Technical Guidance for the Calculation of Asbestos-Related Risk in Soils for the Basic Management Incorporated (BMI) Complex and Common Areas

Prepared For:

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List of Acronyms

ABS – Activity-Based Sampling
ARR – Asbestos Related Risk
AS – Analytical Sensitivity
BCL – Baseline Concentration Level
BMI – Basic Management, Incorporated
BRC – Basic Remediation Company
CSM – Conceptual Site Model
CTE – Central Tendency Exposure
DQOs – Data Quality Objectives
DVSR – Data Validation Summary Report
EDD – Electronic Data Deliverables
EPC – Exposure Point Concentration
FBAS – Fluidized Bed Asbestos Segregator
IRIS – Integrated Risk Information System
IUR – Inhalation Unit Risk Factor
MCL – Maximum Contaminant Level
NAS – National Academy of Sciences
NDEP – Nevada Division of Environmental Protection
OLM – Ordinary Light Microscopy
OSWER – Office of Solid Waste and Emergency Response
PCM – Phase Contrast Microscopy
PCMe – PCM-equivalent
PEF – Particulate Emission Factor
PLM – Polarized Light Microscopy
QA – Quality Assurance
QAPP – Quality Assurance Project Plan
QC – Quality Control
RfC – Reference Concentration
RME – Reasonable Maximum Exposure
SAP – Sampling and Analysis Plan
SOP – Standard Operating Procedure
TEM – Transmission Electron Microscopy
TR – Target Risk
TWF – Time Weighting Factor
UCL – Upper Confidence Limit
USEPA – United States Environmental Protection Agency

1.0 Overview

This guidance document describes a process for characterizing asbestos-related cancer risk (ARR) for asbestos fibers in soils for the Basic Management, Inc. (BMI) Complex and Common Areas in the State of Nevada. The guidance combines information for sampling asbestos in soils, modeling the release and transport of asbestos from soil into air, and calculating ARR from inhalation of respirable asbestos fibers. This document is intended to provide methodological direction to human health risk assessors, contractors, consultants, and managers who are involved in, or who evaluate, soil disturbing activities with known or suspected presence of asbestos contamination in soils at the BMI Complex and Common Areas sites.

Historically, Nevada Division of Environmental Protection (NDEP) guidance for calculating ARR has been based on a 2003 draft protocol for assessing ARR that was prepared for the United States Environmental Protection Agency's (USEPA's) Office of Solid Waste and Emergency Response (OSWER) (Berman and Crump 2003). Berman and Crump's draft protocol assigned different cancer potency factors to chrysotile and amphibole forms of asbestos, and associated inhalation carcinogenicity with fibrous structures longer than 10 µm and with a diameter less than 0.4 µm. In NDEP's previous ARR guidance, the draft protocol was used in conjunction with other work by Berman (Berman and Kolk 2000) for a modified elutriator method to separate respirable asbestos fibers from bulk soil samples. The modified elutriator method has had operational problems; it is difficult to decontaminate the equipment, and the equipment is too large to fit under a standard laboratory hood. Additionally, the modified elutriator method cost per sample is fairly high. As a result of the operational difficulties and the high cost, the modified elutriator is presently not supported by any analytical laboratory.

This revised ARR guidance describes the use of the fluidized bed asbestos segregator (FBAS) to replace Berman and Kolk's modified elutriator. The FBAS is a sample preparation instrument that utilizes air elutriation (separating particles based on size, shape, and density using a stream of gas or liquid flowing in a direction usually opposite to the direction of sedimentation) to separate light weight asbestos structures from heavier matrix particles and to deposit these structures onto a filter (USEPA 2018). The FBAS unit is compact and fits into a standard laboratory fume hood. The components of the unit are relatively easy to decontaminate or are disposable. The FBAS unit construction and operation costs are relatively low and sample throughput is high (up to 20 samples per day) (USEPA 2018).

In this guidance, NDEP also recommends the use of inhalation unit risk factors (IURs) for asbestos fibers described by USEPA in their *Framework for Investigating Asbestos-Contaminated Superfund Sites* (USEPA 2008a).IURs are based on dose-response information summarized in USEPA (1986) and published in the Integrated Risk Information System (IRIS) electronic database[1]. These IUR values are used with an

[1] A database of non-cancer and cancer health effects information maintained by USEPA's National Center for Environmental Assessment used to support risk assessment activities under Superfund and other USEPA programs.

asbestos fiber counting protocol that associates potential cancer risks with fibrous structures longer than 5 µm and with a diameter less than 3 µm.

This guidance is organized in a manner that provides a brief overview of the issues associated with the characterization of ARR including the importance of the data quality objectives (DQO) process and development of a conceptual site model (CSM), and then proceeds to outline the methods and equations used for calculating risk.

2.0 Introduction

Asbestos exposure has been tied to various respiratory diseases, including malignant pleural mesothelioma (i.e., cancer affecting the lining surrounding the lung), lung cancer (i.e., cancer affecting the tissue in the lung), and non-malignant respiratory effects described below. The correlation between asbestos exposure and these effects has been supported by clinical observation and analysis of epidemiological data collected from exposed cohorts. This section sets the stage for ARR assessment, includes a brief review of asbestos toxicology followed by a summary of approaches to sample design, quality control, and site assessment.

