central tendency value is normally distributed. The resulting value is:

IUR (LAA) = 0.169 $(f/cc)^{-1}$ [rounded to 0.17 $(f/cc)^{-1}$]

Note that this value is somewhat lower than the simple sum of the IUR values, because each IUR value is itself an upper bound.

7.2.2.2 Time-Weighting Factors for Less-Than Lifetime Exposure (LAA)

TWFs must also be considered when evaluating less-than lifetime exposures to LAA. Unlike general asbestos, however, the ED term is retained for the LAA TWF because the IUR for LAA is not adjusted for age at first exposure ($_a$) and exposure duration ($_d$) as was the U.S. EPA (1986) IUR. Combining Equation 6 and Equation 11 from RAGS Part F (U.S. EPA, 2009a), and substituting the numerical values for averaging time (AT) in the equation and using the lifetime of 70 years yields the equation below. This equation can be used to calculate the cancer risk from exposure to LAA without further modification. The values of ET, EF, and ED are adjusted to the exposure scenario of interest to account for intermittent and/or less-than-lifetime exposure.

$$ELCR = IUR_{LA} \bullet CA \bullet TWF \quad \text{(Eq. 16)}$$

Where:

$$TWF = ET/24 \bullet EF/365 \bullet ED/70 \quad \text{(Eq. 17)}$$

Example Calculations: LAA

The same exposure scenarios listed in Table 5 (Section 7.2.1.2) are used here.

Example 1: Recreational Exposure – Adult

An adult is exposed to ambient air (CA = 0.04 s/cc) for 1 hr/day, 156 days/year, from age 20 to 44.

IUR = 0.17 $(f/cc)^{-1}$

CA = 0.04 s/cc

TWF = 1 hour/24 hours • 156 days/365 days • 24 years/70 years = 0.0061

ELCR = 0.17 $(f/cc)^{-1}$ • 0.04 s/cc • 0.0061 = 4.2×10^{-5}

Example 2: Recreational Exposure – Child

A child is exposed to ambient air (CA = 0.02 f/cc) in a park for 2 hours/day, 350 days per year, from age 1 to 6.

IUR = 0.17 $(f/cc)^{-1}$

CA = 0.02 s/cc

TWF = 2 hours/24 hours • 350 days/365 days • 5 years/70 years = 0.0057

ECLR = 0.17 $(f/cc)^{-1}$ • 0.02 s/cc • 0.0057 = 1.9 x 10^{-5}

Example 3: Combined Residential Ambient Air Exposure and Gardening Exposure-Adult

An adult receptor is exposed due to disturbance of asbestos-contaminated soil while gardening and to asbestos in ambient air during quiescent activities. The period of exposure is 26 years, starting at age 20. The gardening scenario is assumed to be 10 hours per day, 50 days per year. Exposure to asbestos in ambient air is assumed to occur at all times that gardening is not occurring (14 hours per day for 50 days per year and 24 hours per day for 300 days per year). The asbestos concentration in the breathing zone while gardening during ABS is 0.02 f/cc. The ambient air concentration measured in the community by stationary air monitors is 0.0007 f/cc. The excess lifetime cancer risk from LAA is calculated in three parts.

Gardening Exposure Scenario:

IUR = 0.17 $(f/cc)^{-1}$

CA = 0.02 s/cc

TWF = 10 hours/24 hours • 50 days/365 days • 26 years/70 years = 0.0212

$ECLR_{gardening}$ = 0.17 $(f/cc)^{-1}$ • 0.02 s/cc • 0.0212 = 7.2 x 10^{-5}

Ambient air exposure on days when gardening occurs:

IUR = 0.17 $(f/cc)^{-1}$

CA = 0.0007 s/cc

TWF = 14 hours/24 hours • 50 days/365 days • 26 years/70 years = 0.0297

$ELCR_{ambient\ air\ on\ gardening\ days}$ = 0.17 $(f/cc)^{-1}$ • 0.0007 s/cc • 0.0297 = 3.5 x 10^{-6}

Ambient air exposure on days when gardening does not occur:

$IUR = 0.17\ (f/cc)^{-1}$

$CA = 0.0007$ s/cc

TWF = 24 hours/24 hours • 300 days/365 days • 26 years/70 years = 0.3053

$ELCR_{ambient\ air\ on\ non\text{-}gardening\ days} = 0.17\ (f/cc)^{-1} \bullet 0.0007\ s/cc \bullet 0.3053 = 3.6 \times 10^{-5}$

Total cancer risk is then the sum of the three values to complete 24 hours/day and 365 days/year for the combined exposure scenario:

$$ELCR_{total} = 7.2 \times 10^{-5} + 3.5 \times 10^{-6} + 3.6 \times 10^{-5} = 1.1 \times 10^{-4}$$

7.2.2.3 LAA Uncertainties

There are a number of uncertainties associated with the estimation of cancer risk from LAA using the approach described above. The main sources of uncertainty in the IUR value for LAA include the following (U.S. EPA, 2014a):

1) Low-dose extrapolation
2) Exposure assessment, including analytical measurements uncertainty
3) Model form
4) Selection of exposure metric
5) Assessing mortality corresponding to other cancer endpoints
6) Control of potential confounding in modeling lung cancer mortality
7) Potential effect modification
8) Length of follow-up
9) Use of lifetables to calculate cancer mortality inhalation unit risks
10) Combining of risks to derive a composite cancer IUR
11) Extrapolation of findings in adults to children

All of these factors, as well as any other site-specific factors, should be included in the uncertainty section of a risk assessment that includes cancer effects of LAA.

7.3 Non-Cancer Hazard Assessment

7.3.1 IRIS Approach for General Asbestos

Non-cancer hazard is not assessed quantitatively in the IRIS general asbestos toxicological review (U.S. EPA, 1988a).

7.3.2 Approach for LAA

U.S. EPA has developed a quantitative exposure-response model for non-cancer effects in humans who have inhalation exposure to LAA. Detailed discussions of the data, modeling

approach, and resulting reference concentrations (RfC) are presented in the Toxicological Review of Libby Amphibole Asbestos (U.S. EPA, 2014a).

The LAA RfC (f/cc) = 9 x 10^{-5} f/cc. This value represents a continuous lifetime exposure concentration that is expected to pose no significant risk of adverse non-cancer effects in humans.

In brief, the exposure-response model for non-cancer effects was based on the prevalence of localized pleural thickening (LPT) in a cohort of workers who were exposed to asbestos (primarily LAA) at a workplace in Marysville, Ohio, and who were examined by chest x-ray in 2001-2004 (Rohs et al., 2008). Use of Libby vermiculite in this workplace began about 1959 and continued until about 1980. PCM-based industrial hygiene measurements of asbestos concentrations in air from several locations in the workplace were collected starting in 1972, with continued monitoring until 1994. Because no exposure data were available prior to 1972, U.S. EPA focused on a sub-cohort of 119 workers (106 males; 13 females) who were hired in 1972 or later (U.S. EPA, 2014a).

U.S. EPA tested a variety of different model forms and explanatory variables in order to determine the best exposure-response model to describe the prevalence of LPT in the selected sub-cohort of workers. The model ultimately selected by U.S. EPA is referred to as the bivariate dichotomous Hill model with fixed plateau (BV DH FP):

$$p(x, TSFE) = bkg + \frac{FP - bkg}{1 + \exp\left[-a - b * ln(x) - c * TSFE\right]} \quad \text{(Eq. 18)}$$

where:

p(x,TSFE) = Predicted prevalence of LPT in a cohort of humans with an LAA exposure concentration of x PCM f/cc at a time point of time since first exposure (TSFE) (years)
bkg = Background prevalence of LPT, estimated from the Rohs et al. (2008) study
FP = Fixed plateau, set to 0.85 based on information from the literature (see U.S. EPA, 2014a)
a, b, c = Fitting parameters estimated from the data
x = Average (arithmetic mean) exposure concentration (PCM f/cc)
TSFE = Time since first exposure to time of evaluation (years)

Because the range of TSFE values in the sub-cohort was relatively narrow (23.14 to 32.63 years), U.S. EPA estimated the value of c (the coefficient of TSFE) based on the full cohort (all workers, regardless of date of hire), and then held this value constant when fitting the model to the sub-cohort.

As shown in Table 5-9 of U.S. EPA (2014a), the final model parameters derived from the data are as follows:

FP = 0.85
bkg = 0.03682
a = -1.9798
b = 1.2750
c = 0.1075

Given these model parameters, the Benchmark Concentration (BMC) was defined as the concentration which resulted in a 10% increase in prevalence of LPT, calculated using a TSFE value equal to the mid-point of the available data (TSFE = 28 years). The lower confidence bound on BMC (referred to as the BMCL) at 28 years was determined based on the uncertainty in the model fit. These values are as follows:

BMC (TSFE = 28) = 9.2×10^{-2} f/cc
BMCL (TSFE = 28) = 2.6×10^{-2} f/cc

The RfC was derived from the BMCL value by dividing by a composite uncertainty factor (UF) of 300 (see U.S. EPA, 2014a), which was based on the following:

- An intra-species UF of 10 was applied to account for human variability and potentially susceptible individuals.
- A database UF of 3 was applied to account for database deficiencies in the available literature for the health effects of LAA.
- A data-informed UF of 10 was applied to account for the extrapolation from the BMCL at TSFE = 28 to the BMCL at TSFE = 70 years.

Composite UF = 10 • 3 • 10 = 300

The RfC value was calculated from the BMCL based on this composite uncertainty factor.

RfC (f/cc) = 2.6×10^{-2} f/cc / 300 = 9×10^{-5} f/cc

7.3.2.1 Application of the RfC for LAA

RAGS F (U.S. EPA, 2009a) does not provide guidance on calculation of the Hazard Quotient (HQ) for asbestos. Rather, RAGS F refers risk assessors to the TRW Asbestos Committee. The TRW Asbestos Committee recommends using the following equation for calculating the HQ for LAA:

The RfC for LAA was developed using PCM data and is thus reported in units of f/cc. It is recommended that that air concentrations reported in units of s/cc be compared to toxicity values reported in units of f/cc.

$$HQ = CA \bullet TWF \bullet AF(TSFE) / RfC \quad \text{(Eq. 19)}$$

where:

CA	= Concentration in Air (EPC reported in s/cc or f/cc)
TWF	= Time Weighting Factor
AF(TSFE)	= Adjustment Factor for time since first exposure
RfC	= Reference Concentration (f/cc)

The terms in this equation are discussed below.

Time Weighting Factors for Discontinuous or Less-Than-Lifetime Exposures

As discussed in RAGS F (U.S. EPA, 2009a), RfC values are protective for continuous exposure (24 hours per day, 365 days per year) over the exposure interval. Like cancer risk calculations for asbestos, however, the exposure frequency and duration do not have minima and exposure can be extrapolated downward as needed to assess risk at CERCLA sites. As noted in Section 7.1.2.2, the RfC for LAA applies to a lifetime exposure of 70 years as well. When ED is less than lifetime, the amount of asbestos inhaled and deposited in the respiratory tract decreases, resulting in a decreased hazard of adverse effects. To account for site-specific exposures that are not continuous or less-than-lifetime, the following TWF can be used when calculating the HQ:

$$TWF = ET/24 \bullet EF/365 \bullet ED/70 \quad \text{(Eq. 20)}$$

Adjustment for Time Since First Exposure

Time since first exposure (TSFE) is the time (years) between the age when exposure first began and the time when the health outcome is evaluated. Because LAA is a highly durable particle that persists in the respiratory tract long after exposure ceases, it continues to elicit biological activity even in the absence of continued exposure (Wright et al., 2002). Based on the raw data, it is clear that hazard increases non-linearly as TSFE increases, indicating the need to account for cases where TSFE is less than 70 years. The goal of the Hazard Quotient is to evaluate the hazard of LPT when exposure begins at age ≥ 0 and the health assessment occurs at age 70. Therefore, TSFE is defined as:

$$TSFE = 70 \text{ years} - \text{age at first exposure (years)} \quad \text{(Eq. 21)}$$

An adjustment factor (AF) for the effect of TSFE may be derived from the final hybrid model-predicted dependence of LPT on TSFE, as shown in Figure I-1 (taken from Figure 5-4 in U.S. EPA, 2014a). The red line plots the model-predicted prevalence of LPT for exposure at the BMCL of 0.026 f/cc. The AF for TSFE is computed as the ratio of predicted prevalence of LPT for TSFE < 70 years compared to that for TSFE = 70 years:

$$AF(TSFE) = p(0.026, TSFE) / p(0.026, 70) \quad \text{(Eq. 22)}$$

Prevalence values are computed using the best fit model and parameters presented above (see Equation 15). Resultant values and adjustment factors for TSFE = 1 to 70 are shown in Appendix I[13], Table I-1.

Example Calculations: Single Scenario

Example 1 (Continuous lifetime exposure)

An individual is exposed to LAA (CA = 0.0008 s/cc) continuously (24 hrs/day, 365 days/year) beginning at age 0 and extending to age 70. The HQ is calculated as follows:

RfC = 9×10^{-5}
CA = 0.0008 s/cc
ED = 70 years – 0 years = 70 years
TSFE = 70 years – 0 years = 70 years
AF(70) = 1.00 (from Table I-1)
TWF = 24 hours/24 hours • 365 days/365 days • 70 years/70 years = 1

HQ = 0.0008 s/cc • 1 • 1.00 / 9×10^{-5} = 8.9 (round to 9)

Example 2 (Continuous exposure with typical CERCLA residential exposure assumptions)

An individual is exposed to LAA (CA = 0.0008 s/cc) continuously (24 hrs/day, 365 days/year) beginning at age 0 and extending to age 26. For this scenario, it is assumed that **hazard is assessed at age 70 since LAA is a highly durable and persistent particle that continues to elicit biological activity even in the absence of continued exposure** (Wright et al., 2002). Hence, the HQ is calculated as follows:

TSFE = 70 years – 0 years = 70 years
AF(70) = 1.00 (from Table I-1)
TWF = 24 hours/24 hours • 365 days/365 days • 26 years/70 years = 0.37

HQ = 0.0008 s/cc • 0.37 • 1.00 / 9×10^{-5} = 3.2 (round to 3)

7.3.2.2 Evaluating Simultaneous or Sequential Exposures

In some cases, an individual may be exposed to asbestos by two or more scenarios that all begin at the same time and end at the same time. In this event, calculate the HQ for each scenario and sum the scenario specific values. For example, if exposure over a specified interval occurred as the result of three different activities, the results would be calculated as follows:

TWF1 = ET1/24 • EF1/365 • ED/70 (Eq. 23)
TWF2 = ET2/24 • EF2/365 • ED/70 (Eq. 24)

[13] The toxicity values for Libby Amphibole Asbestos are intended for use with LAA. If users plan to use the LAA toxicity values for other amphiboles, consultation with the TRW Asbestos Committee is strongly recommended.

$$TWF3 = ET3/24 \bullet EF3/365 \bullet ED/70 \quad \text{(Eq. 25)}$$

$$HQ1 = CA1 \bullet TWF1 \bullet AF(TSFE) / RfC \quad \text{(Eq. 26)}$$
$$HQ2 = CA2 \bullet TWF2 \bullet AF(TSFE) / RfC \quad \text{(Eq. 27)}$$
$$HQ3 = CA3 \bullet TWF3 \bullet AF(TSFE) / RfC \quad \text{(Eq. 28)}$$

$$HQ_{total} = HQ1 + HQ2 + HQ3 \quad \text{(Eq. 29)}$$

Example Calculation: Simultaneous Scenario

An individual is exposed to LAA in air during three different activities that all begin at age 20 and stop at age 50.

ED = 50 years – 20 years = 30 years
TSFE = 70 years – 20 years = 50 years
AF(50) = 0.353 (from Table I-1)

Activity-specific parameters are as follows:

Parameter	Activity 1	Activity 2	Activity 3
CA (s/cc)	0.020	0.050	0.0007
ET (hours/day)	4	3	16
EF (days/year)	50	100	215

TWF values for each activity are computed as follows:

TWF1 = 4 hours/24 hours • 50 days/365 days • 30 years/70 years = 0.0098
TWF2 = 3 hours/24 hours • 100 days/365 days • 30 years/70 years = 0.0147
TWF3 = 16 hours/24 hours • 215 days/365 days • 30 years/70 years = 0.1683

HQ values for each activity are computed as follows:

HQ1 = 0.020 s/cc • 0.0098 • 0.353 / 9 x 10^{-5} f/cc = 0.77
HQ2 = 0.050 s/cc • 0.0147 • 0.353 / 9 x 10^{-5} f/cc = 2.88
HQ3 = 0.0007 s/cc • 0.1683 • 0.353 / 9 x 10^{-5} f/cc= 0.46

The total HQ is then the sum of the three scenario-specific HQ values:

HQ_{total} = 0.77 + 2.88 + 0.46 = 4.11 (round to 4)

The concept that hazard depends on time since first exposure complicates the issue of estimating the cumulative hazard from a series of sequential exposure scenarios. Consider the situation where an individual is exposed to an exposure concentration of CA1 from age A to age B (ED1 = age A - age B), and to a subsequent exposure concentration of CA2 from age C to age D (ED2 = age C - age D), the results would be calculated as follows:

Step 1: Calculate the HQ (unadjusted for TSFE) for each scenario separately, as follows:

$$TWF1 = ET1/24 \bullet EF1/365 \bullet ED1/70 \quad \text{(Eq. 30)}$$
$$TWF2 = ET2/24 \bullet EF2/365 \bullet ED2/70 \quad \text{(Eq. 31)}$$

$$HQ1 = CA1 \bullet TWF1/ RfC \quad \text{(Eq. 32)}$$
$$HQ2 = CA2 \bullet TWF2/ RfC \quad \text{(Eq. 33)}$$

Step 2: Calculate the HQ as follows:

$$HQ_{total} = (HQ1 + HQ2) \bullet AF(TSFE) \quad \text{(Eq. 34)}$$

Example Calculation: Sequential Scenario

An individual is exposed to LAA in air during two different age intervals in life. Exposure parameters are as follows:

Parameter	Interval 1	Interval 2
CA (s/cc)	0.0010	0.0080
ET (hours/d)	24	12
EF (days/year)	350	150
Age at start (years)	10	25
Age at stop (years)	20	50
ED (years)	10	25

TWF1 = 24 hours/24 • 350 days/365 • 10 years/70 = 0.137
TWF2 = 12 hours/24 • 150 days/365 • 25 years/70 = 0.073

TSFE = 70 years – 10 years = 60 years
AF(60) = 0.662 (from Table I-1)

HQ1 = 0.001 s/cc • 0.137 / 9 x 10^{-5} f/cc = 1.52
HQ2 = 0.008 s/cc • 0.073 / 9 x 10^{-5} f/cc = 6.49

HQ_{total} = (1.52 + 6.49) • 0.662 = 5.30 (round to 5)

This computational approach closely resembles how the raw exposure data from the Marysville cohort were used in the model fitting exercise used to derive the RfC, and hence this computational approach is considered to be most appropriate from a mathematical perspective.

In cases where there is an interruption of two exposures that occur over a long period of time at different age intervals, it may sometimes be difficult to judge how to stratify these complex exposure patterns into discrete scenarios. A calculation that can be used to estimate the uncertainty in the calculated HQ for this type of scenario is included within Appendix J.

7.4 Risk Characterization

The purpose of risk characterization is to summarize and combine outputs of the exposure and toxicity assessments performed within the HHRA to provide a quantitative assessment of site-related risks. The risk characterization step also identifies contamination with concentrations which exceed acceptable levels, defined by the NCP as an excess lifetime cancer risk greater than $1 \times 10^{-6} - 1 \times 10^{-4}$ or an HI greater than 1. Risks that exceed these benchmarks must be highlighted in the HHRA for risk management consideration. The TRW Asbestos Committee website (https://www.epa.gov/superfund/asbestos-superfund-sites-cleanup-examples) has a variety of examples in risk assessments that include these and other exposure scenarios. The table below provides a summary of the risks and hazards identified for the example scenarios illustrated above:

Scenario	Fiber Type	Risk	Hazard
Recreational Exposure - Adult	General Asbestos	5×10^{-5}	N/A
Recreational Exposure - Child	General Asbestos	7×10^{-5}	N/A
Combined Residential Ambient Air and Gardening Exposure - Adult	General Asbestos	1×10^{-4}	N/A
Recreational Exposure - Adult	LAA	4×10^{-5}	N/A
Recreational Exposure - Child	LAA	2×10^{-5}	N/A
Combined Residential Ambient Air and Gardening Exposure - Adult	LAA	1×10^{-4}	N/A
Continuous Exposure (lifetime)	LAA	N/A	9
Continuous Exposure (residential)	LAA	N/A	3
Simultaneous Exposure	LAA	N/A	4
Sequential Exposure	LAA	N/A	5

7.5 Identifying the Air Action Level

OSWER Directive 9345.4-05 (U.S. EPA, 2004) recommends the development of risk-based, site-specific air action levels (*i.e.*, LOCs) to determine if response actions for asbestos in soil/debris should be undertaken. Because inhalation is the exposure pathway of concern for asbestos, an action (or screening) level for asbestos in air is an appropriate metric for site managers in making the determination of whether a response action, no action, or further, more detailed investigation at a given site is warranted.

It is recommended that the action level for asbestos in air be carefully considered to ensure that it is appropriate for the site. As discussed in Section 3.1.2 and 4.3.5, the air action level, or LOC, may be useful in guiding the data collection effort for site investigations as they can support the identification of appropriate detection levels for establishing DQOs. Technical and statistical issues should be carefully considered in determining whether the average air concentration from ABS can be compared to these risk-based action levels for asbestos in air (*e.g.*, it would not be

appropriate to compare air concentrations generated by a short-term ABS scenario, such as raking or lawn mowing, with an air action level which assumes a continuous residential exposure scenario). The following subsections provide a range of air action values that may be useful for different site-specific circumstances, given the toxicity and exposure parameters for the various fiber types previously described.

7.5.1 General Asbestos

A risk-based action level for general asbestos (*e.g.*, chrysotile) in air may be calculated by rearranging the standard risk equation to compute the concentration of asbestos in air that corresponds to a specified risk level for a specified exposure scenario of concern as follows:

$$\text{LOC (s/cc)} = \frac{\text{Target Risk}}{[\text{IUR} \bullet \text{TWF}]} \qquad \text{(Eq. 35)}$$

Example Calculation:
The following site-specific LOC can be calculated using a hypothetical scenario including exposure for 1-hour/day, 156 days/year for 24 years beginning at age 20:

$$\text{TWF} = \text{ET}/24\ \text{hours} \bullet \text{EF}/365\ \text{days}$$
$$= 1\ \text{hour}/24\ \text{hours} \cdot 156\ \text{days}/365\ \text{days} = 0.018$$

$$\text{IUR} = 0.068\ (\text{f/cc})^{-1}\ \text{(from Table H-4)}$$

Assuming a target risk of $1x10^{-6}$:

$$\text{LOC (s/cc)} = 1x10^{-6} / [0.068\ (\text{f/cc})^{-1} \bullet 0.018] = 0.0008\ \text{s/cc}$$

7.5.2 Libby Amphibole Asbestos

For sites where the mineral fibers are determined to be LAA, the LOC can be determined by both cancer risk and non-cancer hazard. The carcinogenic LOC is determined by rearranging the risk equation in the same way shown above for general asbestos. For LAA, however, there is no adjustment for time from first exposure due to the derivation of the Libby IUR.