2.1 Asbestos

Asbestos is a generic term commonly used to describe a group of fibrous silicate minerals that occur naturally in the environment and have been used extensively in commercial development. One of the most commonly accepted definitions of asbestos includes the fibrous varieties of six minerals that can be broken down into two types: 1) chrysotile (serpentine) and 2) amphiboles (amosite, crocidolite, tremolite, anthophyllite, and actinolite). The relative potency of asbestos is a complex function of its physical and chemical attributes, which include fiber size (diameter and length), shape (aspect ratio), and type (i.e., fiber mineralogy). Individual fibers may be organized or aggregated in groups called structures, which may be in the form of bundles, clusters, or matrices.

Inhalation is the primary route of asbestos exposure for humans and can result in pulmonary diseases including malignant mesothelioma and lung cancer (Bourdes et al. 2000; Metintas et al. 2005; Pira et al. 2005). Noncarcinogenic adverse effects of asbestos inhalation include fibrosis (asbestosis), diffuse pleuritis, and local pleural plaques. USEPA derives and employs reference concentrations (RfCs) to assess the adverse effects of exposure to noncarcinogenic chemicals, but USEPA does not publish an RfC for nonspecific forms of asbestos in IRIS. USEPA has published an RfC for Libby amphibole in IRIS; Libby amphibole is a specific type of amphibole asbestos containing tremolite, winchite, and richterite that is associated with a vermiculite mine in Libby, Montana. However, IRIS notes that this RfC is applicable to Libby amphibole only and therefore it is not applicable to this guidance.

2.2 Asbestos Inhalation Carcinogenicity

Asbestos has been associated in occupational epidemiology studies with a type of fibrosis (asbestosis), diffuse pleuritis, local pleural plaques, lung cancer, and mesothelioma. Among these endpoints, lung cancer and mesothelioma due to inhalation exposures are generally considered to be limiting (ATSDR 2001) and are the basis for the dose-response criteria applied in Superfund (USEPA 2008a) and other regulatory frameworks. As stated in USEPA (2008a), "[I]ngestion of asbestos via drinking water has not historically been considered an important exposure route when compared to inhalation. The release of asbestos from soil and dust to the air is thought to be the primary route of exposure, and warrants inclusion of a methodology for soil and dust analyses."

Asbestos fibers are believed to induce carcinogenicity directly via physical interaction with the mitosis of dividing cells after being phagocytized by the target cells, or indirectly as a result of DNA and chromosome damage by asbestos-induced reactive oxygen and nitrogen species. Asbestos-triggered mutagenic events in genes associated with cell growth, DNA repair, or other functional processes may lead to modification of corresponding signaling pathways. Chronic inflammation due to the presence of fibers may also lead to the accumulation of mutagenic events by increasing cell proliferation and other mechanisms.

Meta-analyses of information derived from epidemiologic studies (Berman and Crump 2008a, 2008b) have suggested that the considerable variability in carcinogenic potency of asbestos across published epidemiology studies, and associated uncertainty, might be substantially reconciled if fiber size and mineral type are considered. Berman and Crump (2008a) derived separate inhalation unit risk (IUR) cancer potency values (units of risk per fibers/cc) for amphibole minerals and chrysotile based on a fiber counting protocol that assigned cancer potency to only fibers >10 µm in length. These IUR estimates were based on the methods developed in their earlier work (Berman and Crump 2003), and again provided a basis for concluding that the cancer potency of chrysotile was significantly less than for amphibole minerals, and that longer fibers were dominant for carcinogenicity. Differing potency is consistent with chrysotile fibers being more readily depleted of magnesium and other cations, thereby weakening the fibers and facilitating their dissolution in the lungs. Amphibole fibers are more resistant to this type of leaching, and therefore have a much longer biological residence time.

In contrast to the conclusions of Berman and Crump (2003, 2008a, 2008b), USEPA's asbestos health assessment (USEPA 1986) assigned equal carcinogenic potency to chrysotile and amphibole forms of asbestos and assigned cancer potency to fibers >5 µm in length. However, both USEPA (1986) and Berman and Crump employed similar models to estimate lung cancer and mesothelioma potency factors from occupational exposure studies and both used lifetable analysis to develop lifetime cancer risk estimates from the potency factors. Lifetable analysis is necessary because the dose-response curve for cancer risk is dependent on the duration of exposure and the age at which an individual's exposure begins.

In the 2000s, EPA's OSWER proposed an approach based on Berman and Crump's work in 2001 and 2003 to estimate cancer potency for each of 20 bins consisting of different combinations of mineral type (chrysotile or amphibole) and dimensions (length and width). To evaluate the defensibility of the IUR value that USEPA developed based on the 1986 asbestos health assessment, USEPA convened a Science Advisory Board panel to review OSWER's proposal (USEPA 2008b). After reviewing the proposal, the panel "generally agreed that the scientific basis as laid out in the technical document in support of the proposed method is weak and inadequate. A primary concern is the lack of available data to estimate the transmission electron microscopy (TEM) specific levels of exposure for the epidemiological studies utilized in this analysis." Subsequent to the Science Advisory Board review, USEPA has not pursued revisions to the 1986 asbestos health assessment and the asbestos IUR value published in IRIS has not been revised since 1988.

Relevant to the primary concern expressed by the Science Advisory Board, Berman has pointed out that site-specific risks related to historical exposures cannot be reliably estimated without accounting for the analytical method, the dimensions of fibers, and the fraction of fiber types at a particular site (Berman 2011). The attributes of the historical epidemiological data that are relied upon for dose-response modeling are notoriously difficult to characterize with regard to relative amounts of chrysotile and amphibole and fiber dimensions. Use of later TEM results to convert historical total fiber counts to counts of specific fiber types, lengths, and diameters requires the considerable assumption that workplaces where early epidemiology studies were done were comparable in these factors to those where the later TEM measures were made. Silverstein et al. (2009) similarly described a number of sources of uncertainty in asbestos risk assessment that can only be partially addressed by modeling, and summarized the nature of the problem facing USEPA in this manner:

> Trying to turn fundamentally unreliable data into valid and reliable output is statistical alchemy, no matter how sophisticated and complex the mathematical models. The repeated efforts by the USEPA to characterize the relative cancer potencies for different asbestos fiber types and sizes have not been able to overcome the limitations of the exposure data in the epidemiological studies, and the resulting problems with the [Berman and Crump] 2008 model led USEPA to conclude that it could not be used to make public policy decisions.

2.2.1 Recommendation for Asbestos IUR Value

NDEP's previous ARR guidance from 2011 recommended that the IUR values for chrysotile and amphibole from Berman and Crump (2008a) be used in conjunction with the modified elutriator method to separate respirable asbestos fibers from bulk soil (Berman and Kolk 2000). A major reason for the recommendation was to maintain consistency with asbestos data from the period beginning in 2003 which utilized these methods. Recognizing that USEPA recommended the use of the IRIS IUR in their Superfund asbestos risk guidance (USEPA 2008a), in the 2011 ARR guidance NDEP provided a comparison of asbestos cancer risk results calculated using the Berman and

Crump IURs with results using EPA's IUR. This comparison is included as Appendix B of this document. The comparisons were made using a range of asbestos soil concentrations from four BMI Complex and Common Areas sampling campaigns and indicated that the two approaches provide similar cancer risk results. As discussed in Section 3.2, the FBAS that is recommended to replace the unavailable modified elutriator (Berman and Kolk 2000) to separate asbestos fibers from the soil matrix has been evaluated using the fiber dimensions pertaining to USEPA's IUR. Direct comparison of soil fiber concentrations from the two instruments is impossible, but it is likely that the differences would have a greater impact on ARR than the relatively small differences between ARR calculated using USEPA versus Berman and Crump IURs for BMI sites. Therefore, NDEP recommends the use of IUR values based on USEPA (1986) and described in Superfund asbestos risk assessment guidance (USEPA 2008a) for calculating ARR using asbestos soil concentrations derived from the FBAS instrument.

2.3 Site Assessment, Sampling Design, and Quality Control

A CSM is used in risk assessment to provide an overall picture of site conditions and to ensure that all potentially complete exposure pathways are addressed for all potential receptors. The CSM provides a means of identifying potential sources of asbestos, impacted media (e.g., soils), exposure routes, and potential receptors during and after remediation. CSM development is generally an iterative process (i.e., updated as new data are collected and/or data gaps are defined) and is therefore useful for decision making at any stage of a project.

A quality assurance/quality control (QA/QC) program should be specified in the Quality Assurance Project Plan (QAPP) to provide an appropriate level of assurance that the data collected during sampling events are both reliable and usable for decision-making purposes. Data validation should be conducted to determine compliance of QA/QC measures and achievement of the project data quality objectives (DQOs), and Data Usability should be completed prior to using the data in an ARR. Criteria that should be included in the subsequent Data Validation Summary Report (DVSR) are discussed in a separate asbestos data validation guidance. The data should not be used for ARR assessment unless these criteria are satisfied.

Site-specific DQOs should be specified to provide the basis for sampling design and analysis as well as to describe how the data will be used for evaluating ARR. The DQOs process (USEPA 2006) is an iterative tool that ensures the systematic application of the scientific method to environmental problems. It is a seven-step planning process for data collection in support of site-specific risk management decisions. This allows for proper planning of the project, including the identification of the types and quality of data required for decision-making purposes. Additionally, the DQOs process is an effective means for determining the necessary amount and quality of data needed to support decision making. This directly affects the outcome of the risk assessment.

For the BMI Complex and Common Areas, there historically have been few or no asbestos fibers found in samples or collections of samples, especially for the post-

remediation assessments that commonly precede release of property. However, even when the number of fibers observed is zero, the reasonable maximum exposure (RME) concentration of fiber counts, which accounts for uncertainty, is nonzero and can result in calculation of an unacceptable ARR. As described in Section 4.0 of this guidance, implementation of the DQOs process can help by ensuring that the number of samples is sufficient so that the uncertainty in the outcome does not drive an unacceptable ARR. The DQOs process steps should be documented in a detailed sampling and analysis plan (SAP), which should be prepared to guide data collection activities that meet the project-specific DQOs.

3.0 Risk Characterization

As noted above, the formulation for asbestos risk calculations is different than for chemical risk calculations. The following subsections provide a brief overview of methods for estimating ARR. Formulae used for characterizing risk for a variety of potential receptors are also provided.

3.1 Potentially Complete Exposure Pathways

The two exposure routes by which asbestos intake can occur are ingestion and inhalation. Dermal absorption of asbestos fibers does not occur, although dermal adherence of fibers may lead to secondary ingestion or inhalation (USDHHS 2005). Asbestos ingestion has also raised concerns in the scientific community with respect to association with cancers other than lung cancer and mesothelioma. The National Academy of Sciences (NAS) has evaluated the potential association of asbestos with pharyngeal, laryngeal, esophageal, stomach, and colorectal cancer (NAS 2006). The NAS committee "found the evidence to be *sufficient* to infer a causal relationship for laryngeal cancer; to be *suggestive* for pharyngeal, stomach, and colorectal cancers; and to be *inadequate* for esophageal cancer." However, these findings are not necessarily associated with direct ingestion of asbestos in drinking water or some other medium, since NAS also noted that exposure of these tissues to asbestos fibers may occur "by swallowing secretions following clearance from the respiratory tract." The USEPA publishes a maximum contaminant level (MCL) drinking water standard for asbestos fibers with length >10 µm of 7 million fibers per liter (http://www.epa.gov/safewater/contaminants/index.html). This MCL is based upon increased risk of developing benign intestinal polyps. However, there are no drinking water sources at the BMI Complex that are contaminated with asbestos.