Example Calculation:
A hypothetical site-specific LOC using the same exposure parameters in the previous example (i.e., exposure for 1-hour/day, 156 days/year for 24 years beginning at age 20) would be calculated as:

$$\text{TWF} = \text{ET}/24\ \text{hours} \bullet \text{EF}/365\ \text{days} \bullet \text{ED}/70\ \text{years}$$
$$= 1\ \text{hour}/24\ \text{hours} \cdot 156\ \text{days}/365\ \text{days} \cdot 24\ \text{years}/70\ \text{years} = 0.0061$$

$$\text{IUR} = 0.17\ (\text{f/cc})^{-1}$$

Assuming a target risk of $1x10^{-6}$:

LOC (s/cc) = $1x10^{-6}$/ [0.17 $(f/cc)^{-1}$ • 0.0061] = 0.001 s/cc

For non-cancer action levels, the LOC is determined by rearranging the hazard quotient equation to compute the concentration of asbestos in air that corresponds to a specified hazard level for a specified exposure scenario of concern (often a *de minimis* hazard level of 1). The LOC is estimated as follows:

$$LOC\ (s/cc) = (Target\ HQ \bullet RfC_{LA}) / (TWF \bullet AF) \qquad \text{(Eq. 36)}$$

where:

TWF = Time-weighting factor
RfC_{LA}= LAA-specific reference concentration (LAA PCM f/cc)
AF = Adjustment factor for less-than-lifetime exposure (Table I-1)

Note: Due to the addition of the adjustment factor, the calculation of the TWF for the hazard quotient differs from the TWF calculation for cancer estimation.

Example Calculations:
Example 1 (Continuous lifetime exposure)

An individual is exposed to LAA continuously (24 hours/day, 365 days/year) beginning at age 0 and extending to age 70. The LOC is calculated as follows:

ED = 70 years – 0 years = 70 years
TSFE = 70 years – 0 years = 70 years
AF(70) = 1.00 (from Table I-1)
TWF = 24 hours / 24 hours • 365 days / 365 days • 70 years / 70 years = 1.0

Assuming a target HQ of 1:

LOC (f/cc) = (1 • 9 x 10^{-5} f/cc) / (1.0 • 1.00)
= 9 x 10^{-5} s/cc

Example 2 (Exposure begins at age 20 with a 24-year duration)

An individual is exposed to LAA in ambient air where the exposure duration is for 1-hour day, 156-day year for 24 years beginning at age 20:

ED = 44 years – 20 years = 24 years
TSFE = 70 years – 20 years = 50 years
AF(50) = 0.353 (from Table I-1)

TWF = 1 hour / 24 hours • 156 days / 365 days • 24 years / 70 years = 0.0061

Assuming a target HQ of 1:

LOC (s/cc) = (1 • 9 x 10^{-5} f/cc) / (0.0061 • 0.353) = 0.042 s/cc

Using the procedures outlined above allows for the development of health-based screening levels that are representative of actual inhalation exposures (the critical exposure route) by means of site-specific, measured (not modeled) air concentrations. Derivation of site-specific action levels for other exposure scenarios would follow the same procedures.

7.6 Risk Management

As is true of all site investigations, risk managers balance a number of different considerations in deciding how to proceed at a site, according to the nine criteria that were defined by the NCP (40CFR §300.430). Below are two risk management decision points that may occur at an asbestos site:

Risk Management Decision Point #1

After completing screening level sampling, risk managers and risk assessors should compare the soil and/or dust sampling results from the screening-level exposure assessment to the risk-based action level for asbestos in that medium and be considered in the context of the other available site data to determine the appropriate next step(s). Typically, there are two basic outcomes possible:

- Outcome 1: Asbestos is not detected above action level (see Section 7.5)
  Asbestos is not detected in the screening-level ABS air samples (if collected) at concentrations that exceed the site-specific air LOC (calculated as described in Section 7.5) or FBAS samples have PCME fiber concentrations that are non-detect or below an LOC decided upon by the Project Team. In this case, if there is reasonable confidence that the ABS/FBAS samples represent the upper end of exposures that might occur at the site, and the analytical results have been obtained using the appropriate methods with an appropriate analytical sensitivity, then no further evaluation of asbestos should be necessary. If confidence in the ABS/FBAS results from the screening level assessment is not high (the area evaluated might not represent the high end of the concentration range at the site, the tests might have been done under conditions when release was not maximal, etc. including considerations discussed in Section 4.3), or if there is visible ACM or elevated asbestos in soil concentrations present, then it may be appropriate to perform more detailed sampling or to take a response action.

- Outcome 2: Asbestos is detected above action level (see Section 7.5)
  Asbestos is detected in at least one or more ABS samples at concentrations at or above the air LOC or in an FBAS sample (or other soil samples) that indicates an elevated concentration of asbestos in soil (as determined by the Project Team). In this case, it may be appropriate to conduct a response action or collect additional data to further quantify the magnitude of exposure and risk, as well as the extent of contamination.

The Framework process is intended to provide flexibility to risk managers. At the end of a screening level assessment, the site team can elect to collect more data or to move directly to a response action.

Following a screening level assessment, if more detailed sampling is determined to be necessary, data should be collected to provide sufficient information about exposures from indoor and outdoor sources such that risk assessment and risk management decisions can be based on the more robust site-specific information. As discussed previously, the recommended approach for obtaining such data is usually ABS to obtain air concentrations of asbestos.

Collecting multiple ABS samples to capture the variability in airborne asbestos concentrations as a function of time, location, and disturbance activity can be important because estimates of exposure and risk from asbestos should be based on the average exposure concentrations that are experienced during each exposure scenario of concern, rather than on the values of individual samples (which may be either higher or lower than the average). The number and type of different ABS samples, air sampling approach, and analytical method needed to adequately characterize exposure for a specified scenario will vary from site to site and from scenario to scenario. As noted above, it is for this reason that the more detailed data collection efforts should be based on a QAPP/SAP developed in accord with standard U.S. EPA procedures. See Sections 4 and 5 for additional information on sampling and analytical considerations. Because ABS sampling will be a new venture for many OSCs and RPMs, assistance can be sought from experienced U.S. EPA-ERT personnel and members of the TRW Asbestos Committee, if needed. All ABS data collected should be evaluated in the context of the full site-specific information available for a given site.

Risk Management Decision Point #2

The analytical results obtained from the air samples following site-specific ABS may be used in the risk calculation for a baseline risk assessment considering both current and future risk. The baseline risk assessment and other criteria can then be used to make a risk management decision on appropriate response actions at the site. Three basic outcomes are typically possible:

1. Estimates of exposure and risk are below the site-specific risk management criteria and the level of uncertainty in the exposure and risk estimates is acceptable to the risk manager. In this case, a no further action alternative is normally appropriate (see Section 7.6.2.1).
2. Estimates of exposure and risk are above the site-specific risk management criteria, and the level of uncertainty in the exposure and risk estimates is acceptable to the risk manager. In this case, response actions or ICs may be implemented.
3. In some circumstances, estimates of exposure and risk at individual sites have too much uncertainty to be the sole basis for making reliable risk management decisions. For example, under the NCP, response to a release of hazardous substances also includes response to the threat of a release, and, in cases where a threat is posed but an actual release has not yet occurred, exposure or risk estimation can be more challenging. In these and similar situations, the risk manager should assess whether additional site assessment or investigation will likely be sufficient to reduce uncertainty to acceptable

levels, or whether the collection of this data will provide minimal value and merely prolong a risk management decision. In all cases, however, justification of a response action must meet the criteria specified in the NCP.

7.6.1 Background Considerations

In some cases, it may also be important to consider "background" levels of asbestos for site assessment and risk management, since "background" concentrations may, in some cases, contribute significantly to the total concentration of asbestos measured in site media (soil, air, dust).

The definition of "background" concentrations may differ from case to case, but U.S. EPA generally defines it as contaminant concentrations at locations that are not influenced by the releases from a site and is usually described as naturally occurring or anthropogenic (U.S. EPA,1989a; U.S. EPA 1995). The level of "background" asbestos in outdoor air has been investigated in numerous studies (see ATSDR, 2001 for a summary; U.S. EPA, 2002b).

In general, except for areas of NOA, levels tend to be highest in urban environments, and lower in rural or "pristine" environments. For indoor air, ATSDR (2001) reports that "measured indoor air values range widely, depending on the amount, type, and condition (friability) of ACM used in the building." In its review, ATSDR notes that the available data suffer from lack of common measurement reporting units. When characterization of "background" levels of asbestos in outdoor or indoor air are needed to support risk management decisions, the data should be collected using the same sampling methods and analytical procedures as are used for on-site data, except that this type of sample is generally collected using stationary air monitors with high flow rates and a long sampling period in order to achieve high sample volumes (and hence low analytical sensitivity). In addition, as is true for all efforts to characterize background, it is important to collect multiple samples that are representative over time and space, and which are sufficient in number to provide a proper basis for statistical comparison of site data with background data. See U.S. EPA, 2018b for a list of frequently asked questions about the development and use of background concentrations at CERCLA sites.

7.6.2 Response Actions

Response actions may be implemented under either removal or remedial authority and may include a wide variety of different activities to reduce the potential for exposure (*e.g.*, remove, cap, fence, etc.). CERCLA removal and remedial actions undertaken pursuant to the CERCLA and NCP are based on a number of factors (see U.S. EPA, 2000b) and criteria (see U.S. EPA, 1988c).

If asbestos present at a site will not be addressed using CERCLA authority (www.epa.gov/superfund), an effort should be made to identify other programs or regulations that may have the authority and capability of addressing risks. Table 8 below includes a list of Federal agencies that regulate asbestos. These standards should be reviewed to determine relevance to the response under consideration. Additionally, State and local authorities may have rules and provisions that may apply, and that should be considered when developing a response.

Table 8. Cross-Reference of Asbestos Regulations

Agency	CFR Citation	Comment
U.S. EPA	40 CFR part 61, subpart M [NESHAP, 1984]	Work practice standards applicable to demolition and renovation of buildings; milling, fabrication, and manufacturing of asbestos-containing products; transportation of asbestos-containing waste materials; active and inactive waste disposal; air-cleaning, reporting; operations that convert asbestos-containing waste material into non-asbestos (asbestos-free) material; and delegation of authority to the States.
	40 CFR part 763, subpart E (U.S. EPA, 2000d)	Requires schools to inspect for asbestos and implement response actions and submit asbestos management plans to States. Specifies use of accredited inspectors, air sampling methods, and waste disposal procedures.
	40 CFR part 427 (U.S EPA, 1974)	Effluent standards for asbestos manufacturing source categories.
	40 CFR part 763, subpart G (U.S. EPA, 2000d)	Protects public employees performing asbestos abatement work in States not covered by OSHA asbestos standard.
OSHA	29 CFR 1910.1001 (OSHA, 1974)	Worker protection measures—engineering controls, worker training, labeling, respiratory protection, bagging of waste, permissible exposure limit (PEL).
	29 CFR 1926.1101 (OSHA, 1979)	Worker protection measures for all construction work involving asbestos, including demolition and renovation-work practices, worker training, bagging of waste, permissible exposure limit.
MSHA	30 CFR part 56, subpart D (MSHA, 1985)	Specifies exposure limits, engineering controls, and respiratory protection measures for workers in surface mines.
	30 CFR part 57, subpart D (MSHA, 2001)	Specifies exposure limits, engineering controls, and respiratory protection measures for workers in underground mines.
DOT	49 CFR parts 171 and 172 (DOT, 2007)	Regulates the transportation of asbestos-containing waste material. Requires waste containment and shipping papers.

Additional guidance is available for developing a risk management-based response strategy that is protective of human health and the environment (U.S. EPA, 1988b).

This recommended framework leaves discretion to the site manager and technical experts to evaluate whether a particular response action is appropriate for the site and to determine the proper method of implementation (U.S. EPA, 2006b). In some cases, a variety of ICs may also be used to help limit current or future exposure and risk (for more information, see

www.epa.gov/superfund/superfund-institutional-controls). Post-response site control actions and operation and maintenance activities should ensure the effectiveness and integrity of the remedy after its completion.

Engineering or institutional controls are particularly important when asbestos is left at depth following a response action. Finally, the response should include consideration of the current and reasonably anticipated future land use. For more information, please refer to the following:

- U.S. EPA, 1995 – "Land Use in the CERCLA Remedy Selection Process" (OSWER Directive 9355.7-04)
- U.S. EPA, 1990b – "Policy on Management of Post-Removal Site Control" (OSWER Directive 9360.2-02)
- U.S. EPA, 1987 – "Guidance on Implementation of the 'Contribute to Remedial Performance' Provision" (OSWER Directive 9360.0-13)
- U.S. EPA, 1993c – "Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA" (OSWER Directive 9360.0-32)

As is true of all site investigations, risk managers balance many different considerations in deciding how to proceed at a site.

7.6.2.1 No Further Evaluation (NFE)

No Sources or Low-Level Sources are Present – No Further Evaluation or Actions are Warranted

Following the framework provides multiple decision points where the data may indicate that no asbestos is present or that low-level sources of asbestos are present (at the surface or subsurface if migration to the surface is reasonably expected), but at concentrations below health-based criterion. For these sites, no further evaluation with no actions being undertaken are the appropriate outcomes.

7.6.2.2 Risk/hazard acceptable level

Low-Level Sources are Present – Actions May or May Not be Warranted

In cases where available data are not sufficient to clearly determine if a source is or is not of significant health concern, the risk manager may consider whether the cost of further investigation to characterize the magnitude of the exposure and risk is likely to approach or exceed the cost of performing a response action. If at any point in the use of the recommended framework the cost of investigation is anticipated to be greater than the cost of an appropriate response action, it may be reasonable to proceed directly to a decision concerning a response action without further site characterization (assuming that the site poses an unacceptable risk to human health as defined by the NCP). However, if it is determined that site investigation may be helpful in narrowing the scope (and hence potentially reducing the cost) of a response action, then further investigation to define the location and extent of sources requiring response action normally should be pursued. Sites that fall into this category have two outcomes: (1) proceed

with response action without further investigation or (2) proceed with additional investigation to determine if a response action is warranted.

7.6.2.3 Risk or Hazard Exceeds Acceptable Levels

As discussed previously (Section 4), the sampling approach should be designed to collect information to support the decision. In some cases, grab samples may be appropriate to inform nature and extent; however, the TRW Asbestos Committee generally recommends using ISM to characterize exposure and support risk-based decisions.

High-Level Sources are Present – Actions Warranted
In some cases, available information may be sufficient to conclude that sources present are very likely to be of concern, even though detailed exposure and risk estimates are not yet available. For example, if data indicate elevated levels of asbestos are present in soil (e.g., visible ACM in soil) or indoor dust (*e.g.*, >100,000 s/cm^2), a risk manager may determine that a response action should be undertaken, and that further efforts to characterize the source or potential airborne exposures before action is taken are not needed.

Remedy Implementation and Confirmation or Clearance Sampling
The framework provides a step-by-step approach to evaluate whether a response action is needed for a site (see Figure 1). Response actions for outdoor contamination consist of excavation/removal, capping or a combination of the two actions while response actions for indoor contamination consist of source removal/encapsulation and cleaning. Given that air concentrations are the preferred metric for evaluating asbestos exposure, post-response action sampling is typically necessary to ensure that the response action was successful, although under certain circumstances, post-response action sampling may not be needed. Consultation with the TRW Asbestos Committee and the regional risk assessor is recommended to develop a post-response action sampling plan.

Technical Assistance
The TRW Asbestos Committee is available for consultation should there be additional questions or site-specific conditions that are not covered in this document.

8.0 Limitations

Although this guidance provides information concerning assessing asbestos exposure at CERCLA sites, some asbestos sources and routes of exposure may not be addressed under the authority of CERCLA. Site assessors should consult their management and legal counsel when evaluating whether to use the authority of CERCLA at a particular site. Ultimately, the site assessors should strive to address any unacceptable current or potential future asbestos exposure risks (see Appendix C, Land Use Considerations).

9.0 References

Addison J and McConnell EE. 2008. A review of carcinogenicity studies of asbestos and non-asbestos tremolite and other amphiboles. Regul Toxicol Pharmacol. 52:S187-199. https://doi.org/10.1016/j.yrtph.2007.10.001

AHERA. 1986. Asbestos Hazardous Emergency Response Act. Title 20, Chapter 52, Sec. 4011. Public Law 99-519. http://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title20-section4011&num=0&edition=prelim.

Amandus H and Wheeler R. 1987. The morbidity and mortality of vermiculite miners and millers exposed to tremolite-actinolite: Part II. Mortality. Am J Ind Med 11:15-26. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajim.4700110103

Amandus H, Althouse R, Morgan WKC, et al. 1987. The morbidity and mortality of vermiculite miners and millers exposed to tremolite-actinolite: Part III. Radiographic findings. Am J Ind Med 11:27-37. https://pubmed.ncbi.nlm.nih.gov/3028137/

ASHARA. 1990. Asbestos School Hazard Abatement Reauthorization Act (ASHARA) of 1990. https://19january2017snapshot.epa.gov/sites/production/files/documents/ashara.pdf

ASTM. 2011. Standard practice for reducing samples of aggregate to testing size. ASTM Method C702/C702M – 11. American Society for Testing and Materials. West Conshohocken, PA: ASTM International. www.astm.org/Standards/C702.htm.

ASTM. 2014. Standard test method for microvacuum sampling and indirect analysis of dust by transmission electron microscopy for asbestos structure number surface loading. ASTM Method D5755-09(2014)e1. American Society for Testing and Materials. West Conshohocken, PA: ASTM International. https://www.astm.org/Standards/D5755.htm.

ASTM. 2016. Standard test method for determination of asbestos in soil. ASTM Method 7521-16. American Society for Testing and Materials. American Society for Testing and Materials. West Conshohocken, PA: ASTM International. https://www.astm.org/Standards/D7521.htm.

ASTM. 2019. Standard test method for wipe sampling of surfaces, indirect preparation, and analysis for asbestos structure number concentration by transmission electron microscopy. ASTM Method D6480-19. American Society for Testing and Materials. West Conshohocken, PA: ASTM International. https://www.astm.org/Standards/D6480.htm.

ATS. 2004. Diagnosis and initial management of nonmalignant diseases related to asbestos. Official statement of the American Thoracic Society. Am J Resp Crit Care Med 170:691-715. https://doi.org/10.1164/rccm.200310-1436ST.

ATSDR. 2001. Toxicological profile for asbestos. Atlanta, GA: Agency for Toxic Substances and Disease Registry. https://www.atsdr.cdc.gov/toxprofiles/TP.asp?id=30&tid=4.

Bandli B and Gunter ME. 2012. Electron backscatter diffraction from unpolished particulate specimens: Examples of particle identification and application to inhalable mineral particulate identification. Am Mineral 97:1269-1273. https://pubs.geoscienceworld.org/msa/ammin/article-abstract/97/8-9/1269/45622/Electron-backscatter-diffraction-from-unpolished?redirectedFrom=fulltext

Bandli B and Gunter ME. 2013. Mineral identification using electron backscatter diffraction from unpolished specimens: Applications for rapid asbestos identification. The Microscope 61(1):37-45. https://www.researchgate.net/publication/265592982_Mineral_Identification_Using_Electron_Backscatter_Diffraction_from_Unpolished_Specimens_Applications_for_Rapid_Asbestos_Identification

Benson R, Berry D, Lockey J, et al. 2015. Exposure-response modeling of non-cancer effects in humans exposed to Libby Amphibole Asbestos; update. Regul Toxicol Pharmacol.;73(3):780-9. https://pubmed.ncbi.nlm.nih.gov/26524929/

Berry D, Januch J, Woodbury L, Kent D. 2019. Detection of Erionite and Other Zeolite Fibers in Soil by the Fluidized Bed Preparation Methodology. The Microscope; Vol. 64:4, pp 147-158. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7376948/

Bishop K, Ring S, Suchanek R, et al. 1978. Preparation losses and size alterations for fibrous mineral samples. Scan Electron Microsc I:207.

Black B, Dodson RF, Bruce JR, et al. 2017. A clinical assessment and lung tissue burden from an individual who worked as a Libby vermiculite miner. Inhal Toxicol.; 29(9):404-413. https://pubmed.ncbi.nlm.nih.gov/29039215/

Breysse P and Steele E. 1991. Electron microscopic analysis of airborne asbestos fibers. Crit Rev Anal Chem. 22(3-4):201-207. https://doi.org/10.1080/10408349108055029.

CAA. 1970. Title I, Part A, Air Quality and Emission Limitations § 101-131

CalEPA. 1991. Determination of asbestos content of serpentine aggregate: Method 435. Sacramento, CA: California Environmental Protection Agency. https://www.arb.ca.gov/toxics/asbestos/tm435/tm435.htm.

CalEPA. 2017. Implementation guidance document: Air Resources Board test method 435, Determination of asbestos content of serpentine aggregate. Field sampling and laboratory practices. Sacramento, CA: California Environmental Protection Agency. https://www.arb.ca.gov/toxics/asbestos/tm435/workshops/m435-asbestosguidance-2017.pdf.

Carbone M, Klein G, Gruber J, et al. 2004. Modern criteria to establish human cancer etiology. Cancer Res 64(15):5518-24. https://doi.org/10.1158/0008-5472.CAN-04-0255.

Chesson J and Hatfield J. 1990. Comparison of airborne asbestos levels determined by transmission electron microscopy (TEM) using direct- and indirect-transfer techniques. United States Environmental Protection Agency Report 560/5-89-004. Office of Toxic Substances, U.S. Environmental Protection Agency, Washington, DC. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=20012KL7.PDF

Chesson J, Hatfield J, Schultz B, et al. 1990. Airborne asbestos in public buildings. Environ Res 51(1):100-7. https://pubmed.ncbi.nlm.nih.gov/2298180/

CERCLA. 1980. Comprehensive Environmental Response, Compensation, and Liability Act. 42 USC §9601 (1980). https://www.epa.gov/laws-regulations/summary-comprehensive-environmental-response-compensation-and-liability-act.

Comba P, Gianfagna A, Paoletti, L. 2003. Pleural mesothelioma cases in Biancavilla are related to a new fluoro-edenite fibrous amphibole. Arch Environ Health. 58(4):229-32. https://www.ncbi.nlm.nih.gov/pubmed/14655903

Deer, W.A., Howie, R.A., and Zussman, J. 1992. An Introduction to The Rock-Forming Minerals. Harlow, England; Pearson Education Limited.