The exposure route that poses the greatest ARR at the BMI Complex is inhalation. Inhalation of asbestos fibers can lead to lung carcinoma and malignant mesothelioma (Bourdes et al. 2000; Pira et al. 2005). Specifically, the exposure pathway of asbestos inhalation following suspension of asbestos fibers from soil is the focus of this asbestos risk assessment guidance.

Receptor exposure scenarios that are considered in this guidance are construction worker, off-site resident, on-site resident, and commercial/industrial worker. The methods by which ARR is estimated for these scenarios are described below.

3.2 Sampling and Analysis Methods

The methods used for surface soil sampling for asbestos are outlined in the Standard Operating Procedures (SOP) 12 section of the December 2008 version of the *BRC Field Sampling and Standard Operating Procedures, BMI Common Areas, Clark County, Nevada* document (Basic Remediation Company 2008). This document outlines the procedures for the collection of grab samples for determining moisture and silt content, composite sample collection, and quality control sampling. Taken from SOP 12, the collection procedures at the BMI Complex and Common Areas consist of:

> Each selected sampling location is to serve as the center of a 50 feet by 50 feet sampling grid, which is to be further divided into four quadrant grid squares that are each 25 feet on a side. Grab samples for determination of moisture and silt content are to be collected from the center of the overall sampling grid. Samples to be collected for determination of asbestos content are to be composites constructed from four component samples with one component collected from a pre-selected, random location from within each of the four grid squares (quadrants) of the sampling grid.

The FBAS instrument and test method (USEPA 2018) uses air flow to separate light weight asbestos fibers from a denser soil matrix. Soil samples are mixed with clean sand, placed in a glass vessel, and fluidized by vibration and air flow. Small particles, including asbestos fibers if present, are elutriated and collected on a filter which is then prepared and analyzed by TEM. Initial testing of different FBAS prototypes indicated that the FBAS was "considerably more sensitive than the Berman elutriator method" (Wright and O'Brien 2007), suggesting that substitution of the modified elutriator method (Berman and Kolk 2000) previously recommended in NDEP ARR guidance with the FBAS should not adversely affect the performance of the segregation method and may result in improved sensitivity.

Januch et al. (2013) described the measurement of asbestos fibers in soil at levels of 0.002–0.005% by weight using the FBAS followed by TEM analysis. Evaluation of the FBAS method for the purpose of quantifying concentrations of the naturally occurring fibrous mineral erionite in soil was conducted by Berry et al. (2019) and resulted in a method detection limit of 0.003% by weight. Additionally, analytical results of performance evaluation standards with nominal concentrations ranging from 0.1% to 0.0001% by weight of erionite were prepared by FBAS soil preparation method and the filters were analyzed by TEM. A linear relationship between the nominal concentration and the concentration estimated by TEM analysis was demonstrated (Berry et al. 2019), providing a measure of confidence in the reliability of the FBAS method. Wroble et al. (2017) compared three preparation and analysis methods for asbestos in soil to determine which method, or combination of methods, produced more reliable soil asbestos data. In addition to FBAS, ASTM Method D7521 (ASTM 2013) was evaluated. ASTM Method D7521 employs sieving to sort soil into different bins by grain size, followed by polarized light microscopy (PLM) and (for the finest size fraction) TEM. Of interest here is their finding that FBAS followed by TEM analysis could detect asbestos fibers at locations where fibers were not detected using the comparable method of ASTM D7521

with TEM analysis (Wroble et al. 2017). Of particular note is that Wroble et al. (2017) also collected personal air samples (where the activity consisted of soil sampling and subsampling) at the locations where soil samples were obtained for the FBAS and ASTM D7521 analyses. Asbestos fibers were detected in nearly every sample filter prepared using the FBAS method, but in only 25% of the ABS samples (Wroble et al. 2017), which might have been due to relatively damp and humid conditions as well as the presence of vegetation. Collectively, these studies support NDEP's recommendation that the FBAS method followed by TEM analysis be utilized to quantify soil concentrations of asbestos fibers.

The main forms of microscopy that have been used for measuring asbestos include ordinary light microscopy (OLM), PLM, phase contrast microscopy (PCM), and TEM. OLM and PLM are used for the purpose of estimating the concentration of asbestos in building materials or soil samples, and PLM supports identification of asbestos mineral fibers based on their optical properties. With respect to identification of smaller fibers of specific dimensions, PCM and TEM methods are applicable.

In the 1980s, the USEPA developed an approach for assessing ARR (*Airborne Asbestos Health Assessment Update*, USEPA (1986)) which assigns equal carcinogenic potencies to amphibole and chrysotile types of asbestos. At the time, the most likely analytical method used for asbestos analysis was PCM. Unlike OLM and PLM, PCM is able to measure smaller asbestos structures and also determine their shape. However, PCM can only resolve particles of sizes greater than approximately 0.25 µm in diameter and 0.5 µm in length. It has been shown in previous studies that PCM significantly underestimates asbestos fiber concentration in air when compared to TEM, primarily because of poor resolution (Perry 2004). Other limitations of PCM include the inability to distinguish between particle mineralogy and in some instances the inability to distinguish between asbestiform and non-asbestiform particles. Depending on the sample matrix, this inability to clearly identify only asbestos fibers could potentially result in overestimation of the concentration of asbestos present on a filter. The possibility of either underestimation from poor resolution, or overestimation from misidentification of non-asbestiform particles, causes PCM to be an inaccurate method for estimation of asbestos concentrations.

Unlike other analytical techniques used for asbestos analysis, TEM is able to distinguish different fiber mineralogies and is able to reveal fibers that are less than 0.01 µm in diameter. As a consequence, different fiber size classes of both amphibole and chrysotile asbestos can be differentiated and asbestos fibers can be distinguished from other types of fibers. Used in conjunction with the cancer potency factors described in IRIS and USEPA asbestos risk assessment guidance (USEPA 2008a), NDEP recommends the use of TEM for asbestos analysis.

NDEP notes that distinction between asbestos structures and fibers are not made in this guidance. NDEP recognizes that asbestos structures are measured using TEM (for example), and that structures can consist of several fibers. ARR is generally based on

measurement of structures rather than fibers, but the terms are used interchangeably in this guidance.

3.3 Exposure Concentration Estimation

Obtaining data for estimating ARR involves obtaining samples from site soils, suspension of soil samples in air, elutriation (that separates asbestos structures from the soil matrix), and analysis by microscopy (USEPA 2018). The sample data in the form of number of fibers of a given type of asbestos per unit volume of air are then combined with fine particulate emission and dispersion models to predict airborne asbestos exposure concentrations and associated risks. Fine particulate emission and dispersion estimates are modeled for different exposure scenarios and are presented separately throughout this guidance, following USEPA (2002). The suitability of these generic particulate emission and dispersion models for predicting concentrations of asbestos fibers in air is defended in Berman and Kolk (2000) by reference to a study of dust emissions from two roads surfaced with asbestos-containing serpentine material. Berman and Kolk (2000; Section 2.3) conclude that the accuracy of modeled airborne asbestos fiber concentrations will be limited by the accuracy of the dust resuspension and dispersion model rather than by the estimate of soil asbestos concentrations or the application of the dust models to asbestos fibers.

EPA's *Framework for Investigating Asbestos-Contaminated Superfund Sites* (USEPA, 2008a) recommends the use of activity-based sampling (ABS) for measuring concentrations of asbestos fibers in air. The ABS approach is based on direct breathing zone sampling of air in response to specific activity. However, it is not clear how the activity (e.g., raking) is applicable to activities associated with exposure scenarios at this site. In addition, this approach would require considerably more resources for sampling, which could involve, for example, raking in protective clothing and increasing the potential for human exposures to a known carcinogen. The reproducibility of ABS measurement is also of concern, since ABS measurements will depend on many factors (e.g., sampler, intensity of activity, wind, moisture content). In this guidance, NDEP recommends modeling of asbestos fiber air concentrations from measured soil concentrations rather than measuring breathing zone concentrations directly during various activities.

Asbestos soil measurements derived using the FBAS method can be combined with particulate emission and dispersion models, which can then be used for predicting airborne exposures and associated risks. The details and protocols for this method are described in USEPA (2018), and examples are provided in Januch et al. (2013), Berry et al. (2019), and Wroble et al. (2017). The USEPA Particulate Emission Factor (PEF) model is used to estimate annual average concentrations of respirable particulates (approximately 10 μm diameter and less) in ambient air (USEPA 2002).

The PEF model has two components. The first component is an atmospheric dispersion term (Q/C_a) that relates air concentrations to particulate emissions from soil. The second component is a particulate emission model related to some specific mechanism of soil

disturbance. The PEF is calculated differently depending on the activities related to the exposure scenario.

The factor Q/C_a reflects the site location, local climate, surface area of the site that is under investigation, and the mechanism of dust dispersion (wind or construction). The dispersion factor is defined in USEPA (2002; Appendix D) as:

[Eq. 1]

$$\frac{Q}{C_a} = A * \exp\left[\frac{(\ln(A_{site}) - B)^2}{C}\right]$$

where A, B, and C are curve-fitting constants (unitless) tabulated in USEPA (2002) and A_{site} is the areal extent of the site or site contamination (acres). The dust emission and dispersion models needed for the construction worker, off-site resident, on-site resident, and commercial/industrial exposure scenarios are outlined in the following subsections.

3.3.1 Construction Worker PEF

The most significant pathway of asbestos exposure to construction workers is by inhalation of fugitive dust from traffic on unpaved roadways and wind erosion of surface soil (USEPA 2002). Construction workers are adults who are generally exposed over a shorter (sub-chronic; between 2 weeks and 7 years) exposure period than residents and commercial/industrial workers. Two PEFs are calculated for this scenario (one for overall construction activities and one for activity on unpaved roadways), which are then used to estimate the total outdoor ambient air dust concentration. The following subsections break the construction worker PEF calculations into three separate parts: 1) sub-chronic PEF for construction activities, 2) sub-chronic PEF for general vehicle traffic on unpaved roadways, and 3) total sub-chronic construction related PEF. As described in Section 5.3.2 of USEPA (2002), dust emissions from unpaved road traffic "typically contribute the majority of dust emissions during construction." The equations in *Part 1* are provided for use at the discretion of site managers should dust emissions from these activities be of particular concern at a site.