Deer WA, Howie RA, Zussman J. 1997. Rock-forming minerals, Volume 2B [Second Edition] Double-chain silicates, The Geological Society of Great Brittan.

Dement and Wallingford. 1990. Comparison of phase contrast and electron microscopic methods for evaluation of occupational asbestos exposures. App Occup Environ Hyg; 5: 242–7. https://www.tandfonline.com/doi/abs/10.1080/1047322X.1990.10389630

Dodson, RF. 2003. Asbestos Fiber Length as Related to Potential Pathogenicity: A Critical Review. American Journal of Industrial Medicine 44:291–297. https://pubmed.ncbi.nlm.nih.gov/12929149/

Dodson RF, Hammar SP, and Poye LW. 2008. A Technical Comparison of Evaluating Asbestos Concentration by Phase-Contract Microscopy (PCM), Scanning Electron Microscopy (SEM), and Analytical Transmission Electron Microscopy (ATEM) as Illustrated from Data Generated from a Case Report. Inhalation Toxicology, 20:723-732. https://www.tandfonline.com/doi/abs/10.1080/08958370701883250

Dodson RF, Mark EJ, Poye LW. 2013. Biodurability/retention of Libby amphiboles in a case of mesothelioma. Ultrastruct Pathol. 38(1):45-51. https://doi.org/10.3109/01913123.2013.821194.

Doll R and Peto J. 1985. Effects on health of exposure to asbestos. London, England: Her Majesty's Stationary Office. http://www.hse.gov.uk/asbestos/assets/docs/exposure.pdf.

DOT. 2007. Hazardous materials regulations. U.S. Department of Transportation. 49 CFR Parts 171-177. https://www.govinfo.gov/content/pkg/CFR-2011-title49-vol2/pdf/CFR-2011-title49-vol2.pdf

Emri S, Demir A, Dogan M, et al. 2002. Lung diseases due to environmental exposures to erionite and asbestos in Turkey. Toxicol Lett. 127(1-3):251-7. https://doi.org/10.1016/S0378-4274(01)00507-0.

Farcas D, Harper M., Januch JW, et al. 2017. Evaluation of fluidized bed asbestos segregator to determine erionite in soil. Environ Earth Sci 76:126. https://doi.org/10.1007/s12665-017-6438-7.

Getman MRC and Webber JS. 2008. Heated Asbestos: Analytical Challenges Posed by Heating Crocidolite and Other Fibrous Amphiboles. Microscope. Vol 56:1 p.29-36. https://www.mccroneinstitute.org/uploads/Getman-Webber_56-1_p29-36_2008-1479249468.pdf

Gianfagna, A and Oberti R. 2001. Fluoro-edenite from Biancavilla (Catania, Sicily, Italy): Crystal chemistry of a new amphibole end-member. American Mineralogist. 86 (11-12): 1489-1493. https://pubs.geoscienceworld.org/msa/ammin/article-abstract/86/11-12/1489/133858/Fluoro-edenite-from-Biancavilla-Catania-Sicily?redirectedFrom=fulltext

Giuseppe DD, Zoboli A, Vigliaturo R, et al. 2019. Mineral Fibres and Asbestos Bodies in Human Lung Tissue: A Case Study. Minerals 2019, 9(10), 618; https://doi.org/10.3390/min9100618

Goldade MP and O'Brien WP. 2014. Use of direct versus indirect preparation data for assessing risk associated with airborne exposures at asbestos-contaminated sites. J Occup Environ Hyg 11(2):67-76. https://doi.org/10.1080/15459624.2013.843779.

Hawthorne FW, Oberti R, Harlow GE, et al. 2012. Nomenclature of amphibole supergroup. Amer Mineral 97(11-12):2031-20148. https://doi.org/10.2138/am.2012.4276.

HEI. 1991. Asbestos in public and commercial buildings: Special report. Boston, MA: Health Effects Institute. https://www.healtheffects.org/publication/asbestos-public-and-commercial-buildings.

Hein MJ, Stayner LT, Lehman E, Dement JM. 2007. Follow-up study of chrysotile textile workers: cohort mortality and exposure-response. Occup Environ Med; 64: 616-625. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2092560/

Hernandez DW. 2019. Does Exposure to Naturally Occurring Asbestos (noa) During Dam Construction Increase Mesothelioma Risk? Environmental and Engineering Geoscience. October. https://doi.org/10.2113/EEG-2291

Hodgson JT and Darnton A. 2000. The quantitative risks of mesothelioma and lung cancer in relation to asbestos exposure. Ann Occup Hyg 44(8):565-601. https://doi.org/10.1093/annhyg/44.8.565.

Hwang CY and Wang ZM. 1983. Comparison of methods of assessing asbestos fiber concentrations. Arch Environ Health 38(1):5-10. https://doi.org/10.1080/00039896.1983.10543972.

IARC. 2012. Monographs on the identification of carcinogenic hazards to humans. Chemical agents and related occupations: A review of human carcinogens. Volume 100 F. Lyon, France: International Agency for Research on Cancer. https://monographs.iarc.fr/wp-content/uploads/2018/06/mono100F.pdf.

IDQTF. 2005. Uniform federal policy for Quality Assurance Project Plans: Evaluating, Assessing, and Documenting Environmental Data Collected and Use Programs. Part 1: UFP-QAPP Manual. Intergovernmental Data Quality Task Force. March. https://www.epa.gov/sites/production/files/documents/ufp_qapp_v1_0305.pdf

IDQTF. 2012. Uniform federal policy for Quality Assurance Project Plans: Optimized UFP-QAPP worksheets. Intergovernmental Data Quality Task Force. https://www.epa.gov/sites/production/files/documents/ufp_qapp_worksheets.pdf..

ISO. 2019a. Ambient air - Determination of asbestos fibres - Direct transfer transmission electron microscopy method. Geneva, Switzerland: International Organization for Standardization. ISO 10312:2019(E). https://www.iso.org/standard/75577.html

ISO. 2019b. Ambient air - Determination of asbestos fibres - Indirect-transfer transmission electron microscopy method. Geneva, Switzerland: International Organization for Standardization. ISO 13794:2019(E). https://www.iso.org/standard/75576.html

ISO. 2019c. Ambient air - Determination of numerical concentration of inorganic fibrous particles - Scanning electron microscopy method. Geneva, Switzerland: International Organization for Standardization. ISO 14966:2019-12(E). https://www.iso.org/standard/75583.html

ITRC. 2012. Incremental Sampling Methodology (ISM) website. Interstate Technology and Regulatory Council. https://www.itrcweb.org/Guidance/ListDocuments?topicID=11&subTopicID=16

Januch J, Brattin W, Woodbury L, et al. 2013. Evaluation of a fluidized bed asbestos segregator preparation method for the analysis of low-levels of asbestos in soil and other solid media. Anal Methods 5(7):1658-1668. http://doi.org/10.1039/C3AY26254E.

Jeyaratman, M. and West, N.G. 1994. A study of heat-degraded chrysotile, amosite and crocidolite by X-ray diffraction. Ann Occup Hyg; 38(2):137-148. https://doi.org/10.1093/annhyg/38.2.137.

Kauffer E, Billon-Galland MA, Vigneron JC, Veissiere S, and Brochard P. 1996. Effect of preparation methods on the assessment of airborne concentrations of asbestos fibres by transmission electron microscopy. Ann Occup Hyg; 40(3):321-330. https://doi.org/10.1016/0003-4878(95)00079-8

Lang JH, Kuhn BD, Thomulka KW, et al. 2000. A study of area and personal airborne asbestos samples during abatement in a crawl space. Indoor Built Environ. 9(3-4):192-200. https://doi.org/10.1159/000057507.

Larson T, Meyer C, Kapil V, et al. 2010a. Workers with Libby amphibole exposure: Retrospective identification and progression of radiographic changes. Radiology 255(3):924-933. http://doi.org/10.1148/radiol.10091447.

Larson TC, Antao VC, Bove FJ. 2010b. Vermiculite worker mortality: Estimated effects of occupational exposure to Libby amphibole. J Occup Environ Med 52(5):555-560. https://doi.org/10.1097/JOM.0b013e3181dc6d45.

Leake BE, Wooley AR, Arps C, et al. 1997. Nomenclature of amphiboles; Report of the subcommittee on amphiboles of the International Mineralogical Association, Commission on New Minerals and Mineral Names. Can Mineral 35(1):219-246. https://doi.org/10.1180/minmag.1997.061.405.13

Lockey JE, Brooks SM, Jarabek AM, et al. 1984. Pulmonary changes after exposure to vermiculite contaminated with fibrous tremolite. Am Rev Respir Dis.;129(6):952-8. https://www.atsjournals.org/doi/abs/10.1164/arrd.1984.129.6.952?journalCode=arrd

Lynch JR, Ayer HE, Johnson DL. 1970. The interrelationships of selected asbestos exposure indices. Am Ind Hyg Assoc J; 31: 598–604. https://doi.org/10.1080/0002889708506298

Marconi A, Menichini E, Paoletti L. 1984. A comparison of light microscopy and transmission electron microscopy results in the evaluation of the occupational exposure to airborne chrysotile fibres. Ann Occup Hyg; 28: 321–31. https://doi.org/10.1093/annhyg/28.3.321

McCrone WC. 1987. Asbestos Identification. McCrone Research Institute, Inc., Chicago, IL. ISBN 0-904962-11-3

McDonald JC, McDonald AD, Armstrong B, et al. 1986. Cohort study of mortality of vermiculite miners exposed to tremolite. Br J Ind Med 43(7):436-444. https://doi.org/10.1136/oem.43.7.436.

Meeker CP, Bern AM, Brownfield IK, et al. 2003. The composition and morphology of amphiboles from the Rainy Creek Complex, near Libby, Montana. Am Mineral 88(11-12):1955–1969. http://doi.org/10.2138/am-2003-11-1239.

Mellini M. 2013. Structure and microstructure of serpentine minerals. EMU Notes in Mineralogy, Vol. 14, Chapter 5, 1–27. https://pubs.geoscienceworld.org/books/book/942/chapter/106815638/Structure-and-microstructure-of-serpentine

Millette JR and Hays SM. 1994. Resuspension of settled dust. In: Settled asbestos dust sampling and analysis. Boca Raton, FL: Lewis Publishers, #-#. https://trove.nla.gov.au/work/11699981?q&versionId=13771068.

MSHA. 1985. Safety and health standards - Surface metal and nonmetal mines: Air quality and physical agents. U.S. Mine Safety and Health Administration. 30 CFR Subpart 56. https://arlweb.msha.gov/regs/30cfr/.

MSHA. 2001. Safety and health standards - Underground metals and nonmetal mines: Air quality, radiation, physical agents, and diesel particulate matter. U.S. Mine Safety and Health Administration. 30 CFR part 57, Subpart D. https://arlweb.msha.gov/regs/30cfr/.

NCP. 1994. National oil and hazardous substances pollution contingency plan: Worker health and safety. 59 FR 47424. To be codified at 40 CFR part 300, subpart B (150). September 15, 1994. https://www.govinfo.gov/content/pkg/CFR-2011-title40-vol28/pdf/CFR-2011-title40-vol28-part300.pdf.

NESHAP. 1984. National Emission Standard for Asbestos. 49 Fed. Reg. 13661. To be codified at 40 CFR part 61, subpart M. April 5, 1984. https://www.govinfo.gov/content/pkg/CFR-2015-title40-vol9/pdf/CFR-2015-title40-vol9-part61-subpartM.pdf. Ammended 1990 and 2004.

NIOSH. 1994a. Manual of Analytic Methods: Method 7400, Issue 2. Asbestos and other fibers by PCM. Cincinnati, OH: National Institute of Occupational Safety and Health. https://www.cdc.gov/niosh/docs/2003-154/pdfs/7400.pdf.

NIOSH. 1994b. Manual of Analytic Methods: Method 7402, Issue 2. Asbestos by TEM. Cincinnati, OH: National Institute of Occupational Safety and. https://www.cdc.gov/niosh/docs/2003-154/pdfs/7402.pdf.

NIOSH. 2019. Manual of Analytic Methods: Method 7400, Issue 3. Asbestos and other fibers by PCM. Cincinnati, OH: National Institute of Occupational Safety and Health. https://www.cdc.gov/niosh/nmam/pdf/7400-method-final.pdf.

NRC. 2004. Air quality management in the United States. Washington, DC: National Research Council. The National Academy Press. https://doi.org/10.17226/10728.

OSHA. 1974. Occupational Safety and Health Standard. 39 FR 23502. To be codified at 29 CFR part 1910. Occupational Safety and Health Administration. June. https://www.osha.gov/laws-regs/federalregister/standardnumber/1910

OSHA. 1979. Safety and Health Regulations for Construction. 44 FR 8577. To be codified at 29 CFR part 1926. Occupational Safety and Health Administration. February 9, 1979. https://www.osha.gov/laws-regs/regulations/standardnumber/1926

Pairon JC, Andujar P, RinaldonM, et al. 2014. Asbestos Exposure, Pleural Plaques, and the Risk of Death from Lung Cancer. AJRCCM Vol. 190, No. 12. https://doi.org/10.1164/rccm.201406-1074OC

Peipins LA, Lewin M, Campolucci S, et al. 2003. Radiographic abnormalities and exposure to asbestos-contaminated vermiculite in the community of Libby, Montana, USA. Environ Health Perspect 111(14):1753-1759. https://doi.org/10.1289/ehp.6346.

Roccaro P, and Vagliasindi FGA. 2009. Occurrence of Fluoro-Edenite Fibres in Natural Matrices at the Biancavilla (Catania, Italy) Site of National Interest: Role and Relevance of Contaminated Drinking Water Sources. The International Conference BOSICON, Rome, Italy. https://doi.org/10.2138/am-2001-11-1217

Rouxhet PG, Gillard JL, and Fripiat JJ. 1972. Thermal decomposition of amosite, crocidolite, and biotite. Mineralogical Magazine, Vol. 38. pp. 583-92. https://doi.org/10.1180/minmag.1972.038.297.07

Rohs AM, Lockey JE, Dunning KK, et al. 2008. Low-level fiber-induced radiographic changes caused by Libby vermiculite: A 25-year follow-up study. Am J of Respir Crit Care Med 177(6):630-637. http://doi.org/10.1164/rccm.200706-841OC.

Sahle W and Laszlo I. 1996. Airborne inorganic fibre monitoring by transmission electron microscope (TEM): Comparison of direct and indirect sample transfer methods. Ann Occup Hyg 40(1):29-44. https://doi.org/10.1016/0003-4878(95)00064-X.

Saint-Eidukat B and Triplett J. 2014. Erionite and offretite from the Killdeer Mountains, Dunn County, North Dakota, U.S.A. Am Mineral 99(1):8-15. https://doi.org/10.2138/am.2014.4567.

Sakai K, Hisanaga N, Shibata E, et al. 2006. Asbestos exposures during reprocessing of automobile brakes and clutches. Int J Occup Health 12(2):95-105. https://doi.org/10.1179/oeh.2006.12.2.95.

SDWA. 1974. 42 U.S.C. § 300f Section 22

SERAS. 2017. Standard Operating Procedures: Activity-based air sampling for asbestos. Scientific Engineering Response and Analytical Services. SOP: 2084, Revision 1.1. September.

Sullivan PA. 2007. Vermiculite, respiratory disease and asbestos exposure in Libby, Montana: Update of a cohort mortality study. Environ Health Perspect 115(4):579-585. https://doi.org/10.1289/ehp.9481.

Suzuki Y, Yuen SR, Ashley R. 2005. Short, thin asbestos fibers contribute to the development of human malignant mesothelioma: pathological evidence. Int J Hyg Environ Health. 208(3):201-10. https://doi.org/10.1016/j.ijheh.2005.01.015

TSCA. 1976. Toxic Substances Control Act. 15 U.S.C. § 2601 – 2692 (1976). https://www.epa.gov/laws-regulations/summary-toxic-substances-control-act.

Turci F, Favero-Longo SE, Gazzano C, et al. 2016. Assessment of asbestos exposure during a simulated agricultural activity in the proximity of the former asbestos mine of Balangero, Italy. J Hazard Mater 308:321-327. https://doi.org/10.1016/j.jhazmat.2016.01.056.

U.S. EPA. 1974. Asbestos manufacturing point source category. U.S. Environmental Protection Agency. 40 CFR 427. https://www.govinfo.gov/app/details/CFR-2010-title40-vol29/CFR-2010-title40-vol29-part427.

U.S. EPA. 1986. Airborne asbestos health assessment update. Washington, DC: U.S. Environmental Protection Agency. EPA 600884003F. https://nepis.epa.gov/EPA/html/DLwait.htm?url=/Exe/ZyPDF.cgi/20009EBT.PDF?Dockey=20009EBT.PDF.

U.S. EPA. 1987. Guidance on implementation of the "Contribute to Remedial Performance" provision. Washington, DC: U.S. Environmental Protection Agency. OSWER Directive 9360.0-13. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9100UHLG.TXT.

U.S. EPA. 1988a. Integrated Risk information System (IRIS) chemical assessment summary: Asbestos; CASRN 1332-21-4. Washington, DC: U.S. Environmental Protection Agency. https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0371_summary.pdf.

U.S. EPA. 1988b. CERCLA compliance with other laws manual: Interim final. Washington, DC: U.S. Environmental Protection Agency. EPA 540G89006. https://nepis.epa.gov/Exe/ZyPDF.cgi/10001VMG.PDF?Dockey=10001VMG.PDF.

U.S. EPA. 1988c. Guidance for conducting remedial investigations and feasibility studies under CERCLA. Washington, DC: U.S. Environmental Protection Agency. OSWER Directive 9355.3-01. EPA540G89004. https://rais.ornl.gov/documents/GUIDANCE.PDF.

U.S. EPA. 1989a. Risk Assessment Guidance for Superfund. Volume I. Human health evaluation manual (Part A). Washington, DC. U.S. Environmental Protection Agency. EPA540189002. https://www.epa.gov/sites/production/files/2015-09/documents/rags_a.pdf.

U.S. EPA. 1989b. Designation of hazardous substances. U.S. Environmental Protection Agency. 40 CFR 302.4. https://www.govinfo.gov/content/pkg/CFR-2004-title40-vol26/pdf/CFR-2004-title40-vol26-sec302-4.pdf.

U.S. EPA. 1990a. National oil and hazardous substances pollution contingency plan - Subpart E - Hazardous substance response. U.S. Environmental Protection Agency. 40 CFR subchapter J. https://www.govinfo.gov/content/pkg/CFR-2011-title40-vol28/pdf/CFR-2011-title40-vol28-part300.pdf.

U.S. EPA. 1990b. Policy on management of post-removal site control. Washington, DC: U.S. Environmental Protection Agency. OSWER Directive 9360.2-02. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9100UHNE.TXT.

U.S. EPA. 1992. Supplemental guidance to RAGS: Calculating the concentration term. Washington, DC: U.S. Environmental Protection Agency. OSWER Directive 9285.7-08I. PB92963373. https://rais.ornl.gov/documents/UCLsEPASupGuidance.pdf.

U.S. EPA. 1993a. Test Method: Method for the determination of asbestos in bulk building materials. Washington, DC: U.S. Environmental Protection Agency. EPA 600R93116. https://www.nist.gov/system/files/documents/nvlap/EPA-600-R-93-116.pdf.

U.S. EPA. 1993b. Response actions at sites with contamination inside buildings. Washington, DC: U.S. Environmental Protection Agency. OSWER Directive 9360.3-12. https://nepis.epa.gov/Exe/ZyPDF.cgi/910165Y9.PDF?Dockey=910165Y9.PDF.

U.S. EPA. 1993c. Guidance on conducting non-time-critical removal actions under CERCLA. Washington, DC: U.S. Environmental Protection Agency. OSWER Directive 9360.0-32. EPA540R93057. https://semspub.epa.gov/work/HQ/122068.pdf.

U.S. EPA. 1994. Methods for derivation of inhalation reference concentrations and application of inhalation dosimetry. Washington, DC: U.S. Environmental Protection Agency. EPA600890066F. http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=473051.

U.S. EPA. 1995. Land use in the CERCLA remedy selection process. Washington, DC: U.S. Environmental Protection Agency. OSWER Directive: 9355.7-04. https://www.epa.gov/sites/production/files/documents/landuse.pdf.

U.S. EPA. 1997. Rules of thumb for Superfund remedy selection. Washington, DC: U.S. Environmental Protection Agency. OSWER 9355.0-69. EPA 540R97013. https://nepis.epa.gov/Exe/ZyPDF.cgi/2000FHZZ.PDF?Dockey=2000FHZZ.PDF.

U.S. EPA. 1999. M/DBP Stakeholder Meeting Statistics Workshop Meeting Summary: November 19, 1998, Governor's House, Washington DC. Final. Report prepared for U.S. Environmental Protection Agency, Office of Ground Water and Drinking Water by RESOLVE, Washington, DC, and SAIC, McLean, VA, EPA Contract No. 68-C6-0059.

U.S. EPA. 2000a. Science policy council risk characterization handbook. Washington, DC: U.S. Environmental Protection Agency. EPA 100B00002. https://www.epa.gov/sites/production/files/2015-10/documents/osp_risk_characterization_handbook_2000.pdf.

U.S. EPA. 2000b. Use of non-time critical removal authority in Superfund response actions. Memorandum to Program and Legal Division Directors, Regions I-X. Washington, DC: U.S. Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPDF.cgi/9100L9F9.PDF?Dockey=9100L9F9.PDF.

U.S. EPA. 2000c. Data quality objectives process for hazardous waste site investigations. Washington, DC: U.S. Environmental Protection Agency. EPA QAG4HW. https://www.epa.gov/quality/data-quality-objectives-process-hazardous-waste-site-investigations-epa-qag-4hw-january-2000.

U.S. EPA. 2000d. Asbestos. U.S. Environmental Protection Agency. 40 CFR 763. https://www.epa.gov/sites/production/files/documents/2003pt763_0.pdf.

U.S. EPA. 2001c. EPA requirements for Quality Assurance Project Plans. Washington, DC: U.S. Environmental Protection Agency. EPA 240B01003. https://www.epa.gov/sites/production/files/2016-06/documents/r5-final_0.pdf.

U.S. EPA. 2002a. Guidance for Quality Assurance Project Plans. Washington, DC: U.S. Environmental Protection Agency. EPA 240R02009. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=20011HPE.TXT.

U.S. EPA. 2002b. Role of background in the CERCLA cleanup program. Washington, DC: U.S. Environmental Protection Agency. OSWER Directive 9285.6-07P. https://www.epa.gov/sites/production/files/2015-11/documents/bkgpol_jan01.pdf.

U.S. EPA. 2003a. Interim final WTC residential confirmation cleaning study. Volume 1: Section 3.4. Washington, DC: U.S. Environmental Protection Agency. https://archive.epa.gov/wtc/web/pdf/confirmation_cleaning_study.pdf.

U.S. EPA. 2003b. Libby asbestos site residential/commercial cleanup action level and clearance criteria technical memorandum. Denver, CO: U.S. Environmental Protection Agency. https://semspub.epa.gov/work/08/1266260.pdf.

U.S. EPA. 2003c. Final draft pilot study to estimate asbestos exposure from vermiculite attic insulation: Research conducted in 2001 and 2002. Washington, DC: U.S. Environmental Protection Agency. http://xoomer.virgilio.it/amianto_asbesto/insulationreport.pdf.

U.S. EPA. 2004. Memorandum: Clarifying cleanup goals and identification of new assessment tools for evaluating asbestos at Superfund cleanups. Washington, DC. U.S. Environmental Protection Agency. OSWER Directive 9345.4-05. https://nepis.epa.gov/Exe/ZyPDF.cgi/90180500.PDF?Dockey=90180500.PDF.

U.S. EPA. 2005b. Final report on the World Trade Center (WTC) dust screening method study. Washington, DC: U.S. Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPDF.cgi/9101QERW.PDF?Dockey=9101QERW.PDF.

U.S. EPA. 2006b. Guidance on systematic planning using data quality objectives process. Washington, DC: Office of Environmental Information. EPA240B06001. https://www.epa.gov/sites/production/files/documents/guidance_systematic_planning_dqo_process.pdf.

U.S. EPA. 2008. Framework for investigating asbestos-contaminated Superfund sites. Washington, DC. U.S. Environmental Protection Agency. OSWER Directive: 9200.0-68. https://semspub.epa.gov/work/HQ/175329.pdf.

U.S. EPA. 2009a. Risk Assessment Guidance for Superfund Volume I: Human health evaluation manual. Part F: Supplemental guidance for inhalation risk assessment. Washington, DC: U.S. Environmental Protection Agency. EPA 540R070002. https://www.epa.gov/risk/risk-assessment-guidance-superfund-rags-part-f.

U.S. EPA. 2009b. Human Health and Ecological Risk Assessment for the North Ridge Estates Site, Klamath Falls, Oregon. December 2009. https://www.deq.state.or.us/Webdocs/Controls/Output/PdfHandler.ashx?p=b89b648a-937d-488f-a517-e6476d2ce2f0pdf&s=RI-2335-RI-01-18-2010-Appendix-A-HHRA-and-ERA.pdf

U.S. EPA. 2009c. Superfund removal guidance for preparing action memoranda. Washington, DC: U.S. Environmental Protection Agency. https://www.epa.gov/emergency-response/superfund-removal-guidance-preparing-action-memoranda.

U.S. EPA. 2009c. Guidance for labeling externally validated analytical data for Superfund use. Washington, DC: U.S. Environmental Protection Agency. EPA 540R08005. http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1002WWF.txt.

U.S. EPA. 2011. Risk Evaluation for Activity-Based Sampling Results, Sumas Mountain Asbestos Site, Whatcom County, Washington, Revision 1.1 https://semspub.epa.gov/work/10/500011383.pdf

U.S. EPA. 2013. The roles of project managers and laboratories in maintaining the representativeness of incremental and composite soil samples. Washington, DC: U.S. Environmental Protection Agency. OSWER 9200.1-117FS. https://clu-in.org/download/char/RolesofPMsandLabsinSubsampling.pdf.

U.S. EPA. 2014a. Toxicological review of Libby amphibole asbestos. In support of summary information on the Integrated Risk Information System (IRIS). Washington, DC: U.S. Environmental Protection Agency. EPA635R11002F. https://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/1026tr.pdf.

U.S. EPA. 2014b. Memorandum. Human health evaluation manual, supplemental guidance: Update of standard default exposure factors. Washington, DC: U.S. Environmental Protection Agency. OSWER Directive 9200.1-20.

https://www.epa.gov/sites/production/files/2015-11/documents/oswer_directive_9200.1-120_exposurefactors_corrected2.pdf.

U.S. EPA. 2015a. Site-wide human health risk assessment. Libby asbestos Superfund site, Libby Montana. Denver, CO: U.S. Environmental Protection Agency Region 8. https://semspub.epa.gov/work/08/1562963.pdf.

U.S. EPA. 2015b. Standard Operating Guidelines: ERRB projects and compliance with the asbestos rules and regulations. SOG#: T104. Version 2.0. Region IV Emergency Response Program. January.

U.S. EPA. 2016a. Superfund community involvement handbook. Washington, DC: U.S. Environmental Protection Agency. https://semspub.epa.gov/work/HQ/100002505.pdf

U.S. EPA. 2016b. Policy and procedures on protection of human subjects in EPA conducted or supported research. Washington, DC: U.S. Environmental Protection Agency. https://www.epa.gov/sites/production/files/2016-06/documents/2016_policy_order_revision_6-10-16.pdf.

U.S. EPA. 2016c. TEM Validation Process Guidelines for Asbestos Data Review. OLEM Directive: 9200.2-180. OSRTI. October. https://semspub.epa.gov/work/HQ/196840.pdf

U.S. EPA. 2016d. PLM validation process guidelines for asbestos data review. Washington, DC: U.S. Environmental Protection Agency. OLEM Directive: 9200.2-179. https://semspub.epa.gov/work/HQ/196839.pdf.

U.S. EPA. 2018a. Other Test Method (OTM) – 42: Sampling, Sample Preparation and Operation of the Fluidized Bed Asbestos Segregator. Draft. July 31. https://www.epa.gov/sites/production/files/2018-08/documents/otm_42_sampling_sample_preparation_and_operation_of_fluidized_bed_asbestos_segregator.pdf

U.S. EPA. 2018b. Frequently asked questions about the development and use of background concentrations at Superfund sites: Part one, general concepts. Washington, DC: U.S. Environmental Protection Agency. OLEM Directive 9200.2-141 A. https://semspub.epa.gov/work/HQ/100001657.pdf.

U.S. EPA. 2018c. Data Summary Report: 2016 Background Soil Sampling Libby Asbestos Superfund Site Libby, Montana. May.

Vallero DA, Kominsky JR, Beard ME, et al. 2009. Efficiency of sampling and analysis of asbestos fibers on filter media: Implications for exposure assessment. J Occup Environ Hyg 6(1):62-72. https://doi.org/10.1080/15459620802577485.

Van Gosen BS, Blitz TA, Plumlee GS, et al. 2013. Geologic occurrences of erionite in the United States: An emerging national public health concern for respiratory disease. Environ Geochem Health. 35(4):419–430. https://doi.org/10.1007/s10653-012-9504-9.

Verma DK and Clark NE. 1995. Relationships between phase contrast microscopy and transmission electron microscopy results of samples from occupational exposure to airborne chrysotile asbestos. Am Ind Hyg Assoc J 56(9):866–73. https://doi.org/10.1080/15428119591016494.

Voulvoulis N and Georges K. 2015. Industrial and agricultural sources and pathways of aquatic pollution. In: McKeown A, Bugyi G, eds. 2016. Impact of water pollution on human health and environmental sustainability. Hershey, PA: IGI Global, 29. http://doi.org/10.4018/978-1-4666-9559-7.

WHO. 1986. Environmental health criteria 53: Asbestos and other natural mineral fibres. Geneva, Switzerland: World Health Organization. www.inchem.org/documents/ehc/ehc/ehc53.htm.

Wright RS, Abraham JL, Harber P, et al. 2002. Fatal Asbestosis 50 Years after Brief High Intensity Exposure in a Vermiculite Expansion Plant. AJRCCM Vol. 165, No. 8. https://doi.org/10.1164/ajrccm.165.8.2110034

Wroble J, Frederick T, Frame A, Vallero D. 2017. Comparison of soil sampling and analytical methods for asbestos at the Sumas Mountain Asbestos Site - Working towards a toolbox for better assessment. PLoS One. 12(7): e0180210. https://doi.org/10.1371/journal.pone.0180210

Wroble J, Frederick T, Vallero D. 2020. Refinement of Sampling and Analysis Techniques for Asbestos in Soil. Environmental and Engineering Geoscience. 26 (1): 129–131. https://doi.org/10.2113/EEG-2283

Appendix A – Glossary

ABS — **Activity-based sampling**

An empiric approach in which airborne concentrations of asbestos are measured during an event where the source material (soil or dust) is disturbed rather than predicted or modeled from source material concentration.

Actinolite — A calcic amphibole mineral in the tremolite-ferroactinolite solid solution series. Actinolite can occur in both asbestiform and non-asbestiform mineral habits. The asbestiform variety is often referred to as actinolite asbestos. A mineral in the calcic amphibole group. It is generally not used commercially, but it is a common impurity in chrysotile asbestos.

AHERA — **Asbestos Hazard Emergency Response Act of 1986**
In 1986, the Asbestos Hazard Emergency Response Act (AHERA) was signed into law as Title II of the Toxic Substance Control Act. Additionally, the Asbestos School Hazard Abatement Reauthorization Act (ASHARA), passed in 1990, requires accreditation of personnel working on asbestos activities in schools, and public and commercial buildings. See applicability discussion (Section 2).

Amosite — A magnesium-iron-manganese-lithium amphibole mineral in the cummingtonite-grunerite solid solution series that occurs in the asbestiform habit. The name amosite is a commercial term derived from the acronym for "Asbestos Mines of South Africa." Amosite is sometimes referred to as "brown asbestos."

Amphibole — A group of minerals composed of double-chain SiO_4 tetrahedra linked at the vertices and generally containing ions of iron and/or magnesium in their structures. Amphibole minerals are of either igneous or metamorphic origin. Amphiboles can occur in a variety of mineral habits including asbestiform and non-asbestiform. A group of double chain silicate minerals.

Analytical sensitivity — The sample-specific lowest concentration of asbestos the laboratory can detect for a given method. Represented by "S" in equations.

Anthophyllite A magnesium-iron-manganese-lithium amphibole mineral in the anthophyllite gedrite solid solution series that can occur in both the asbestiform and non-asbestiform mineral habits. The asbestiform variety is referred to as anthophyllite asbestos. A type of asbestos in the amphibole group; it is also known as azbolen asbestos.

Asbestiform Fibrous minerals possessing the properties of commercial grade asbestos (*e.g.,* flexibility, high tensile strength, or long, thin fibers occurring in bundles).

Asbestos A group of highly fibrous silicate minerals that readily separate into long, thin, strong fibers that have sufficient flexibility to be woven, are heat resistant and chemically inert, are electrical insulators, and therefore, are suitable for uses where incombustible, nonconducting, or chemically resistant materials are required. The generic name used for a group of naturally occurring mineral silicate fibers of the serpentine and amphibole series, displaying similar physical characteristics although differing in composition.

Asbestosis A non-cancerous disease associated with inhalation of asbestos fibers and characterized by scarring of the air-exchange regions of the lungs.

ASHARA **Asbestos School Hazard Abatement Reauthorization Act**
Passed in 1990; requires accreditation of personnel working on asbestos activities in schools, and public and commercial buildings. See applicability discussion (Section 2).

Aspect ratio Length to width ratio of a particle or fiber.

ATSDR **Agency for Toxic Substances and Disease Registry**
A principal federal public health agency involved with hazardous waste issues, responsible for preventing or reducing the harmful effects of exposure to hazardous substances on human health and quality of life. ATSDR is part of Center for Disease Control and Prevention which is part of the U.S. Department of Health and Human Services.

BMC **Benchmark Concentration**
The concentration which results in a 10% increase in prevalence of localized pleural thickening (LPT).

BMCL The lower confidence bound on a benchmark concentration (BMC).

Bulk sample A sample of suspected media (*e.g.*, soil or dust) is obtained from a site to be analyzed microscopically for asbestos content. Bulk sample analysis can be part of a process to assess the hazard from asbestos at a site.

CARB 435 **California Air Resources Board analytical method 435**
A specialized polarized light microscopy (PLM) method used for testing asbestos content in the serpentine aggregate storage piles, on conveyer belts, and on covered surfaces such as roads, play-yards, shoulders and parking lots. The method includes reporting the asbestos content by performing a 400-point count technique which has a detection limit of 0.25%. Many agencies and laboratories also use this method for measuring asbestos in soil. The method has undergone revision in 2017.

Carcinogen Any substance that causes cancer.

Chrysotile A mineral in the serpentine mineral group that occurs in the asbestiform habit. Chrysotile generally occurs segregated as parallel fibers in veins or veinlets and can be easily separated into individual fibers or bundles. Often referred to as "white asbestos," chrysotile is used commercially in cement or friction products and for its good spinnability in the making of textile products. A fibrous member of the serpentine group of minerals. It is the most common form of asbestos used commercially, also referred to as white asbestos.

Contaminant A substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects.

Continuous Exposure Exposure that occurs 24 hours/day, 365 days/year.

Crocidolite A sodic amphibole mineral in the glaucophane-riebeckite solid solution series. Crocidolite, commonly referred to as "blue asbestos," is a varietal name for the asbestiform habit of the mineral riebeckite. A type of asbestos in the amphibole group; it is also known as blue asbestos.

Detection limit The minimum concentration of an analyte in a sample, that with a high level of confidence is not zero.

Direct preparation	In direct preparation, the filter is examined by microscopy. In contrast with indirect preparation, where a filter with too much material undergoes a separation step (commonly ashing followed by dispersion/dilution in water) to allow for analysis.
Dose	The amount of a substance to which a person is exposed (air, soil, dust, or water) over some time period.
Electron diffraction	A specialized technique used to study matter by firing electrons at a sample and observing the resulting interference pattern.
Exposure	Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].
f/cc	**Fibers per cubic centimeter** Units of measurement for asbestos in air.
FBAS	**Fluidized Bed Asbestos Segregator** The FBAS is a sample preparation method/instrument that utilizes air elutriation to concentrate light, aerodynamic asbestos structures from heavier matrix particles and deposit these structures onto an air filter which can be analyzed by TEM or other appropriate microscopic technique(s).
Fibrous habit	Having the morphologic properties similar to organic fibers.
GOs	**Grid openings** An area that overlays a mounted sample to aid in its microscopic examination.
Hazardous substance	Any material that poses a threat to public health and/or the environment. Typical hazardous substances are materials that are toxic, corrosive, ignitable, explosive, or chemically reactive.
ICs	**Institutional controls** Institutional controls are actions, such as legal controls, that help minimize the potential for human exposure to contamination by ensuring appropriate land or resource use.
Indirect preparation	A method whereby a filter with too much material undergoes a separation step to allow for analysis.

Ingestion	The act of swallowing something through eating, drinking, or mouthing objects. A hazardous substance can enter the body this way [see route of exposure].
Inhalation	The act of breathing. A hazardous substance can enter the body this way [see route of exposure].
IRIS	**Integrated Risk Information System** A compilation of electronic reports on specific substances found in the environment and their potential to cause human health effects.
ISO 10312	**International Organization for Standardization Method 10312** Ambient air -- Determination of asbestos fibres -Direct transfer transmission electron microscopy method.
IUR	**Inhalation unit risk** The excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration 1 µg/m^3 in air.
Libby Amphibole Asbestos (LAA)	The term used in this document to identify the mixture of amphibole mineral fibers of varying elemental composition (*e.g.*, winchite, richterite, tremolite, etc.) that have been identified in the Rainy Creek complex near Libby, MT, as described in Meeker et al. (2003).
MCE	**Mixed cellulose ester** A type of filter used for air sampling.
MCL	**Maximum Contaminant Level**
Media	Soil, water, air, plants, animals, or any other part of the environment that can contain contaminants.
Mesothelioma	A malignant tumor of the covering of the lung or the lining of the pleural and abdominal cavity often associated with exposure to asbestos.
Microvacuum samples	A microvacuum sample, commonly called microvacuum, as per ASTM D5755, is similar to a wipe sample with the exception that a predefined area is “vacuumed” using a low-volume (1–5 L/minute) personal air pump equipped with a sample cassette that contains a cellulose filter instead of wiping with a wet wipe.

NESHAP **National Emission Standards for Hazardous Air Pollutants**
Section 112 of the Clean Air Act requires U.S. EPA to develop emission standards for hazardous air pollutants. In response, U.S. EPA published a list of hazardous air pollutants and promulgated the National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations.

NIOSH **National Institute for Occupational Safety and Health**
The National Institute for Occupational Safety and Health (NIOSH) is the federal agency responsible for conducting research and making recommendations for the prevention of work-related injury and illness. NIOSH is part of the Centers for Disease Control and Prevention in the Department of Health and Human Services.

NIOSH PCM Method 7400 A light microscopy analytical method, also known as NIOSH Phase Contrast Microscopy [PCM] Method 7400.

NIOSH PLM Method 7402 NIOSH 7402 uses transmission electron microscopy (TEM) to qualify and quantify asbestos fibers found in the air. This technique provides complimentary results to fiber counts determined by NIOSH 7400, and provides more accurate asbestos fiber counts as non-asbestos particles are eliminated using this method.

OSHA **Occupational Safety and Health Administration**
The Occupational Safety and Health Administration, since its inception in 1971, aims to ensure employee safety and health in the United States by working with employers and employees to create better working environments.

OSWER **Office of Solid Waste and Emergency Response**

PCM **Phase contrast microscopy**
A light-enhancing microscope technology that employs an optical mechanism to translate small variations in phase into corresponding changes in amplitude, resulting in high-contrast images. Historically, this method was used to measure airborne fibers in occupational environments; however, it cannot differentiate asbestos fibers from other fibers.

PCMe	**PCM-equivalent** This refers to chrysotile and amphibole structures identified through transmission electron microscopy (TEM) analysis that are equivalent to those that would be identified in the same sample through phase contrast microscopy analysis, with the main difference being that TEM additionally permits the specific identification of asbestos fibers.
Personal air monitor	Also known as a low-flow or low-volume sample pump, this is an air sample pump that is portable so that it can be worn by a member of the sampling team during activity based sample collection. The air flow for a personal sample pump is typically 1 to 10 liters per minute.
Pleural fibrosis	The development of fibrous tissue in the pleura.
PLM	**Polarized light microscopy** A microscope technology that uses the polarity (or orientation) of light waves to provide better images than a standard optical microscope.
QAPP	**Quality assurance project plan** The U.S. EPA has developed the QAPP as a tool for project managers and planners to document the type and quality of data needed for environmental decisions and to describe the methods for collecting and assessing those data. The development, review, approval, and implementation of the QAPP are components of U.S. EPA's mandatory Quality System.
RfC	**Reference concentration** An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious non-cancer health effects during a lifetime. The inhalation reference concentration is for continuous inhalation exposures.
SAED	**Selected area electron diffraction** A crystallographic laboratory technique, a specialized electron microscopy technique, which can be performed inside a transmission electron microscope (TEM).

SAP — **Sampling and analysis plan**
A plan intended to assist organization in documenting the procedural and analytical requirements for a one-time or time-limited project involving the collection of water, soil, sediment, or biological samples taken to characterize areas of potential environmental contamination. It combines, in a short form, the basic elements of a Quality Assurance Project Plan (QAPP) and a Field Sampling Plan (FSP).

Serpentine — A name given to several members of a polymorphic group of magnesium silicate minerals—those having essentially the same chemistry but different structures or forms. Chrysotile asbestos is a member of the serpentine group.

Stationary air monitor — An air sample monitor that is placed in a single, fixed location and is not moved during one or more sampling events.

Structures — A single fiber, fiber bundle, cluster, or matrix.

TEM — **Transmission electron microscopy**
A microscope technology and an analytical method to identify and count the number of asbestos fibers present in a sample. It uses the properties of electrons to provide more detailed images than polarized light microscopy (PLM). Capable of achieving a magnification of 20,000x.

Tremolite — A mineral in the calcic amphibole group, that occurs as a series in which magnesium and iron can freely substitute for each other. Tremolite is the mineral when magnesium is predominant; otherwise, the mineral is actinolite. It is generally not used commercially in the United States.

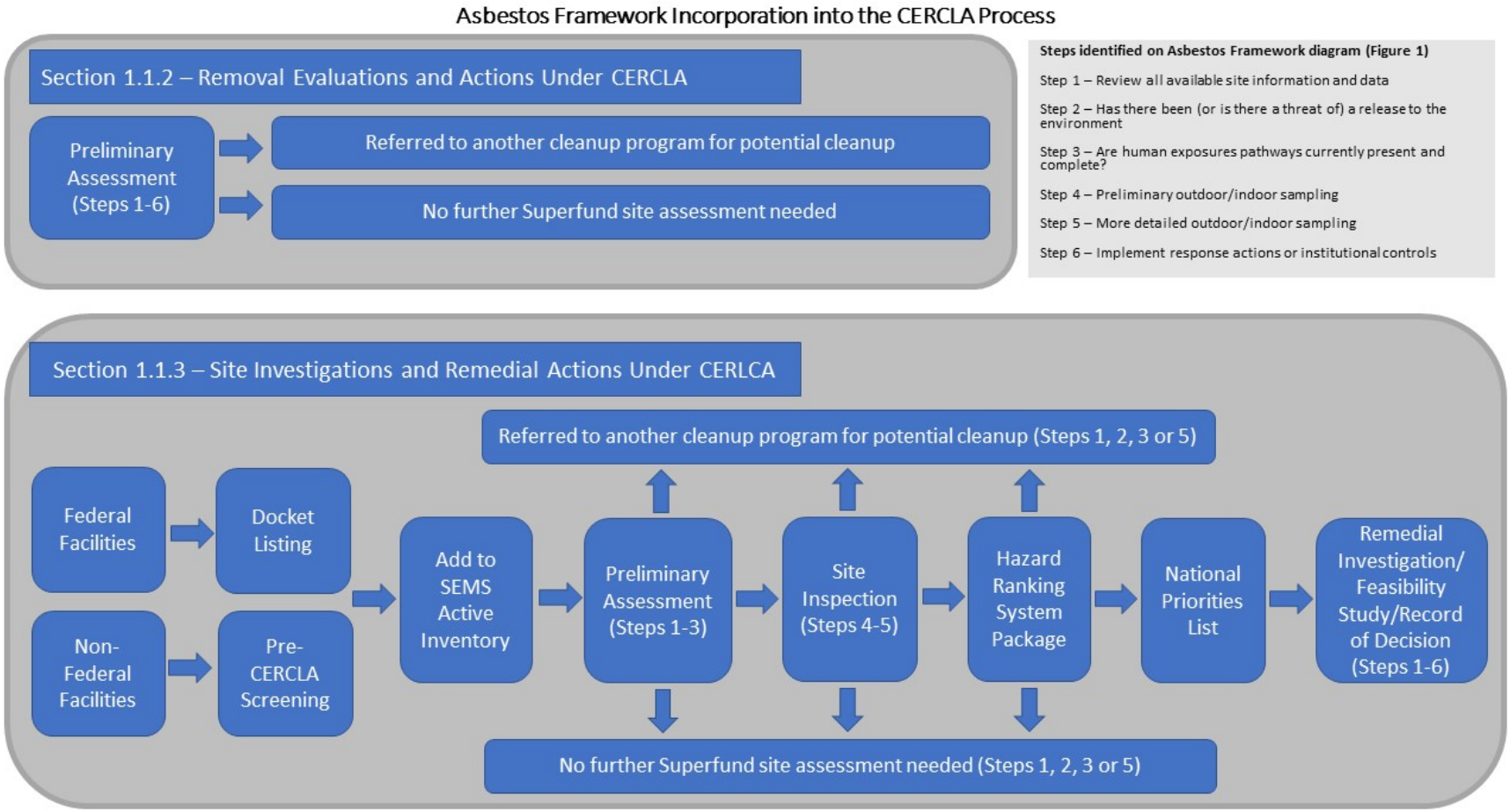
TSCA — **Toxic Substances Control Act**
The Toxic Substances Control Act (TSCA) of 1976 was enacted by Congress to give U.S. EPA the ability to track the 75,000 industrial chemicals currently produced or imported into the United States.