Part 1: Sub-chronic PEF for construction activities

The first part of the PEF for construction workers is the sub-chronic PEF for construction activities (PEF_{sc}). This is presented in Eq. 2 and calculated according to Equation E-26 of USEPA (2002) and further defined in Eq. 3 through Eq. 5:

[Eq. 2]

$$PEF_{sc} = \frac{Q}{C}_{sa} * \frac{1}{F_D} * \frac{1}{J'_T}$$

where $\frac{Q}{C}_{sa}$ is the sub-chronic air dispersion factor for the area source related to construction activities (g/m^2 – sec per kg/m^3):

[Eq. 3]

$$\frac{Q}{C_{sa}} = A * \exp\left[\frac{(\ln(A_{site}) - B)^2}{C}\right]$$

where A_{site} is the areal extent of the site or site contamination (acres), and A (value = 2.4538), B (value = 17.5660), and C (value = 189.0426) are fixed constants (USEPA 2002; Equation 5-15, referenced from Equation E-26). The curve-fitting factors A, B, and C used in the PEF_{sc} equation are not location specific, unlike the values for wind-related erosion. Therefore, the values defined for constants A, B, and C apply to sites at any location.

F_D is the dispersion correction factor (unitless) and is calculated according to Equation E-16 of USEPA (2002) by:

[Eq. 4]

$$F_D = 0.1852 + \left(\frac{5.3537}{t_c}\right) + \left(\frac{-9.6318}{t_c^2}\right)$$

in which t_c is the overall construction period in units of hours, and J'_T is the total time-averaged PM_{10} emission flux (g/m^2-sec) and is calculated according to Equation E-25 of USEPA (2002) and further defined in Eq. 6 through Eq. 12:

[Eq. 5]

$$J'_T = \frac{(M_{wind} + M_{excav} + M_{doz} + M_{grade} + M_{till})}{A_{surf} * T}$$

In Eq. 5, T is the overall construction period in units of seconds, calculated as:

[Eq. 6]

$$T = \frac{t_c}{3{,}600\ s/hr}$$

Appendix E in the *U.S. EPA Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (USEPA 2002) defines the time variables *T* and t_c as identical, but with different units with respect to the dispersion correction factor (F_D), described in Equation E-16 in USEPA (2002). In Equation E-25 of USEPA (2002) for J'_T, the variable *T* is defined as the "duration of construction." However, in the *Particulate Matter Case Example* shown in Appendix E, *T* is defined as the length of time that workers are present within the overall construction period whereas t_c is defined as the overall construction period. The Case Example uses a 6-month period, and *T* = 3,744,000 sec while t_c = 4,380 hrs (15,768,000 sec). With respect to t_c, which is used in the calculation of F_D, it appears that F_D is insensitive to reasonable expected values of t_c. When t_c = 3 months, F_D = 0.188, and when t_c = 3 years, F_D = 0.185. The construction PEFs are sensitive to *T*. Construction worker PEFs increase as the value of *T* increases, which means that atmosphere dust loading is inversely proportional to *T*. The relationship of *T* and the construction PEF only seems logical if *T* represents the overall construction

period, such that the mass generated by construction activities is spread out over a longer time period. This interpretation of *T* is also consistent with the time-averaged PM_{10} emission parameter (J'_T), because the mass of wind-generated dust emission and the mass generated by mechanical disturbances must be integrated across a common length of time, which should be the overall construction period. Therefore, a conclusion can be drawn that the *Particulate Matter Case Example* in USEPA (2002) is in error, and that t_c and *T* are identical and relate to the overall construction period. In this guidance, it is assumed that t_c and *T* are identical, but have different units.

M_{wind} is the fugitive dust emitted from wind erosion (g), M_{excav} is the fugitive dust emitted from excavation (g), M_{doz} is the fugitive dust emitted from dozing (g), M_{grade} is the fugitive dust emitted from grading (g), and M_{till} is the fugitive dust emitted from tilling (g). Each of these parameters is defined below.

The fugitive dust emitted from wind erosion is calculated according to Equation E-20 of USEPA (2002) by:

[Eq. 7]

$$M_{wind} = 0.036 * (1 - V) * (\frac{U_m}{U_t})^3 * F(x) * A_{surf} * ED * 8{,}760\ hr/yr$$

where V is the fraction of vegetative cover (unitless – default is set to 0 for construction), U_m is the mean annual wind speed (approximately 3.3 m/s for Las Vegas), U_t is the equivalent threshold of windspeed at 7 m (default is 11.32 m/s), $F(x)$ is a function dependent on U_m/U_t derived from Cowherd et al. (1985) (default is 0.194), A_{surf} is the areal extent of site surface contamination (acres), and ED is the exposure duration (years).

The fugitive dust emitted from excavation is calculated according to Equation E-21 of USEPA (2002) by:

[Eq. 8]

$$M_{excav} = 0.35 * 0.0016 * \frac{\left(\frac{U_m}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} * \rho_{soil} * A_{excav} * d_{excav} * N_A * 10^3 g/kg$$

where U_m is the mean annual wind speed (approximately 3.3 m/s for Las Vegas), M is the gravimetric soil moisture content (EPA (2002; Eq 21) default is 12%), ρ_{soil} is the wet soil bulk density (EPA (2002; Eq 21) default is 1.68 Mg/m^3), A_{excav} is the areal extent of site excavation (m^2), d_{excav} is the average depth of site excavation (m), and N_A is the number of times soil is dumped (EPA (2002; Eq 21) default is 2).