TWF — **Time weighting factor**
This factor accounts for less-than-continuous exposure during a year.

Vermiculite A chemically inert, lightweight, fire resistant, and odorless magnesium silicate material that is generally used for its thermal and sound insulation in construction and for its absorbent properties in horticultural applications. A major source of vermiculite is the mine in Libby, Montana, which has been demonstrated to contain various amounts of amphibole minerals.

Wipe sample A wipe sample consists of using a wipe and a wetting agent that is wiped over a specified area using a template. The wipe picks up settled dust in the template area and provides an estimate of the number of fibers per area.

Appendix B – Asbestos Framework Incorporation into the CERCLA Process



Appendix C – Land Use Considerations

One of the critical elements in development of ABS typically is determining site-specific exposure scenarios based on land use. The evaluation of probable land use scenarios normally is an iterative process. Probable land use can be selected based on the land use of the site with reference to current and currently planned future land use and the effectiveness of institutional or legal controls placed on the future use of the land (Risk Assessment Guidance for Superfund; U.S. EPA, 1989). For information regarding land use determinations, refer to OSWER Directive 9355.7-04 "Land Use in the CERCLA Remedy Selection Process" (U.S. EPA, 1995) and similar directives.

Land use assumptions can be based on a factual understanding of site-specific conditions and reasonably anticipated use. The land use evaluated for the assessment can be based on a residential exposure scenario unless residential land use is not plausible for the site.
The basic or primary land use exposure scenarios for evaluation may include:

- Residential
- Commercial/Industrial
- Agricultural
- Recreational
- Excavation/Remediation (Short term exposure scenario).

The basic land use may be further divided and categorized as dictated by available information.

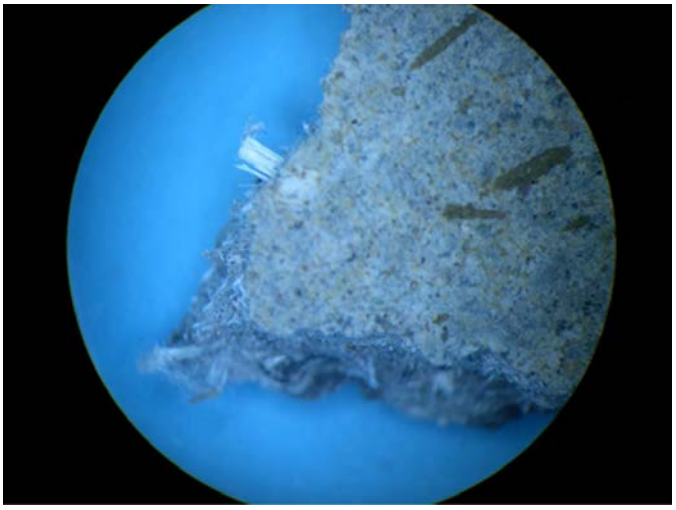
- Future land use assumptions should be consistent with the reasonably anticipated future land use.
- A range of land uses, and therefore exposure assumptions, may be considered, depending on the amount and certainty of information supporting a land use evaluation.
- Discussions with planning boards, appropriate officials, and the public, as appropriate, should be conducted as early as possible in the scoping phase of the project.
- Federal, State, and local facilities/property may have different land use considerations than private property because the future land use assumptions (*e.g.*, agricultural, industrial, recreational, etc.) at sites which may be transferred to the public may be different than at sites where a governmental agency will be maintaining control of the facility.
- Numerous sources of information, including planning boards, master plans, flood zones, etc., can be utilized in making educated decisions regarding potential land use for a site. Land use assumptions may take into consideration the interests of all affected parties, including the local residents and State/Local governments.
- Land use issues are to be carefully documented and all assumptions clearly defined.

For asbestos sites, the future land use considerations listed above apply; however, additional consideration must be given to how the asbestos material could change in the future. Natural weathering and changes resulting from human activities may change the nature (fiber size distribution) and extent (spatial distribution) of asbestos contamination across the site. For example, subsurface asbestos may migrate to the surface over time.

Appendix D - Photographs of ACM in Soil

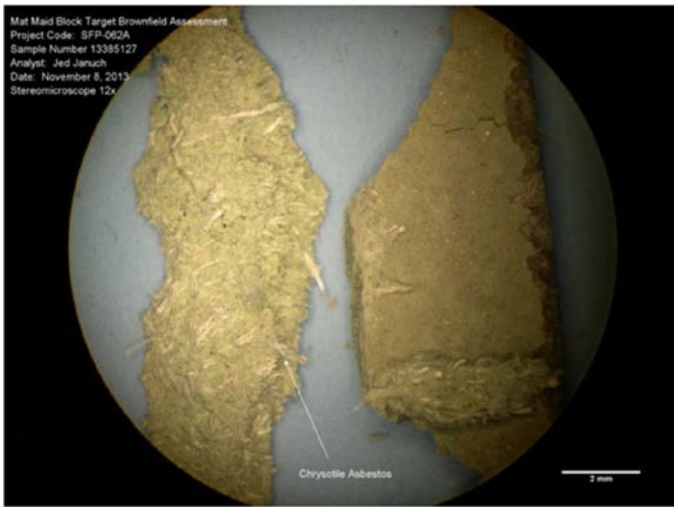
Stereomicroscope Images of ACM

EPA Region 2 Sample – 2010 - Stereomicroscope Image, CAB - chrysotile

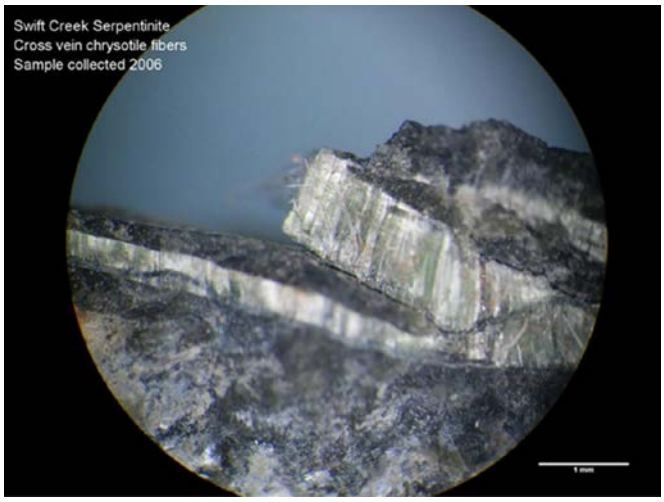


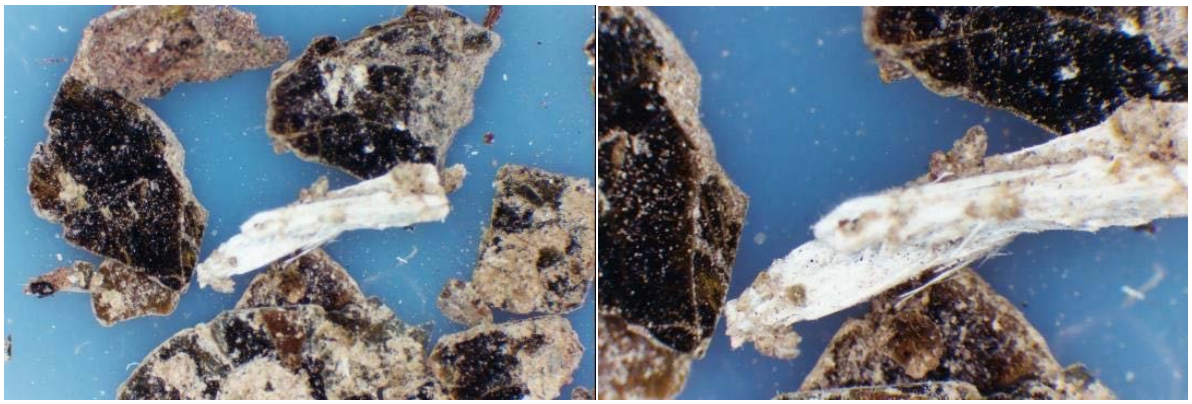
Warmhouse Beach Dumpsite – 2018 - Stereomicroscope Image – tar and foil

Matanuska Maid Brownfield Site – 2013 - Stereomicroscope Image - CAB

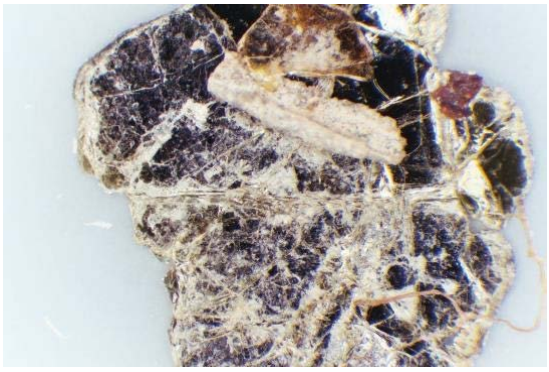


Swift Creek – 2006 - Stereomicroscope Image – serpentinite with cross vein chrysotile fibers

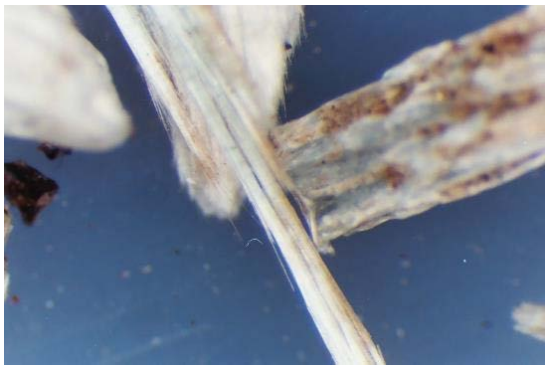




Vermiculite Northwest Site – Spokane 2002 - Vermiculite Stoner Rock with amphibole viewed with stereomicroscope.



Vermiculite Northwest Site – Spokane 2002 - Vermiculite Stoner Rock with amphibole viewed with stereomicroscope.



Vermiculite Northwest Site – Spokane 2002 - Amphibole structures viewed with stereomicroscope.

Photographs of ACM Found at Sites

Example of a typically nonfriable material (concrete asbestos board) that has become weathered by fire and weather over time leading to an increase in releasable fibers.

Stenton Ave - ACM illegally removed from building and strewn about

Mountain Home AFB – 2007 - Cement Asbestos Pipe (chrysotile and crocidolite)

Mountain Home AFB – 2007 - Cement Asbestos Pipe (chrysotile and crocidolite)

North Ridge Estates – 2008
CAB - chrysotile

North Ridge Estates – 2008
CAB - chrysotile

EPA Region 2 Sample – 2010
CAB - chrysotile

Powhatan Site – processed asbestos ore waste left under home

Powhatan Site – processed asbestos ore waste left under home

Powhatan Site – asbestos waste "dust" seeping out of building

Powhatan Site – residual asbestos waste after processing

Powahatan Site – what generally is considered "classic" ACM – broken asbestos shingles

Powhatan Site – buried asbestos waste after ore processing

Powhatan Site – buried asbestos waste after ore processing

Asbestos mixed in with soil.

Borit Site – Asbestos cement and pipes strewn along stream bank

Borit Site – Asbestos cement and pipes strewn along stream bank

Borit Site – Asbestos cement and pipes strewn along stream bank

Borit Site – weathered asbestos pipe becoming friable with weathering

Borit Site – pieces of ACM (pipes and cement) lying near groundhog hole

Appendix E – ERT Helpful Hints for ABS Sampling for Asbestos is Air

ERT HELPFUL HINTS for ACTIVITY-BASED SAMPLING FOR ASBESTOS IN AIR

Asbestos fibers pose a risk to human health overwhelmingly by way of the inhalation pathway. A relationship between the concentration of asbestos in a source material (typically soil) and the concentration of fibers in air that results when the source is disturbed is very complex and depends on a broad range of variables. Many have tried and all have failed to produce a "rule" describing this complex relationship. That is, no method has been found to predict the concentration of asbestos in air reliably as it relates to a measured concentration of asbestos in the source material. Suffice it to say, a small concentration of asbestos in source material may, when disturbed, produce a substantial airborne exposure. Not always, but sometimes. Therefore, personal monitoring in the form of activity-based sampling (ABS) for asbestos in air may be the most appropriate technique to estimate exposure. Personal exposure is influenced by the activities performed, the duration of the activity, and the site-specific soils of interest. EPA has developed ABS to mimic the activities of a potential receptor.

The official guidance document for assessing asbestos impact at sites is *Framework for Investigating Asbestos-Contaminated Comprehensive Environmental Response, Compensation and Liability Act Sites*, OLEM Directive #9200.0-90 (U.S. EPA, 2021), referred to in this document simply as the Framework. It is an important document and must be read before engaging in ABS. All steps explained in the Framework should be considered thoroughly before conducting screening (Step 4 of the Framework). The Environmental Response Team (ERT) strives to make asbestos ABS projects less stressful from every aspect: planning, execution, outcome, and reporting. With this document, we hope to provide OSCs, RPMs, and other Regional personnel with the benefit of our collective experience dealing with ABS for asbestos in air. ERT has provided assistance for ABS evaluation at many sites and has encountered a fair share of misunderstanding, misinterpretation, and general "what do I do now" questions to prompt ERT to compile this tip sheet to aid investigators. While ERT does not make policy decisions regarding ABS for asbestos in air, these helpful hints are provided as an extra service to those whom we assist.

This document is divided into the following sections: A. General Tips, B. Conceptual Site Model and Decision Unit, C. Perimeter Air Sampling, D. Sensitivity, Detection Limit, and Reporting Limit, E. Filter Overloading, F. Flow Rate Considerations, G. Concentration Determination for Samples Collected Consecutively, H. Difference between Screening (Step 4 of the Framework) and Site-Specific Activity-Based Sampling (Step 5 of the Framework) Scenarios and I. Sample Handling, Containers, and Storage Procedures.

A. General Tips

This Section provides general recommendations that we believe will make any ABS event much easier. The other Sections provide more detailed tips concerning some of the more complex aspects of ABS for asbestos in air.

- Establish a project team with a cross section of the necessary skills and experience early in the planning process. For example, it is very important to engage the assistance of a Regional risk assessor and/or personnel from ATSDR, especially at the outset when you are coming up with exposure assumptions to calculate risk. Calculations to determine the air screening level and resultant risk are not difficult but are based on concepts and assumptions that may be beyond the scope of the OSC's or RPM's regular duties.
- Use spun-bonded polyethylene (SBP) outer suits, also known as "dust suits," during ABS activities, especially during warm/hot months. The ubiquitous Tyvek® suits are vapor permeable but it is important to understand that while water vapor is a gas, sweat is bulk water and moisture in liquid form. Therefore, liquid from the wearers sweat will accumulate inside the suit. SBP suits are breathable (water moves both ways unimpeded) and lightweight. SBP coveralls are used in the asbestos abatement industry and are protective against particulate matter and present a minor heat stress hazard when compared to Tyvek® suits.
- Have sufficient staff available to assign one person to equipment handling and pump calibration; one to assist the activity personnel with dressing out and performing the activity; and one person for data management.
- Utilize more than one person in the ABS activity and practice the backpack switching process in advance to assure a smooth transition during the actual timed activity.
- To the best extent possible utilize a new inexpensive backpack for each new area studied in order to prevent migration of potential contamination.
- Instruct the activity personnel to perform the activity in a manner that represents "reality" and advise them that exaggerated and over-stressed behavior is counter-productive and may lead to overloading of the air filter cassettes. For example, raking should be realistic but not unnecessarily aggressive or repetitive; lawn mowing should progress at a usual speed, etc.
- Sampling should be performed during periods of dry weather that are climatologically representative of the area being studied. Soil moisture plays a major role in determining potential exposure. Soil moisture content should be specified in the site specific QAPP, ensuring all the decision makers are in agreement. Additional guidance on evaluation of soil moisture prior to conducting ABS is included in the ERT ABS SOP.
- In some cases, it may be worthwhile to incorporate the results from ABS along with soil concentration data and if applicable, dust loading, from the same area in order to make decisions.
- Another technique that may be considered, the Fluidized Bed Asbestos Segregator (Other Test Method–42: Sampling, Sample Preparation and Operation of the Fluidized Bed Asbestos Segregator), may provide an alternative approach in certain situations. https://www.epa.gov/sites/production/files/2020-08/documents/otm_42_sampling_sample_preparation_and_operation_of_fluidized_bed_asbestos_segregator.pdf

B. Conceptual Site Model and Decision Unit

Guidance for the development of conceptual site models (CSMs) is available in U.S. EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA,* OSWER Directive 9355.3-01 (U.S. EPA, 1988), U.S. EPA's *Data Quality Objectives Process for Hazardous Waste Site Investigations, EPA/600/R-00/007* (U.S. EPA, 2000) and the OLEM/OSRTI

fact sheet from 2011: EPA 542-F-11-011 *Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model.* Note that examples of CSMs in these guidance documents focus on human health or ecological risk assessment concerns and may need to be modified to address additional, non-risk-related environmental hazards.

It is important to develop the CSM early in the planning process and to carefully define the decision unit (DU) and the decision(s) which the data collected from the DU are expected to support (DQO process). A DU is defined as a physical area of soil where a decision is to be made based on data specific to the targeted soil. Decision units are established so large-scale variability of soil conditions across a site will be adequately isolated and characterized through designation of separate DUs. DUs can be focused on areas of potential exposure as well as areas of contamination like backyards, play areas, a driveway, a former waste pile area, or a road. The appropriate type, size, shape and number of DUs for a given project is site-specific and must take into consideration the historical, current, and future use of the site and the specific type of environmental hazards posed by the targeted contaminants. Investigation objectives can change as a project proceeds and in some cases, additional or alternate DUs may need to be established. For example, DUs established for site characterization purposes may need to be refined for the remedial phase of the project to isolate high-priority areas.

An important goal of the site investigation is to estimate the representative, mean concentration of a targeted chemical for the designated volume of DU soil. In an ideal world, the entire DU would be analyzed as a single, laboratory aliquot. However, this is not possible in reality. The raking-screening protocol (Step 4 of the Framework) applied on a DU can be thought of as an exercise in incremental sampling. By raking the entirety of the decision unit, one is effectively averaging the very high contamination areas with the moderate and low contamination areas to end up with an area–weighted result that automatically provides the mean concentration of asbestos in air due to that activity. This is the easiest and most straightforward method. Smaller-scale variability of asbestos concentrations within a targeted DU volume of soil does not normally need to be determined or evaluated, at least at the initial phase of an investigation when a screening risk level is not exceeded. If a greater resolution of contaminant concentration variability within the soil is in fact needed to address the objectives of the site investigation then, by definition, the DU is too large and the area should be re-divided into smaller decision units.

As an alternative, “representative” air samples are collected through ABS within a portion of the DU and submitted for analysis. The data generated are then used to make a decision for the entire volume of soil represented by the DU. This method assumes that the distribution of asbestos across the DU is fairly uniform and the mean asbestos content in one part of the DU is the same across the entire DU. This assumption may or may not be true. This is when the investigator has to rely on a robust CSM.

Establishing DUs early in the site investigation process helps to ensure that the objectives of a site investigation are clearly thought out and defined, well before screening or site-specific ABS samples are collected. This aids in the preparation of an effective Quality Assurance Project Plan (QAPP) or Sampling and Analysis Plan (SAP) and helps ensure that the data collected will be adequate to meet the objectives of the investigation. It is important to ask basic questions about the intent of a site investigation as potential DUs are identified and designated.

- How does the DU fit into the overall objectives of the investigation?
- How will data from the DU be used to address these objectives and what decisions will it inform?
- Have screening risk values been determined for the DU?
- What further action will be taken if the screening risk values are exceeded? If the values are not exceeded?

If you find yourself reducing the size of a decision unit down to a single, discrete sample (*e.g.*, making removal/remedial decisions for individual sample points) then adequate thought has probably not been given to the objectives of the site investigation.

C. Perimeter Air Sampling

Perimeter samples are defined as samples collected upwind, downwind, or crosswind of a specific ABS area, DU or entire site. The standard operating procedure (SOP) #ERT-PROC-2084-20, *Activity-Based Air Sampling for Asbestos*, states that perimeter air sampling should be performed to ensure that ABS activities do not result in excessive airborne asbestos emissions from the area. In practice, ERT usually collects air samples downwind of each individual activity site to ascertain if activities on the site are causing emissions. Likewise, ERT usually collects air samples upwind of an activity to determine background asbestos concentrations or if there is an upwind source. ERT typically recommends that air samples (two downwind and one upwind) be collected and analyzed to determine the concentrations of asbestos at an ABS area or DU perimeter. These perimeter air samples are collected over the same time period as the activity being performed. If multiple types of activities are performed on a parcel, ERT typical would collect separate perimeter samples for each type of activity. Keep in mind that, if cumulative perimeter samples are collected and positive results are found, there is no way to determine which activity caused the result. In some situations, this activity may not be required, if no upwind source is suspected or no adjacent receptors are present.

As perimeter samples involve a low volume of air and a high sensitivity value, these air samples may provide a qualitative indication of whether or not an activity would expose anyone nearby to a possible asbestos inhalation risk.

Keep in mind, however, that either form of perimeter air sampling has some shortcomings. For example, windblown asbestos fibers may be highly directional and may not spread out laterally (*i.e.*, the asbestos plume may go between the air samplers and no fibers may be collected on the filters). Also, in many situations, the wind changes direction due to daily shifts and seasonal changes or there may be little to no measurable wind present during sampling. These conditions may confound what is considered upwind/downwind or coming from background. Because of this, the ERT SOP #ERT-PROC-2084-20 recommends that historical and real-time meteorological conditions be taken into consideration and recorded to assist in data interpretation. Unfortunately, in many cases, the meteorological data collected has shown that wind direction is highly variable and upwind and downwind directions are poorly defined. It is recommended to utilize a local forecast prior to the start of the day in order to determine wind direction and corresponding sampling locations. These local forecasts are available through www.weather.gov and are updated regularly during the day.

To confound the issue even more, at several sites there have been asbestos fibers detected in both types of perimeter samples while the ABS personal air samples have had no observable fibers. The interpretation of perimeter samples such as these is very difficult and can lead to some spirited debate within the project team.

So, where does this leave you and your project team? Simply put, perimeter air samples, even with the issues noted above can provide clues as to the possibility of a risk to anyone adjacent to an activity or the possibility of off-site asbestos fiber releases. It is recommended that perimeter air samples not be used directly for risk assessment, but rather as a qualitative indication of the presence or absence of asbestos fiber migration due to a site activity.

In the end, any asbestos fiber detection in perimeter air samples would need to be considered from both a public perception and a site management perspective. Each project team should weigh the value of collecting perimeter air samples against the cost when developing the DQOs. ERT generally recommends the collection of perimeter air samples around ABS activities.

Entire site fence line or entire site perimeter samples (collected at site boundaries) may also be deemed necessary to meet site-specific sampling objectives (i.e. proof of negative results). These samples should run the entire workday.

Background or samples from upwind locations should be considered for all sampling events and should be addressed in a site-specific QAPP/SAP. These samples are strongly recommended for all outdoor sampling events and encouraged for any indoor sampling. A background sample is defined as a sample collected upwind, while a reference sample location can be collected away from the immediate sampling area at a distance sufficient to prevent being influenced by the simulated activities and may be on or off the site. To the degree practical, the area selected for background sampling should be free of known asbestos contamination. These samples should run the entire work day which allows for a large volume of air and a very low sensitivity value.

D. Sensitivity, Detection Limit, and Reporting Limit

One issue that ERT is repeatedly asked to provide guidance on involves the determination/selection of an analytical sensitivity value. Before starting any ABS work, the required analytical sensitivity should be determined and included in QAPP/SAP. Do not simply rely on the information provided by the analytical lab in the quote proposal. The best approach is for the project team, including risk assessor, to meet before preparation of the QAPP/SAP and decide *a priori* (and consistent with the DQO process for site investigation) what fiber concentration in air will yield a risk value of interest, whether it be 10^{-4} or 10^{-6}, or some other risk level. Not all EPA Regions (or States) evaluate risk in the same manner so it is important to involve the risk assessor ahead of time (before you mobilize to the field and collect samples or find a laboratory to analyze samples).

Some confusion persists regarding the word “sensitivity;” at least in relation to asbestos filter microscopy. Asbestos analysis consists of counting fibers (or structures, it’s not that important a distinction here). Counting fibers produces an integer (whole number) or nothing. *Sensitivity* is a discrete variable while *limit of detection* (or detection limit) is continuous. With sensitivity, there

is no “gray area.” Either a fiber is present in the optical field or it isn’t. Stated simply, the concept of “below the limit of detection” does not apply exactly to asbestos filter microscopy.

In general, sample volumes collected are tailored to meet site-specific needs. The level of concern (LOC) calculated for a site can be used to establish the analytical limit of detection (LOD) requirements, which must be determined prior to sample collection. The LOD should be at or below the LOC. The LOD is 2.996 times the analytical sensitivity. Therefore, for example, if your LOC for the site is determined to be 0.03 f/cc then the analytical LOD might be set at 0.03 f/cc which corresponds to an analytical sensitivity of 0.01 f/cc. The sensitivity (S) is defined as the concentration corresponding to the detection of one structure in the analysis according to American Society for Testing and Materials Method D 6620-19, *Standard Practice for Asbestos Detection Limit Based on Counts*. The LOD is equivalent to a detection level and expresses the uncertainty around the sensitivity level for non-detects. For a direct preparation, the analytical sensitivity for a sample is determined by the volume of air drawn through the filter, the active area of the filter, the number of grid openings (GOs) analyzed by a microscopist, and the area of each GO analyzed.

As explained in the Framework, a risk-based action level for asbestos in air is the concentration of asbestos in air that corresponds to a specified risk level for a specified exposure scenario of concern. This action (or screening) level for asbestos in air is an appropriate metric for making the determination of whether a response action, no action, or further, more detailed investigation at a given site is warranted. So, before sampling, you must determine what sensitivity value must be obtained from the laboratory in order to evaluate whether or not the air action level has been exceeded. In other words, you don’t want to receive data from the lab where the sensitivity was so high that you can’t determine if an unacceptable risk is present.

For asbestos filter analysis, in principle, the sensitivity value for any sample of air with a given volume can be reduced to any value desired simply by examining more of the sample (*i.e.*, by counting more grid openings), and there is no inherent (hypothetical) limit imposed by the instrument. Looking at more grid openings decreases the sensitivity value (*i.e.*, 0.01 to 0.001) and by corollary lowers the limit of what can be detected. The alternate method of improving the sensitivity would be to increase the volume of air collected but this often leads to filter overloading which is discussed in the next section.

Many Regional risk assessors have suggested that a sensitivity value of no greater than ~0.001 f/cc for general asbestos (for non-cancer effects are a potential concern, this sensitivity should be adjusted to incorporate the Libby RfC) be used since this equates to a default Baseline Residential Exposure (BRE) risk of 1 in 10,000 or 10^{-4}. The BRE assumes exposure to a resident 350 days a year, 24 hours a day from birth to 26 years old. This is a very conservative approach and arguably an unlikely exposure scenario in most settings, especially disturbance activities associated with ABS. While it is possible in theory to continually decrease the sensitivity value by counting more grid openings, it may not be economically feasible or reasonable. The cost difference between analyzing an asbestos air filter to a sensitivity of 0.001 f/cc rather than 0.01 f/cc may be too high for your budget, depending on the loading of the sample.

To demonstrate, consider the following that is based on the analytical subcontracting of ERT’s contractor over the past few years. The typical analytical SOW will require the laboratory to

examine up to 10 grids with the precise number included in the standard per sample fee. The majority of the labs have included an extra charge for additional grid openings counted over 10. Counting rules for analysis generally will cease counting at 100 grid openings. Suppose your base analytical cost is $150 plus $10 (or more) for each additional grid counted. It is possible by the time the microscopist reaches the point when the stopping rules apply (end of analysis) that up to 100 grid openings have been counted and the result for the sample is no fibers detected. Again, this is an issue that should be discussed with the project team before any ABS samples are collected.

Prior planning will help prevent unnecessary and excessive costs for analysis and potentially unusable data. Consult the analytical SOWs to help clarify the process. Due to the nature of risk assessment, the risk assessors will make a number of assumptions regarding the site and it may serve you well to understand the reasoning behind these assumptions to ensure they match your project objectives. Ask questions and get answers and gain understanding. Use a conceptual site model to understand what exposures are of concern currently and for reasonable hypothetical future land uses. Will the risk assessors use a mean and maximum fiber value for their assessment? What scenarios will be useful in assessing risk for the likely population of concern? For example, if the site is a former mine, does it make sense to do a "child digging scenario"? If the site is a railroad siding does it make sense to calculate risk for a child starting at birth? How much effort will be involved to examine scenarios that will intuitively produce no measurable risk like standing or sitting for prolonged periods? It is important to be realistic in your planning and choose scenarios that make sense or time, energy, and funding may be needlessly wasted.

E. Filter Overloading

The sampling method used to collect asbestos fibers in air is an extension of the NIOSH nuisance dust method that uses an air filter with an open face cassette. In their traditional incarnation, NIOSH sampling methods anticipated a preponderance of contaminant with little if any interfering matrix. In most situations you will encounter, the conditions will be exactly the opposite; there will be an atmosphere skewed toward mostly interfering matrix with a small concentration of asbestos fibers. Simply said, far more non-asbestos particulate than asbestos fibers will be present on the filter. Sampling under these conditions makes it easy to overload the sample filter with particulate matter.

The recommended analytical method for asbestos air samples, ISO 10312, recently updated the particulate overloading level to state that the direct preparation analytical method cannot be used if the general particulate loading obscures more than 25% of the filter. If the particulate loading is over 25%, the indirect method, ISO 10374, is used for the analysis. The direct preparation method is simpler, faster, and less expensive than the indirect method. It also avoids problems with data interpretation and over-estimation of exposure from sampling frangible fibers/structures that may disassociate under sonication during filter preparation using the indirect method. Measured fiber concentrations may differ based upon specific methods used during the indirect preparation process (Kauffer, 1996; Eypert-Blaison et al., 2010)).

Also note that some Regions and/or regional risk assessors prefer not to use indirect method results for quantitative risk assessment purposes but may use the results for a qualitative judgment in

decision making. The project team should determine its position on filter overloading and the use of indirect values when setting up the sampling and analytical approach.

F. Flow Rate Considerations

Sampling larger volumes of air and/or analyzing greater areas of the filter media can theoretically lower the analytical sensitivity value. Of course, doing either of these can lead to increased filter loading or increased analytical costs. There is a definite tradeoff between improving sensitivity through larger sample volume (cheaper than counting more grid openings) and the downside of increasing the potential for overloading (the subject of Section E). For sites with the possibility to entrain a lot of non-asbestos particulate (dirt/dust), the sample collection flow rate may need to be decreased with an increased sample duration in your attempt to avoid overloading the sample filter. As discussed, too much particulate in the presence of a very small amount of asbestos inevitably obscures fibers that may be present.

Therefore, it may be more efficient to collocate two or more sampling trains using different flow rates to collect a high- to low-volume range of air. This increases the likelihood that at least one of these samples can be analyzed using the direct preparation analytical method rather than losing the sample due to overloading or having to analyze by the indirect method. The sample collection team will also need to develop a sample hierarchy instructing the laboratory how to analyze the samples and in which order to analyze them. However, the disadvantage of multiple sampling volumes is a potential reduction in representativeness of the sample for the exposure of interest. While the use of multiple sampling trains has worked for some in the past, it is also possible that the low-volume sampling train may also become overloaded with particulate. Therefore, it is best for the project team to develop an early strategy to assess the proper flow rate to avoid overloading.

One strategy for assessing the likelihood of filter overloading is doing a “dry-run” ABS event. It is easy to observe the degree of loading simply by looking at the filter. If the filter appears to be “dirty” or discolored, it is probable that it is overloaded with extraneous particulate matter. It is even possible to have a phase-contrast (PCM) microscopist on site to examine the filters. Using an onsite microscopist, it was determined that a sample collection rate of 1.0 liters per minute (LPM) for 30 minutes was the only way to collect a sample with favorable particulate loading at one site. In contrast while riding ATVs on dusty soil with elevated soil moisture and low available particulate on another site, a higher sample collection rate of 5.0 LPM was acceptable. Collecting a required volume of air to meet the sensitivity required to by the DQOs is simply a matter of flow rate multiplied by time.

Low flow rates can range from 1 to 5 LPM and high flow rates can range from 5 to 10 LPM. Site specific conditions will dictate ideal flow rates for a given project. These conditions could demonstrate the need to deviate from the general low and high ranges.

G. Concentration Determination for Samples Collected Consecutively

Another strategy to avoid filter overloading is to use multiple filters over the course of an ABS scenario to determine exposure. As the samples will represent the same area and exposures, they can be used to determine the exposure over the period from when the consecutive samples are collected. Three methods to determine a mean concentration are discussed below. The arithmetic mean (a straight average), the weighted mean (either by volume or duration) and the pooled mean.

Pooling data is a common technique employed at asbestos-contaminated sites to generate an exposure point concentration (EPC) from a group of exchangeable sample results and can be used to determine average air concentrations from a set of data. Consult with your Regional risk assessor to determine which method may be best suited to a specific situation.

Three ISO Methods for analysis of asbestos in air (Indirect-transfer TEM, Direct-transfer TEM, and SEM) were reviewed to assess how pooling the samples would affect the final average concentration versus using a time-weighted average. Initial instinct was that it would be more appropriate to use a time-weighted average but a pooled mean was also considered.

Computing the mean concentration of asbestos when applying ISO-14966 (scanning electron microscope method) is straightforward. The calculation of the mean is addressed in Annex E (Combination of Results from Multiple Samples) of the document:

> *"A mean air concentration for the same location, but over a longer period of time, can also be derived by combining the results from a number of air samples collected sequentially over the required time period.*
>
> *The measured fibre concentration is determined by two parameters: the number of fibres counted during the SEM examination and the volume of air examined by the analyst. The detection limit is determined solely by the volume of air examined by the analyst.*
>
> *A mean concentration c_i, for fibres of type i is derived by summation of the fibres from all contributing samples and dividing by the summation of the individual volumes analysed in each sample*."

Note, that it is not time weighted but rather summed and divided by the total of the volumes. Rather like a "pooled" approach. Also note the phrase "*air samples collected sequentially over the required time period"*. For our example we will use three samples to be collected sequentially over a 2-hour time period.

For determining asbestos concentration using ISO-10312 (direct transfer TEM) or ISO-137294 (indirect transfer TEM) it is more complicated. Concentration is computed by multiplying the mean number of fibers/structures per grid opening with sensitivity.

The sensitivity associated with an asbestos concentration is computed from multiple parameters, some of which will remain approximately the same across all samples collected, such as the area of the collection filter and the area of the grid openings. Other parameters that are included in the computation of sensitivity will change per sample, such as:

- the number of grid openings examined – complicating this is that the maximum number of grid openings which will be examined is determined in advance based on the volume of air and the analytical sensitivity that is desired, and
- the volume of air sampled

A time-weighted average would account for the differences in lengths of sampling times and provide an average concentration. If a pooled mean is calculated, at first it appears that the

differences in the elapsed sampling time as related to the fiber count is lost. However, volume is directly related to the elapsed time and volume is accounted for in the sensitivity computations.

In our example we are looking to capture a concentration of asbestos fibers that would be collected over a 2-hour period.

A guidance document developed for the Nevada Department of Environmental Protection titled *Technical Guidance for the Calculation of Asbestos Related Risk in Soils for the Basic Management Incorporated (BMI) Complex and Common Areas* published in February 2015 addresses pooling analytical sensitivity as related to the summation of sample results:

> "*The pooled analytical sensitivity for all sample results is used for the summation of sample results. This is because each sample result (number of fibers) is assumed to come from a Poisson distribution (Berman and Crump, 2003) (pg.24).*"
>
> "*Using a simplifying assumption that these factors are constant among samples, the analytical sensitivity for 2 samples is ½ the analytical sensitivity of 1 sample. The analytical sensitivity for n samples is 1/n times the analytical sensitivity for 1 sample. So, for n samples that were taken and analyzed under identical conditions, the analytical sensitivity for multiple samples is 1/n times the single sample analytical sensitivity. In this case, the mean and variance of the Poisson distribution that represents the total fiber count for the n samples is nλ. In practice, the pooling formula for analytical sensitivity is not quite so simple because there are small variations in the aforementioned factors. The appropriate formula for pooled analytical sensitivity then is the reciprocal of the sum of the reciprocals of the single sample analytical sensitivities. (pg. 24)*".

Note that the sampling method is different than traditional air sampling:

> *"Soil samples are placed in a dust-generator to separate and concentrate the respirable fraction of the sample. The respirable fraction is deposited on a filter, which is then prepared for analysis by microscopy. (pg 9)*"

For the sample set below the pooled and weighted mean always came out extremely close. The differences would most likely not affect the risk decisions anyone would make on a Site.

After review, the findings point towards the pooled approach to obtain a representative concentration of asbestos fibers collected over a 2-hour sampling period.

Example of ABS samples - collected from 3 samples over a 2-hour period

Sample ID	Concentration (s/cc)	Time (Minutes)	Volume (liters)	Sensitivity $(cc)^{-1}$	Number of Fibers	Reciprocal of Sensitivity (cc)
ABS1	0.0137	60	120	0.0137	1	72.9927
ABS2	0	30	60	0.0142	0	70.42254
ABS3	0	30	60	0.0144	0	69.44444

Number of Samples:	3
Total Minutes:	120
Total Number of Fibers:	1
Sum of Reciprocals:	212.8597
Pooled Mean:	0.004698
Arithmetic Mean:	0.004567
Weighted Mean:	0.00685

From the data set above, a pooled mean can be determined by summing the reciprocal of the analytical sensitivity of each sample. The total number of fibers collected in those samples is divided by the sum of the reciprocals yielding a pooled air concentration. The pooled mean is preferred, especially when one or more of the samples do not contain any fibers.

H. Difference between Screening (Step 4 of the Framework) and Site-Specific Activity-Based Sampling (Step 5 of the Framework) Scenarios

ERT has observed some misunderstanding regarding Step 4 of the Framework as it applies to sites without plausible current or future activities. First, Step 4 is a screening procedure using an activity to disturb soil. The idea is a soil disturbance will entrain asbestos from the soil in the air and make it available for an inhalation exposure. If the air value is above the screening level risk, there may be additional investigations (Step 5 of the Framework) using activities that are plausible at the site. There may be no further action at the site if the risk is below the screening criteria.

Step 4 of the Framework is a corollary method for determining if asbestos in soil is releasable; that is, a relationship between an activity onsite and asbestos becoming entrained in air as a result. It has been demonstrated that trace amounts of asbestos in soil are almost always releasable when a very aggressive method of disturbing soil (such as raking for several hours) is employed, although this will vary depending upon site-specific conditions. Suffice it to say then that a reported soil concentration of "trace" by polarized light microscopy (PLM) is equivalent to Step 4 as means to determine if there is enough asbestos in the soil to exceed the conservative default air action level (>0.00001 f/cc in air), although it may be difficult to achieve because of issues related to overloading and cost. If soil data indicate the concentration is "trace" by PLM, it makes sense to skip Step 4 and proceed to Step 5, "Assessment by Site-Specific Scenario."

The misunderstanding is circulating that the "canned" scenarios as presented in the SOP #ERT-PROC-2084-20 are the only ones available to use. This is not so! ERT believes that the ABS scenarios used in Step 5 should be site-specific and plausible. It would not be possible to include all potential scenarios in the ABS SOP so it should be understood that the SOP's scenarios are

simply examples. Developing your site-specific scenarios exactly as described in the ABS SOP would be a costly mistake. The ABS SOP's "raking" scenario is perhaps the most overused and most misapplied. For example, does a lot of "raking" go on at an abandoned mine site? In many cases where the site is remote and industrial, "walking around" or "trespassing" may be the only realistic scenarios.

Previous documentation in an earlier version of ERT-PROC-2084-20, *Activity-Based Air Sampling for Asbestos,* has included incredibly prescriptive scenario behavior such as "rake a 10' x 10' area for 2 hours, switching direction through N, E, S, W every 15 minutes." Experience has informed us this is not the correct approach because the area, type of activity, level of effort during the activity, and time should be decided based on site specific conditions and the site objectives. The project team must rely on their developed CSM to guide them through the selection of plausible scenarios. Please refer to the Section B on "Conceptual Site Models and Decision Unit" for further details.

I. Sample Handling, Containers, and Storage Procedures

Air sample cassettes must be oriented with the open face pointing down at a 45° angle to preclude large particles from falling or settling onto the filter media. Using a cassette opener (from SKC, Inc. or equivalent) prevents fumbling.

Do not put the inlet cap on the cassette or remove the cassette from the tubing before turning off the pump. The quick change in pressure (suction) can pop the filter out of place or tear it and ruin (void) the sample.

When preparing the air sample cassettes for shipping, be sure to place them right side up so that the cassette inlet cap is on top and cassette base is on bottom. Samples must be handled gently so as not to disturb the dust deposited on the filter media. Place samples into a shipping container and use enough packing material to prevent jostling or damage. Do not use any type of fibrous packing material. Additionally, avoid storing samples in areas of excessive heat (i.e. closed vehicle, direct sunlight) as the cassette plugs could melt.

Appendix F - Photographs of ABS Scenarios

Raking:

Raking scenario with perimeter monitoring.

Raking scenario.

Raking scenario with perimeter monitoring.

Raking scenario with perimeter monitoring.

Raking on a beach scenario with perimeter monitoring.

Raking scenario with perimeter monitoring.

Children Playing/Recreational Activities:

Child playing in dirt.

Child playing in dirt.

Child playing in sand.

Playing in/with river rock.

Playing in/with river rock.

Playing in/with river rock.

Baby stroller walking scenario.

Playing volleyball scenario.

Playing baseball scenario.

Playing soccer scenario.

Biking scenario.

ATV riding scenario
Note: second rider with greater potential exposure

Mowing/Gardening/Farm Work:

Mowing scenario.

Mowing scenario

Mowing scenario.

Gardening scenario.

Gardening scenario.

Digging soil scenario with perimeter monitorin

Barn work scenario.

Barn work scenario.

Construction Activities:

Checking a trench area.

Dig and haul activity.

Raking and moving dirt with perimeter monitoring.

Indoor Activities (sweeping):

Appendix G – Computing the Average Concentration in Air Using a Pooled Mean

Pooling the data is a common technique employed at asbestos-contaminated sites to generate an EPC from a group of exchangeable sample results and can be used to determine average air concentrations from a set of data. When pooling results, it is assumed that all the air samples collected within a group are exchangeable (i.e., interchangeable for the same exposure population). The pooled concentration is calculated as follows:

$C_{pooled} = \sum N_i / \sum (1/S_i)$

where:

C_{pooled} = the pooled air concentration (s/cc)
N_i = the total number of structures observed in analysis 'i' (s)
$1/S_i$ = the reciprocal of the achieved sensitivity in analysis 'i' (cc)

Example:
For an ABS data set from a site, there were 22 results available for which data could be pooled. The analytical sensitivities ranged from 3.2×10^{-4} f/cc to 3.4×10^{-4} f/cc. Only one PCMe fiber was detected in this data set. If these samples are assumed to be exchangeable (which they are since they all represented the same site area and exposures were assumed to be similar across this area), then the data could be pooled. The single fiber detected is assumed to be found over the total volume of air collected for these samples, resulting in a pooled concentration of 1.5×10^{-5} PCMe s/cc (see Table G-1).