The fugitive dust emitted from dozing is calculated according to Equation E-22 of USEPA (2002) by:

[Eq. 9]

$$M_{doz} = 0.75 * \left(\frac{0.45 * s^{1.5}}{M^{1.4}}\right) * \frac{\sum VKT_{doz}}{S_{doz}} * 10^3 g/kg$$

where s is the percent weight of silt in the soil (EPA (2002; Eq 22) default is 6.9%), M is the gravimetric soil moisture content (EPA (2002; Eq 22) default is 7.9%), S_{doz} is the mean vehicle speed (default is 11.4 km/hr), and $\sum VKT_{doz}$ is the sum of dozing kilometers traveled (km). A calculation $\sum VKT_{doz}$ based on an example provided on page E-28 of USEPA (2002) is given here. This calculation pertains to both dozing and grading, and assumes that the site area is dozed and graded three times during construction with blades that are 8 ft (2.44 m) in length:

[Eq. 10]

$$\sum VKT_{doz} = \frac{\left(\frac{{A_{surf}}^{0.5}}{2.44}\right) * \left({A_{surf}}^{0.5}\right) * 3}{1000\ m/km}$$

The fugitive dust emitted from grading is calculated according to Equation E-23 of USEPA (2002) by:

[Eq. 11]

$$M_{grade} = 0.60 * \left(0.0056 * {S_{grade}}^2\right) * \sum VKT_{grade} * 10^3 g/kg$$

where S_{grade} is the mean vehicle speed (EPA (2002); Eq 23) default is 11.4 km/hr) and $\sum VKT_{grade}$ is the sum of grading kilometers traveled (km) and is integrated in the example calculation for $\sum VKT_{doz}$.

The fugitive dust emitted from tilling is calculated according to Equation E-24 of USEPA (2002) by:

[Eq. 12]

$$M_{till} = 1.1 * s^{0.6} * A_{till} * 4{,}047\ m^2/acre * 10^{-4} ha/m^2 * 10^3 g/kg * NA$$

where s is the site-specific percent weight of silt in the soil, A_{till} is the area extent of the tilling (acres), and NA is the number of times soil is tilled (default is 2).

Part 2: Sub-chronic PEF for unpaved road traffic

During construction, there is generally a considerable amount of construction traffic that operates on unpaved roadways. Activity on these roadways can contribute to the ambient air dust concentrations during construction and therefore can place construction workers at risk. To account for this factor, a sub-chronic PEF for unpaved road traffic (PEF_{sc_road}) during construction is calculated as:

[Eq. 13]

$$PEF_{sc\_road} = \frac{Q}{C_{sr}} * \frac{1}{F_D} * \frac{T * A_R}{M_{road}}$$

Where $\frac{Q}{C_{sr}}$ is the sub-chronic dispersion factor for road segment (g/m^2 – sec per kg/m^3):

[Eq. 14]

$$\frac{Q}{C_{sr}} = A * \exp\left[\frac{(\ln(A_{site}) - B)^2}{C}\right]$$

where A_{site} is the areal extent of the site or site contamination (acres), and A (value = 12.9351), B (value = 5.7383), and C (value = 71.7711) are fixed constants. F_D is the dispersion factor (unitless) as calculated in Eq. 4 (above), T is the total time over which construction occurs (s; equal to exposure duration), A_R is the surface area of contaminated road segment (m^2) in which:

[Eq. 15]

$$A_R = L_R * W_R * 0.092903\ m^2/ft^2$$

where L_R is the length of the road segment (ft; equal to the square root of the site or site contamination for a square area) and W_R is the width of the road segment (default is 20 ft). M_{road} is the fugitive dust emitted from traffic on unpaved roads and is calculated as:

[Eq. 16]

$$M_{road} = \frac{2.6 * \left(\frac{s}{12}\right)^{0.8} * \left(\frac{W}{3}\right)^{0.4}}{\left(\frac{M_{dry}}{0.2}\right)^{0.3}} * \left(\frac{365 - p}{365}\right) * 281.9 * \sum VKT_{road}$$

where s is the road surface silt content (default from historical Site data is 8.5%), W is the mean vehicle weight (default, by example for Eq. E-18 in USEPA (2002) is 8 tons), M_{dry} is the road surface material moisture content under dry, uncontrolled conditions (default is 0.2%), p is the number of days per year with at least 0.01 inches of precipitation (from Exhibit E-4 of USEPA (2002)), and $\sum VKT_{road}$ is the sum of fleet vehicle kilometers traveled during the exposure duration (km) in which:

[Eq. 17]

$$\sum VKT_{road} = \frac{N_V * L_D * \left(\frac{52\ wks/yr}{2} * 5\ days/wk\right)}{1000\ m/km}$$

where N_V is the total number of vehicles traveling the road segment during construction (default, by example for Eq. E-18 in USEPA (2002) is 30) and L_D is the length traveled by each vehicle per day (m/day; assumed to be equal to L_R)[2].

Part 3: Total sub-chronic construction-related PEF

By combining the sub-chronic PEFs for construction activities and unpaved roadways, the total sub-chronic construction-related PEF (PEF_{sc_total}) can then be calculated by:

[Eq. 18]

$$PEF_{sc\_total} = \frac{1}{\left(\frac{1}{PEF_{sc_{road}}}\right) + \left(\frac{1}{PEF_{sc}}\right)}$$

The inverse of PEF_{sc_total} can then be taken to give the total outdoor ambient air dust concentration ($D_{construct}$; kg/m^3):

[Eq. 19]

$$D_{construct} = \frac{1}{PEF_{sc_{total}}}$$

3.3.2 Off-Site Resident PEF

Off-site residents include children and adults who live near the site. Similar to on-site construction workers, the most significant pathway of asbestos exposure to off-site residents is by inhalation of fugitive dust from traffic on unpaved roadways and wind erosion of surface soil (USEPA 2002). Off-site residents are generally exposed over a longer (chronic) exposure period, both during and after construction activities at the adjacent site. During construction activities, off-site residents are assumed to be exposed to fugitive dust emissions resulting from unpaved road traffic, excavation, dozing, grading, tilling, and wind erosion. Post-construction, the receptor is assumed to be exposed to fugitive dust resulting from wind erosion.