Table G-1. Pooled Mean Example

Location	Type	Sample	Sensitivity $(cc)^{-1}$	Number of Fibers	Reciprocal
Decision Unit 1	Surface	Replicate 1	3.4E-04	0	2.9E+03
		Replicate 2	---	---	---
		Replicate 3	---	---	---
	Sub-surface	Replicate 1	3.2E-04	0	3.1E+03
		Replicate 2	3.4E-04	0	2.9E+03
		Replicate 3	3.4E-04	0	2.9E+03
Decision Unit 2	Surface	Replicate 1	3.4E-04	0	2.9E+03
		Replicate 2	3.4E-04	0	2.9E+03
		Replicate 3	3.4E-04	0	2.9E+03
	Sub-surface	Replicate 1	3.4E-04	0	2.9E+03
		Replicate 2	3.3E-04	0	3.0E+03
		Replicate 3	3.2E-04	0	3.1E+03
Decision Unit 3	Surface	Replicate 1	3.3E-04	1	3.0E+03
		Replicate 2	3.2E-04	0	3.1E+03
		Replicate 3	3.4E-04	0	2.9E+03
	Sub-surface	Replicate 1	3.4E-04	0	2.9E+03
		Replicate 2	3.4E-04	0	2.9E+03
		Replicate 3	3.3E-04	0	3.0E+03
Decision Unit 4	Surface	Replicate 1	3.4E-04	0	2.9E+03
		Replicate 2	3.4E-04	0	2.9E+03
		Replicate 3	3.3E-04	0	3.0E+03
	Sub-surface	Replicate 1	3.3E-04	0	3.0E+03
		Replicate 2	3.3E-04	0	3.0E+03
		Replicate 3	3.3E-04	0	3.0E+03
				Sum of Reciprocals	**6.6E+04**

$C_{pooled} = \sum Ni / \sum (1/Si) = 1/6.6E+04 = 1.5E-05$

Appendix H – Derivation of Cancer Unit Risk for Continuous and Less-Than-Lifetime Inhalation Exposure to General Asbestos

1.0 OVERVIEW

As discussed in U.S. EPA (1986), excess cancer risk from inhalation exposure to asbestos is quantified in a two-step procedure:

Step 1: Derive Cancer Potency Factors

Potency factors are derived by fitting established risk models to data from available epidemiological studies in workers exposed to asbestos in workplace air. The potency factor for lung cancer is referred to as KL, and has units of $(f/cc\text{-}year)^{-1}$. The potency factor for mesothelioma is referred to as KM, and has units of $(f/cc\text{-}years^3)^{-1}$.

Step 2: Implement Life Table Calculations

Potency factors are not equivalent to cancer unit risks. In order to compute the lifetime excess risk of lung cancer or mesothelioma to an exposed individual, it is necessary to implement a life-table approach. In brief, the exposure pattern for the exposed population is specified by indicating the concentration of asbestos in air, the age at which exposure begins and the age at which exposure ends. Based on this, the potency factors are used to compute the probability of dying from lung cancer or mesothelioma in each year of life. These probabilities of asbestos induced death are combined with the probability of death from all other causes to yield an estimate of the lifetime total probability of dying as a consequence of asbestos-induced cancer.

2.0 RISK ESTIMATES PROVIDED BY U.S. EPA (1986)

Based on epidemiological data available at the time, and expressing the concentration of asbestos in terms of PCM fibers per cc, U.S. EPA (1986) derived the following potency factors for lung cancer and mesothelioma:

Lung cancer: $KL = 1E\text{-}02\ (PCM\ f/cc\text{-}years)^{-1}$
Mesothelioma: $KM = 1E\text{-}08\ (PCM\ f/cc\text{-}years^3)^{-1}$

Because these potency factors are based on occupational exposures (8 hours per day, 5 days per week), they must be adjusted for application to non-occupational settings. For evaluation of continuous exposure (24 hours per day, 7 days per week), U.S. EPA (1986) performed this adjustment as follows:

$$Adjustment\ Factor = \frac{24\ hours/day}{8\ hours/day} \bullet \frac{7\ days/week}{5\ days/week} = 4.2$$

Thus, the potency factors used by U.S. EPA (1986) for computing risks from continuous exposure were:

$KL = 4.2E\text{-}02\ (PCM\ f/cc\text{-}years)^{-1}$
$KM = 4.2E\text{-}08\ (PCM\ f/cc\text{-}years^3)^{-1}$

U.S. EPA (1986) utilized these potency factors to implement life table risk calculations for a number of alternative exposure scenarios. These scenarios all assume exposure occurs 24 hours per day, 7 days per week, but each scenario may begin and end at different ages. The results are provided in Table 6-3 of U.S. EPA (1986), which is reproduced here as Table H-1 of this Appendix. As seen, risks (expressed as asbestos-induced cancer deaths per 100,000 people) are provided for exposure to 0.01 PCM f/cc for a range of differing ages at onset (age at first exposure) and exposure durations, stratified by cancer type (lung cancer and mesothelioma) and by gender.

In this table, the exposure duration column labeled "LT" (lifetime) should be understood to mean the risk associated with exposure from the age at onset until death, either from asbestos-induced disease, or from any other cause of death.

3.0 RE-ADJUSTMENT OF EXTRAPOLATION FROM WORKERS TO CONTINUOUS EXPOSURE

In 1988, IRIS revised the method for extrapolation from workers to continuous exposure so that the factor was based on the ratio of the amount of air inhaled per day rather than the ratio of the exposure time per day. The risks associated with occupational exposure were adjusted to continuous exposure based on the assumption of 20 m^3 per day for total ventilation and 10 m^3 per 8-hour workday in the occupational setting:

$$Revised\ Adjustment\ Factor = \frac{20\ m^3/day}{10\ m^3/day} \cdot \frac{7\ days/week}{5\ days/week} = 2.8$$

Table H-2 presents the risk values for people with continuous exposure (24 hours per day, 7 days per week) after re-adjustment of the risk values presented in U.S. EPA (1986) by a factor of 2.8/4.2. For convenience, results are also averaged across gender and summed across cancer type. All values are shown to two significant figures.

4.0 DERIVATUION OF UNIT RISK VALUES

4.1 Continuous Exposure

The risk values for people with continuous exposure (24 hours/day, 7 days/week) given in Table H-2 may be converted to unit risks by dividing by a factor of 100,000 (so that risks are
expressed as cases per person), and dividing by the assumed exposure concentration of

0.01 PCM f/cc (so that risk is expressed as cases per person per f/cc). The results for the combined risk of mesothelioma and cancer in males and females combined are shown in Table H-3. As above, results are expressed to two significant figures.

Continuous Lifetime Unit Risk

Note that the unit risk for lung cancer and mesothelioma (combined) in an individual with continuous exposure from birth (age of onset = 0) for a lifetime is 0.23 $(PCM\ f/cc)^{-1}$. This is the unit risk value that is presented in IRIS. This value is applicable only to an individual with exposure from birth to death and should not be used to evaluate risks to people whose exposures do not span a full lifetime.

Less-Than-Lifetime Unit Risks

Table H-3 gives the unit risk values for residents for a number of less-than-lifetime exposure scenarios. These should be used whenever the continuous exposure scenario of interest (age of onset and exposure duration) is represented in Table H-3. However, there may be a number of other exposure scenarios of interest to CERCLA risk assessors that are not presented in this table. For example, no unit risk value is given for a resident who is exposed starting at birth and lasting 26 years (the usual assumption for an RME resident).

Ideally, unit risk values for residential exposure scenarios not already included in Table H-3 would be derived using the life table approach. However, U.S. EPA (1986) did not include the detailed mortality and smoking data needed to exactly reproduce the unit risk values reported. Therefore, as an alternative to regenerating the original life table analysis, the residential unit risk values in Table H-3 were plotted (see Figure H-1) and were fit to an equation of the following form:

$$UR_{a,d} = k1 \cdot [1-\exp(-k2 \cdot d)]$$

where:

$UR_{a,d}$	=	Unit risk for a continuous exposure beginning at age of onset "a" and extending for a duration of "d" years
k1 and k2	=	empiric fitting parameters derived from the data

This equation was selected to model the data because it arises from a value of zero when duration is zero, and plateaus as exposure duration approaches lifetime.

Both k1 and k2 depend on age at onset. These relationships are well characterized equations of the following form:

$k1 = b1 + b2 \cdot \exp(-a / b3)$

$k2 = b4 + b5 \cdot \exp(-a / b6)$

where b1 to b6 are empiric fitting parameters. The resulting best-fit parameters derived by minimization of the sum of the squared errors are summarized below:

Parameter	Value
b1	-0.0176401
b2	0.2492567
b3	24.7806941
b4	0.0415839
b5	0.0039973
b6	-18.2212632

These equations fit the data well, with an R^2 value of 0.9998 and an F-value of 21306.9. The root mean squared error (the average difference between the observed and predicted unit risk value) is 0.0008. Fitting the data using a commercial surface fitting software package did not yield any solutions that were superior.

These equations may be used to estimate unit risks for any continuous exposure duration of interest for any age of onset between zero and 50. For example, the unit risk for a resident exposed from age zero to age 30 is computed as follows:

$k1 = -0.0176401 + 0.2492567 \cdot \exp(-0 / 24.7806941) = 0.232$

$k2 = 0.0415839 + 0.0039973 \cdot \exp(-0 / -18.2212632) = 0.0456$

$UR_{0,30} = 0.232 \cdot (1-\exp(-0.0456 \cdot 30)) = 0.17$

Note that multiple significant figures are carried during the calculation, but that the final result is expressed to only two significant figures.

Also note that this value is substantially higher than would be derived using a simple time-based adjustment of the lifetime residential unit risk value reported in IRIS ($0.23 \bullet 30/70 = 0.099$).

Table H-4 uses this mathematical approach to compute continuous (24 hours/day, 365 days/year) unit risks for a number of additional exposure scenarios of potential interest to CERCLA risk assessors. In some cases there are minor differences in the value derived from the fitted equations and the values shown in Table H-3. This is due to minor discrepancies in the fitted mathematical surface (shown in Figure H-1) and the data used to define the surface. However, these differences are very small compared to the overall uncertainty in the unit risks values and should not be considered as cause for concern.

4.2 Less- Than Continuous Exposure

As noted above, the unit risk values given in Table H-3 and H-4 are all based on the assumption that exposure is continuous (24 hours/day, 365 days/year) during the exposure period of interest. If exposure is less than continuous, this is accounted for by using the TWF approach described in Section 7.2.1.2. If exposure is continuous, the value of the TWF is, by definition, 1.0.

Example 1: Evaluation of Risks to Workers

When exposure of workers is to be evaluated, the TWF that should be used is simply the inverse of the adjustment factor of 2.8 that was used by IRIS (1988) to extrapolate from workers to continuous exposure:

$TWF_{(worker)} = 1 / 2.8 = 0.357$

If the worker worked for 25 years beginning at age 20, the appropriate unit risk factor (taken from Table H-4) would be:

$UR_{20,45} = 0.069$

Based on these two factors, the excess lifetime cancer risk would be computed

as: ELCR = C • 0.357 • 0.069

Example 2: Recreational Jogger

In this example, the goal is to compute the risks to an individual who is exposed by running on a jogging trail that is located in an area where the air is contaminated by asbestos from some local source. Assume that the time spent jogging through the contaminated area is 2 hours per run, and that jogging through the contaminated area occurs 80 days per year. Based on these assumed example values, the TWF for this scenario would be:

$$TWF = \frac{2\ hour/day}{24\ hour/day} \cdot \frac{80\ days/year}{365\ days/year} = 0.0183$$

Assume the person jogs starting at age 30 and continues for 30 years. The continuous unit risk for this scenario is 0.048 (see Table H-4).

The ELCR is then computed as: ELCR = C • 0.0183 • 0.048

5.0 ESTIMATION OF LIFETIME CANCER RISK

Lifetime cancer risk for asbestos (not LAA) is estimated using the age-adjusted potency factors provided in Table H-4, an adjustment for less than lifetime exposures (TWF), and the air concentration (fibers//cc). The resultant value is an estimation of the probability of asbestos

induced death combined with the probability of death from all other causes to yield an estimate of the lifetime total probability of dying as a consequence of asbestos-induced cancer.

TABLE H-1
EXCESS CANCER RISKS FOR CONTINUOUS EXPOSURES
(Excess cancer deaths/100,000 people per 0.01 PCM f/cc) Stratified by Disease and Gender
(U.S. EPA, 1986 Table 6-3)

Mesothelioma in Females

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	14.6	67.1	120.8	196.0	275.2
10	9.4	42.6	75.5	118.7	152.5
20	5.6	25.1	43.5	65.7	78.8
30	3.1	13.3	22.4	31.9	35.7
50	0.6	2.1	3.2	3.9	3.9

Lung Cancer in Females

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	1.0	4.6	9.2	18.5	52.5
10	1.0	4.6	9.2	18.6	43.4
20	1.0	4.6	9.2	18.2	34.3
30	1.0	4.6	9.0	16.7	25.1
50	0.7	3.1	5.5	8.1	8.8

Mesothelioma in Males

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	11.2	51.0	91.1	145.7	192.8
10	7.0	31.2	58.2	84.7	106.8
20	4.1	17.5	30.1	44.5	51.7
30	2.1	8.8	14.6	20.4	22.3
50	0.3	1.1	1.8	2.0	2.1

Lung Cancer in Males

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	2.9	14.8	29.7	59.2	170.5
10	2.9	14.9	29.8	59.5	142.0
20	3.1	15.0	30.0	59.4	113.0
30	3.1	14.9	29.8	56.6	84.8
50	2.5	11.5	20.3	29.1	30.2

LT = Lifetime (from age of onset until death from any cause)

TABLE H-2
EXCESS CANCER RISKS FOR CONTINUOUS EXPOSURES
(Excess cancer deaths/100,000 people per 0.01 PCM f/cc)
Adjusted by Factor of 2.8 / 4.2

Mesothelioma in Males and Females

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	8.6	39.4	70.6	113.9	156.0
10	5.5	24.6	44.6	67.8	86.4
20	3.2	14.2	24.5	36.7	43.5
30	1.7	7.4	12.3	17.4	19.3
50	0.3	1.1	1.7	2.0	2.0

Lung Cancer in Males and Females

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	1.3	6.5	13.0	25.9	74.3
10	1.3	6.5	13.0	26.0	61.8
20	1.4	6.5	13.1	25.9	49.1
30	1.4	6.5	12.9	24.4	36.6
50	1.1	4.9	8.6	12.4	13.0

Total (Mesotheloma + Lung Cancer) -- Population Average

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	9.9	45.8	83.6	139.8	230.3
10	6.8	31.1	57.6	93.8	148.2
20	4.6	20.7	37.6	62.6	92.6
30	3.1	13.9	25.3	41.9	56.0
50	1.4	5.9	10.3	14.4	15.0

TABLE H-3
UNIT RISK VALUES FOR CONTINUOUS EXPOSURES
(PCM f/cc)$^{-1}$

Mesothelioma in Males and Females

Age at Onset	Duration of Exposure				
	1	5	10	20	LT
0	8.6E-03	3.9E-02	7.1E-02	1.1E-01	1.6E-01
10	5.5E-03	2.5E-02	4.5E-02	6.8E-02	8.6E-02
20	3.2E-03	1.4E-02	2.5E-02	3.7E-02	4.4E-02
30	1.7E-03	7.4E-03	1.2E-02	1.7E-02	1.9E-02
50	3.0E-04	1.1E-03	1.7E-03	2.0E-03	2.0E-03

Lung Cancer in Males and Females

Age at Onset	Duration of Exposure				
	1	5	10	20	LT
0	1.3E-03	6.5E-03	1.3E-02	2.6E-02	7.4E-02
10	1.3E-03	6.5E-03	1.3E-02	2.6E-02	6.2E-02
20	1.4E-03	6.5E-03	1.3E-02	2.6E-02	4.9E-02
30	1.4E-03	6.5E-03	1.3E-02	2.4E-02	3.7E-02
50	1.1E-03	4.9E-03	8.6E-03	1.2E-02	1.3E-02

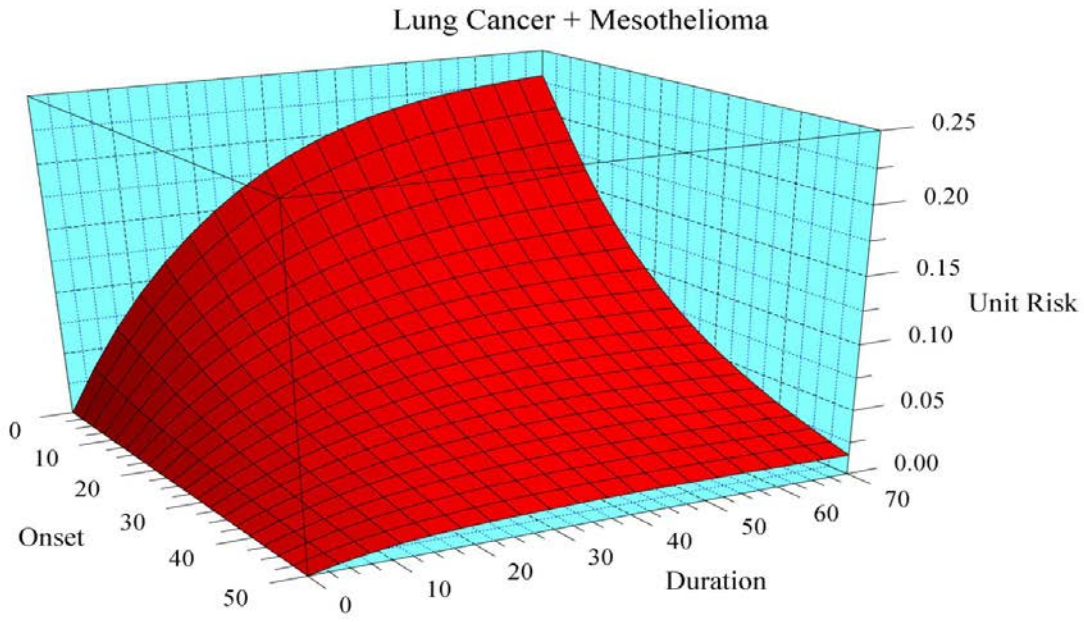
Total (Mesotheloma + Lung Cancer) in Males and Females

Age at Onset	Duration of Exposure				
	1	5	10	20	LT
0	9.9E-03	4.6E-02	8.4E-02	1.4E-01	2.3E-01
10	6.8E-03	3.1E-02	5.8E-02	9.4E-02	1.5E-01
20	4.6E-03	2.1E-02	3.8E-02	6.3E-02	9.3E-02
30	3.1E-03	1.4E-02	2.5E-02	4.2E-02	5.6E-02
50	1.4E-03	5.9E-03	1.0E-02	1.4E-02	1.5E-02

TABLE H-4
Extrapolated Unit Risk Values for Continuous and Less-Than-Lifetime Exposures (PCM f/cc)

Age at Onset	Exposure Duration																		
	1	2	3	4	5	6	8	10	12	14	16	20	24	25	30	40	50	60	LT
0	1.0E-02	2.0E-02	3.0E-02	3.9E-02	4.7E-02	5.5E-02	7.1E-02	8.5E-02	9.8E-02	1.1E-01	1.2E-01	1.4E-01	1.5E-01	1.6E-01	1.7E-01	1.9E-01	2.1E-01	2.2E-01	2.3E-01
1	9.9E-03	1.9E-02	2.8E-02	3.7E-02	4.5E-02	5.3E-02	6.8E-02	8.1E-02	9.4E-02	1.0E-01	1.2E-01	1.3E-01	1.5E-01	1.5E-01	1.7E-01	1.9E-01	2.0E-01	2.1E-01	2.2E-01
2	9.6E-03	1.9E-02	2.7E-02	3.6E-02	4.4E-02	5.1E-02	6.5E-02	7.8E-02	9.0E-02	1.0E-01	1.1E-01	1.3E-01	1.4E-01	1.5E-01	1.6E-01	1.8E-01	1.9E-01	2.0E-01	2.1E-01
3	9.2E-03	1.8E-02	2.6E-02	3.4E-02	4.2E-02	4.9E-02	6.3E-02	7.5E-02	8.7E-02	9.7E-02	1.1E-01	1.2E-01	1.4E-01	1.4E-01	1.5E-01	1.7E-01	1.8E-01	1.9E-01	2.0E-01
4	8.8E-03	1.7E-02	2.5E-02	3.3E-02	4.0E-02	4.7E-02	6.0E-02	7.2E-02	8.3E-02	9.3E-02	1.0E-01	1.2E-01	1.3E-01	1.3E-01	1.5E-01	1.6E-01	1.8E-01	1.8E-01	1.9E-01
5	8.5E-03	1.7E-02	2.4E-02	3.2E-02	3.9E-02	4.6E-02	5.8E-02	7.0E-02	8.0E-02	8.9E-02	9.8E-02	1.1E-01	1.3E-01	1.3E-01	1.4E-01	1.6E-01	1.7E-01	1.7E-01	1.9E-01
6	8.2E-03	1.6E-02	2.3E-02	3.1E-02	3.7E-02	4.4E-02	5.6E-02	6.7E-02	7.7E-02	8.6E-02	9.4E-02	1.1E-01	1.2E-01	1.2E-01	1.3E-01	1.5E-01	1.6E-01	1.7E-01	1.8E-01
7	7.9E-03	1.5E-02	2.3E-02	2.9E-02	3.6E-02	4.2E-02	5.4E-02	6.4E-02	7.4E-02	8.3E-02	9.1E-02	1.0E-01	1.2E-01	1.2E-01	1.3E-01	1.4E-01	1.5E-01	1.6E-01	1.7E-01
8	7.6E-03	1.5E-02	2.2E-02	2.8E-02	3.5E-02	4.1E-02	5.2E-02	6.2E-02	7.1E-02	7.9E-02	8.7E-02	1.0E-01	1.1E-01	1.1E-01	1.2E-01	1.4E-01	1.5E-01	1.5E-01	1.6E-01
9	7.3E-03	1.4E-02	2.1E-02	2.7E-02	3.3E-02	3.9E-02	5.0E-02	5.9E-02	6.8E-02	7.6E-02	8.4E-02	9.6E-02	1.1E-01	1.1E-01	1.2E-01	1.3E-01	1.4E-01	1.5E-01	1.6E-01
10	7.0E-03	1.4E-02	2.0E-02	2.6E-02	3.2E-02	3.8E-02	4.8E-02	5.7E-02	6.6E-02	7.3E-02	8.0E-02	9.2E-02	1.0E-01	1.0E-01	1.1E-01	1.3E-01	1.4E-01	1.4E-01	1.5E-01
11	6.8E-03	1.3E-02	1.9E-02	2.5E-02	3.1E-02	3.6E-02	4.6E-02	5.5E-02	6.3E-02	7.1E-02	7.7E-02	8.9E-02	9.8E-02	1.0E-01	1.1E-01	1.2E-01	1.3E-01	1.3E-01	1.4E-01
12	6.5E-03	1.3E-02	1.9E-02	2.4E-02	3.0E-02	3.5E-02	4.4E-02	5.3E-02	6.1E-02	6.8E-02	7.4E-02	8.5E-02	9.4E-02	9.6E-02	1.0E-01	1.2E-01	1.2E-01	1.3E-01	1.4E-01
13	6.3E-03	1.2E-02	1.8E-02	2.3E-02	2.9E-02	3.4E-02	4.3E-02	5.1E-02	5.8E-02	6.5E-02	7.1E-02	8.2E-02	9.1E-02	9.2E-02	1.0E-01	1.1E-01	1.2E-01	1.2E-01	1.3E-01
14	6.1E-03	1.2E-02	1.7E-02	2.3E-02	2.8E-02	3.2E-02	4.1E-02	4.9E-02	5.6E-02	6.3E-02	6.8E-02	7.9E-02	8.7E-02	8.9E-02	9.7E-02	1.1E-01	1.1E-01	1.2E-01	1.2E-01
15	5.9E-03	1.1E-02	1.7E-02	2.2E-02	2.7E-02	3.1E-02	3.9E-02	4.7E-02	5.4E-02	6.0E-02	6.6E-02	7.5E-02	8.3E-02	8.5E-02	9.3E-02	1.0E-01	1.1E-01	1.1E-01	1.2E-01
16	5.6E-03	1.1E-02	1.6E-02	2.1E-02	2.6E-02	3.0E-02	3.8E-02	4.5E-02	5.2E-02	5.8E-02	6.3E-02	7.2E-02	8.0E-02	8.2E-02	8.9E-02	9.8E-02	1.0E-01	1.1E-01	1.1E-01
17	5.4E-03	1.1E-02	1.6E-02	2.0E-02	2.5E-02	2.9E-02	3.7E-02	4.4E-02	5.0E-02	5.6E-02	6.1E-02	7.0E-02	7.7E-02	7.8E-02	8.5E-02	9.4E-02	1.0E-01	1.0E-01	1.1E-01
18	5.2E-03	1.0E-02	1.5E-02	1.9E-02	2.4E-02	2.8E-02	3.5E-02	4.2E-02	4.8E-02	5.3E-02	5.8E-02	6.7E-02	7.4E-02	7.5E-02	8.1E-02	9.0E-02	9.5E-02	9.8E-02	1.0E-01
19	5.1E-03	9.9E-03	1.4E-02	1.9E-02	2.3E-02	2.7E-02	3.4E-02	4.0E-02	4.6E-02	5.1E-02	5.6E-02	6.4E-02	7.1E-02	7.2E-02	7.8E-02	8.6E-02	9.1E-02	9.4E-02	9.8E-02
20	4.9E-03	9.5E-03	1.4E-02	1.8E-02	2.2E-02	2.6E-02	3.3E-02	3.9E-02	4.4E-02	4.9E-02	5.4E-02	6.2E-02	6.8E-02	6.9E-02	7.5E-02	8.3E-02	8.7E-02	9.0E-02	9.3E-02
21	4.7E-03	9.2E-03	1.3E-02	1.7E-02	2.1E-02	2.5E-02	3.1E-02	3.7E-02	4.3E-02	4.7E-02	5.2E-02	5.9E-02	6.5E-02	6.6E-02	7.2E-02	7.9E-02	8.3E-02	8.6E-02	8.9E-02
22	4.5E-03	8.8E-03	1.3E-02	1.7E-02	2.0E-02	2.4E-02	3.0E-02	3.6E-02	4.1E-02	4.6E-02	5.0E-02	5.7E-02	6.2E-02	6.3E-02	6.9E-02	7.6E-02	8.0E-02	8.2E-02	8.5E-02
23	4.4E-03	8.5E-03	1.2E-02	1.6E-02	2.0E-02	2.3E-02	2.9E-02	3.5E-02	3.9E-02	4.4E-02	4.8E-02	5.4E-02	6.0E-02	6.1E-02	6.6E-02	7.2E-02	7.6E-02	7.8E-02	8.1E-02
24	4.2E-03	8.2E-03	1.2E-02	1.6E-02	1.9E-02	2.2E-02	2.8E-02	3.3E-02	3.8E-02	4.2E-02	4.6E-02	5.2E-02	5.7E-02	5.8E-02	6.3E-02	6.9E-02	7.2E-02	7.4E-02	7.7E-02
25	4.1E-03	7.9E-03	1.2E-02	1.5E-02	1.8E-02	2.1E-02	2.7E-02	3.2E-02	3.6E-02	4.0E-02	4.4E-02	5.0E-02	5.5E-02	5.6E-02	6.0E-02	6.6E-02	6.9E-02	7.1E-02	7.3E-02
26	3.9E-03	7.7E-03	1.1E-02	1.4E-02	1.8E-02	2.1E-02	2.6E-02	3.1E-02	3.5E-02	3.9E-02	4.2E-02	4.8E-02	5.2E-02	5.3E-02	5.8E-02	6.3E-02	6.6E-02	6.8E-02	7.0E-02
27	3.8E-03	7.4E-03	1.1E-02	1.4E-02	1.7E-02	2.0E-02	2.5E-02	3.0E-02	3.4E-02	3.7E-02	4.1E-02	4.6E-02	5.0E-02	5.1E-02	5.5E-02	6.0E-02	6.3E-02	6.4E-02	6.6E-02
28	3.7E-03	7.1E-03	1.0E-02	1.3E-02	1.6E-02	1.9E-02	2.4E-02	2.8E-02	3.2E-02	3.6E-02	3.9E-02	4.4E-02	4.8E-02	4.9E-02	5.3E-02	5.7E-02	6.0E-02	6.1E-02	6.3E-02
29	3.5E-03	6.9E-03	1.0E-02	1.3E-02	1.6E-02	1.8E-02	2.3E-02	2.7E-02	3.1E-02	3.4E-02	3.7E-02	4.2E-02	4.6E-02	4.7E-02	5.0E-02	5.5E-02	5.7E-02	5.8E-02	6.0E-02
30	3.4E-03	6.6E-03	9.7E-03	1.2E-02	1.5E-02	1.8E-02	2.2E-02	2.6E-02	3.0E-02	3.3E-02	3.6E-02	4.0E-02	4.4E-02	4.5E-02	4.8E-02	5.2E-02	5.4E-02	5.5E-02	5.7E-02
31	3.3E-03	6.4E-03	9.3E-03	1.2E-02	1.5E-02	1.7E-02	2.1E-02	2.5E-02	2.9E-02	3.2E-02	3.4E-02	3.9E-02	4.2E-02	4.3E-02	4.6E-02	4.9E-02	5.1E-02	5.3E-02	5.4E-02
32	3.2E-03	6.2E-03	9.0E-03	1.2E-02	1.4E-02	1.6E-02	2.1E-02	2.4E-02	2.7E-02	3.0E-02	3.3E-02	3.7E-02	4.0E-02	4.1E-02	4.4E-02	4.7E-02	4.9E-02	5.0E-02	5.1E-02
33	3.1E-03	6.0E-03	8.7E-03	1.1E-02	1.4E-02	1.6E-02	2.0E-02	2.3E-02	2.6E-02	2.9E-02	3.1E-02	3.5E-02	3.8E-02	3.9E-02	4.2E-02	4.5E-02	4.6E-02	4.7E-02	4.8E-02
34	3.0E-03	5.7E-03	8.3E-03	1.1E-02	1.3E-02	1.5E-02	1.9E-02	2.2E-02	2.5E-02	2.8E-02	3.0E-02	3.4E-02	3.7E-02	3.7E-02	4.0E-02	4.2E-02	4.4E-02	4.5E-02	4.6E-02
35	2.9E-03	5.5E-03	8.0E-03	1.0E-02	1.3E-02	1.5E-02	1.8E-02	2.1E-02	2.4E-02	2.7E-02	2.9E-02	3.2E-02	3.5E-02	3.5E-02	3.8E-02	4.0E-02	4.2E-02	4.2E-02	4.3E-02
36	2.8E-03	5.3E-03	7.7E-03	1.0E-02	1.2E-02	1.4E-02	1.8E-02	2.1E-02	2.3E-02	2.5E-02	2.7E-02	3.1E-02	3.3E-02	3.4E-02	3.6E-02	3.8E-02	3.9E-02	4.0E-02	4.1E-02
37	2.7E-03	5.1E-03	7.5E-03	9.6E-03	1.2E-02	1.3E-02	1.7E-02	2.0E-02	2.2E-02	2.4E-02	2.6E-02	2.9E-02	3.2E-02	3.2E-02	3.4E-02	3.6E-02	3.7E-02	3.8E-02	3.8E-02
38	2.6E-03	5.0E-03	7.2E-03	9.2E-03	1.1E-02	1.3E-02	1.6E-02	1.9E-02	2.1E-02	2.3E-02	2.5E-02	2.8E-02	3.0E-02	3.0E-02	3.2E-02	3.4E-02	3.5E-02	3.6E-02	3.6E-02
39	2.5E-03	4.8E-03	6.9E-03	8.9E-03	1.1E-02	1.2E-02	1.5E-02	1.8E-02	2.0E-02	2.2E-02	2.4E-02	2.7E-02	2.8E-02	2.9E-02	3.0E-02	3.2E-02	3.3E-02	3.4E-02	3.4E-02
40	2.4E-03	4.6E-03	6.6E-03	8.5E-03	1.0E-02	1.2E-02	1.5E-02	1.7E-02	1.9E-02	2.1E-02	2.3E-02	2.5E-02	2.7E-02	2.7E-02	2.9E-02	3.1E-02	3.1E-02	3.2E-02	3.2E-02
45	1.9E-03	3.7E-03	5.4E-03	6.9E-03	8.2E-03	9.5E-03	1.2E-02	1.3E-02	1.5E-02	1.6E-02	1.7E-02	1.9E-02	2.0E-02	2.0E-02	2.1E-02	2.2E-02	2.3E-02	2.3E-02	2.3E-02
50	1.5E-03	2.9E-03	4.1E-03	5.3E-03	6.3E-03	7.2E-03	8.7E-03	1.0E-02	1.1E-02	1.2E-02	1.3E-02	1.4E-02	1.4E-02	1.4E-02	1.5E-02	1.5E-02	1.5E-02	1.5E-02	1.6E-02

Figure H-1
UNIT RISKS FOR CONTINUOUS EXPOSURES AS A FUNCTION OF AGE AT ONSET AND EXPOSURE DURATION



Appendix I – Supplemental Information on Use of the LAA Non-Cancer RfC

Table I-1. Adjustment Factors for Time Since First Exposure (TSFE)

Age first exp.	TSFE	$p(BMCL_{28},TSFE)$	AF(TSFE)
0	70	0.614	1.000
1	69	0.595	0.970
2	68	0.576	0.939
3	67	0.556	0.906
4	66	0.536	0.873
5	65	0.515	0.839
6	64	0.493	0.804
7	63	0.472	0.769
8	62	0.450	0.733
9	61	0.428	0.698
10	60	0.406	0.662
11	59	0.385	0.627
12	58	0.364	0.592
13	57	0.343	0.559
14	56	0.323	0.526
15	55	0.303	0.494
16	54	0.284	0.463
17	53	0.266	0.433
18	52	0.249	0.405
19	51	0.232	0.379
20	50	0.217	0.353
21	49	0.202	0.329
22	48	0.188	0.307
23	47	0.176	0.286
24	46	0.164	0.267
25	45	0.153	0.249
26	44	0.142	0.232
27	43	0.133	0.217
28	42	0.124	0.202
29	41	0.116	0.189
30	40	0.109	0.177
31	39	0.102	0.166
32	38	0.096	0.156
33	37	0.090	0.147
34	36	0.085	0.139
35	35	0.080	0.131
36	34	0.076	0.124
37	33	0.072	0.118
38	32	0.069	0.112
39	31	0.066	0.107
40	30	0.063	0.102
41	29	0.060	0.098
42	28	0.058	0.094
43	27	0.056	0.091
44	26	0.054	0.088
45	25	0.052	0.085
46	24	0.051	0.083
47	23	0.049	0.080
48	22	0.048	0.078
49	21	0.047	0.076
50	20	0.046	0.075
51	19	0.045	0.073
52	18	0.044	0.072
53	17	0.043	0.071
54	16	0.043	0.070
55	15	0.042	0.069
56	14	0.042	0.068
57	13	0.041	0.067
58	12	0.041	0.066
59	11	0.040	0.066
60	10	0.040	0.065
61	9	0.040	0.065
62	8	0.039	0.064
63	7	0.039	0.064
64	6	0.039	0.063
65	5	0.039	0.063
66	4	0.038	0.063
67	3	0.038	0.062
68	2	0.038	0.062
69	1	0.038	0.062

Figure I-1. Dependence of LPT Prevalence on TSFE. Source: Figure 5-4 in U.S. EPA (2014)

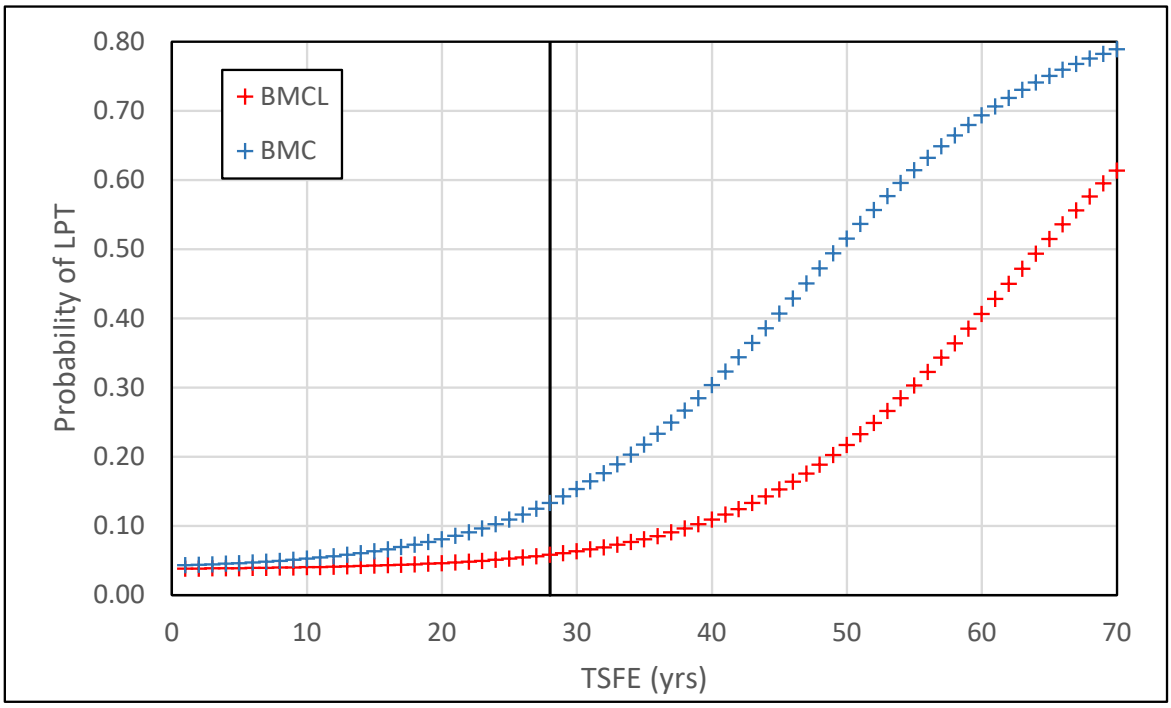
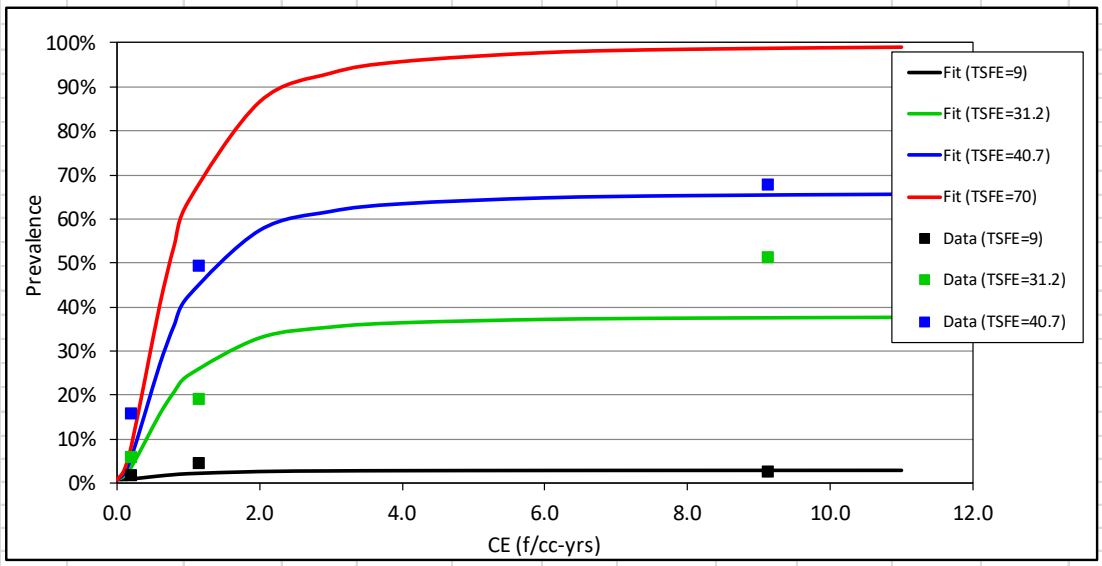
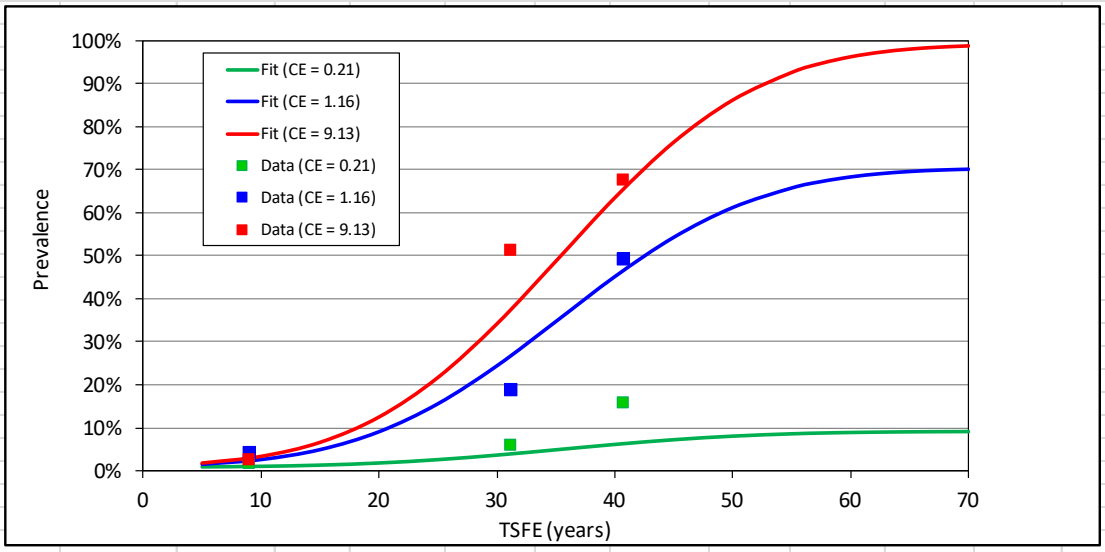


Figure I-2. Observed vs predicted prevalence of localized pleural thickening (LPT) based on the cumulative normal dichotomous Hill (CNDH) model.

Panel A: Observed vs Predicted Prevalence of LPT as a Function of CE, Stratified by TSFE



Panel B: Observed vs Predicted Prevalence of LPT as a Function of TSFE, Stratified by CE



CE Bins	LB	UB	N	Median
1	0.00	0.64	145	0.21
2	0.64	2.06	144	1.16
3	2.06	96.9	145	9.13
All	0.00	96.9	434	1.16

TSFE Bins	LB	UB	N	Median
1	0.0	23.0	144	9.0
2	23.0	35.5	145	31.2
3	35.5	54.0	145	40.7
All	0.00	54.0	434	31.3

The smooth lines are the model predictions, while the square symbols represent the data. Panel A compares observed and predicted prevalence as a function of cumulative exposure CE), stratified by time since first exposure (TSFE). Panel B compares observed and predicted prevalence as a function of TSFE, stratified by CE.

Appendix J – Evaluating Uncertainty for Sequential Exposures to LAA

In cases where there is an interruption of two exposures that occur over a long period of time at different age intervals, it may sometimes be difficult to judge how to stratify complex exposure patterns into discrete scenarios. At the discretion of the Regional risk assessor/TRW Asbestos Committee, the HQ calculated using equation 32 (Section 7.3.2.2) should be reported in the main body of the HHRA text. In the Uncertainty Section of the HHRA, the HQ calculated using equation 32 (Section 7.3.2.2) and the HQ calculated using the following equations can be used as an estimate of the potential range in the uncertainty:

Step 1: Calculate the HQ for each scenario separately, as follows:

$$TWF1 = ET1/24 \bullet EF1/365 \bullet ED1/70 \quad \text{(Eq. J-1)}$$
$$TWF2 = ET2/24 \bullet EF2/365 \bullet ED2/70 \quad \text{(Eq. J-2)}$$

$$HQ1 = CA1 \bullet TWF1 \bullet AF(TSFE1) / RfC \quad \text{(Eq. J-3)}$$
$$HQ2 = CA2 \bullet TWF2 \bullet AF(TSFE2) / RfC \quad \text{(Eq. J-4)}$$

Step 2: Calculate the HQ as follows:

$$HQ(total) = HQ1 + HQ2 \quad \text{(Eq. J-5)}$$

Note that the HQ value computed using equation J-5 will be generally be smaller than the HQ value computed using equation 34 in the main body of the text (Section 7.3.2.2). The interval between the two values may be characterized as an estimate of the uncertainty in the hazard.

Example Calculation:

If approved by the U.S. EPA Regional Risk Assessor/TRW Asbestos Committee, an alternate HQ may also be calculated to generate an estimate of the uncertainty in the hazard.

Example: An individual is exposed to LAA in air during two different age intervals in life. Exposure parameters are as follows:

Parameter	Interval 1	Interval 2
CA (s/cc)	0.0010	0.0080
ET (hours/d)	24	12
EF (days/year)	350	150
Age at start (years)	10	25
Age at stop (years)	20	50
ED (years)	10	25

HQ calculated using Equation 34 in the main body of the text (Section 7.3.2.2):

TWF1 = 24 hours/24 • 350 days/365 • 10 years/70 = 0.137

TWF2 = 12 hours/24 • 150 days/365 • 25 years/70 = 0.073

TSFE = 70 years – 10 years = 60 years
AF(60) = 0.662 (from Table I-1)

HQ1 = 0.001 s/cc • 0.137 / 9 x 10^{-5} f/cc = 1.52
HQ2 = 0.008 s/cc • 0.073 / 9 x 10^{-5} f/cc = 6.49

HQ(total) = (1.52 + 6.49) • 0.662 = 5.30 (round to 5)

<u>HQ calculated using Equations J-1 through J-5:</u>
TWF1 = 24 hours/24 • 350 days/365 • 10 years/70 = 0.137
TWF2 = 12 hours/24 • 150 days/365 • 25 years/70 = 0.073

TSFE1 = 70 years – 10 years = 60 years
AF(60) = 0.662 (from Table I-1)
TSFE2 = 70 years – 25 years = 45 years
AF(45) = 0.249 (from Table I-1)

HQ1 = 0.001 s/cc • 0.137• 0.662 / 9 x 10^{-5} f/cc = 1.01
HQ2 = 0.0080 s/cc • 0.073 • 0.249 / 9 x 10^{-5} f/cc = 1.62

HQ(total) = 1.01 + 1.62 = 2.63 (round to 3)