Calculation of the PEF for the off-site resident is performed in an identical manner as for an on-site receptor. However, the atmospheric dispersion term (Q/C_a) pertains to particulate concentrations at the *edge*, rather than the *center*, of a square source area.

The PEF for off-site residents (PEF_{off}) is defined as:

[Eq. 20]

$$PEF_{OFF} = \frac{Q}{C_{OFF}} * \left(\frac{1}{J'_{T_{off}}}\right)$$

[2] Assumes each vehicle traverses the road segment, L_R, once per day; refer to fugitive dust emissions of unpaved road traffic section in Appendix E of USEPA (2002).

Where $\frac{Q}{C}_{OFF}$ is the air dispersion factor for the area source (g/m^2 – sec per kg/m^3):

[Eq. 21]

$$\frac{Q}{C}_{OFF} = A * \exp\left[\frac{(\ln(A_{site}) - B)^2}{C}\right]$$

where A_{site} is the areal extent of the site or site contamination (acres), and A, B, and C are location-specific constants for different United States cities from Appendix E, Exhibit E-5 in *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (USEPA 2002). NDEP recommends using the values for Las Vegas, Nevada for risk assessment at the BMI Complex and Common Areas. The location-specific constants are included in the spreadsheet that accompanies this guidance. $J'_{T_{off}}$ is the total time-averaged PM_{10} emission factor:

[Eq. 22]

$$J'_{T\_off} = \frac{M_{road}+M_{wind}+M_{excav}+M_{doz}+M_{grade}+M_{till}+M_{windPC}}{A_{surf}*ED*3.1535E7\ s/yr}$$

where M_{wind} is defined in Eq. 7, M_{excav} is defined in Eq. 8, M_{doz} is defined in Eq. 9, M_{grade} is defined in Eq. 11, M_{till} is defined in Eq. 12, and M_{road} is defined in Eq. 16. A_{surf} is the areal extent of the site (acres), and ED is the exposure duration (years). M_{windPC}, which is the fugitive dust emission from post-construction wind erosion (g), is calculated as in Eq. 7, but the ED parameter is changed to reflect the exposure duration of an off-site receptor and the V parameter may be changed to reflect post-construction vegetation conditions (the default value is 0.5; Equation 5-11 of USEPA (2002)).

The inverse of PEF_{OFF} can then be taken to give the outdoor ambient air dust concentration (D_{OFF}; kg/m^3) for off-site residents:

[Eq. 23]

$$D_{OFF} = \frac{1}{PEF_{OFF}}$$

3.3.3 Commercial and Industrial Worker PEF

Commercial and industrial workers are human receptors that work on the site post-construction. Similar to off-site residents, the most significant pathway for asbestos exposure to commercial or industrial workers is by inhalation of fugitive dust due to wind erosion of surface soil (USEPA 2002). Commercial and industrial workers are generally exposed over the long term (chronic exposure).

[Eq. 24]

$$PEF_{worker} = \frac{Q}{C_{Wind}} * \frac{3{,}600\ s/hr}{0.036 * (1 - V) * \left(\frac{U_m}{U_t}\right)^3 * F(x)}$$

Where $\frac{Q}{C_{Wind}}$ is the air dispersion factor for the area source (g/m^2 – sec per kg/m^3):

[Eq. 25]

$$\frac{Q}{C_{Wind}} = A * \exp\left[\frac{(\ln(A_{site}) - B)^2}{C}\right]$$

where A_{site} is the areal extent of the site or site contamination (acres), and A, B, and C are location-specific constants for different United States cities from Appendix E, Exhibit E-3 in *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (USEPA 2002). NDEP recommends using the values from Las Vegas, Nevada for the BMI Complex and Common Areas. As described in Section 3.3.2, Q/C pertains to particulate concentrations at the *center* of a square source area. The site-specific constants are included in the spreadsheet that accompanies this guidance. V is the fraction of vegetative cover (unitless; default is 0.5), U_m is the mean annual wind speed (approximately 3.3 m/s for Las Vegas), U_t is the equivalent threshold value of windspeed at 7 m (default is 11.32 m/s), and $F(x)$ is a function dependent on U_m/U_t (default is 0.194) derived using Cowherd et al. (1985).

The inverse of PEF_{Worker} provides the outdoor ambient air dust concentration (D_{Worker}; kg/m^3) for commercial and industrial workers:

[Eq. 26]

$$D_{Worker} = \frac{1}{PEF_{Worker}}$$

3.3.4 On-site Resident PEF

On-site residents are receptors that live in areas where future residential development is planned. Similar to commercial and industrial workers, inhalation of fugitive dust due to wind erosion of surface soil (USEPA 2002) is the primary exposure pathway.

[Eq. 27]

$$PEF_{onsite\ resident} = \frac{Q}{C_{Wind}} * \frac{3{,}600\ s/hr}{0.036 * (1 - V) * \left(\frac{U_m}{U_t}\right)^3 * F(x)}$$

Where $\frac{Q}{C_{Wind}}$ is the air dispersion factor for the area source (g/m^2 – sec per kg/m^3):

[Eq. 28]

$$\frac{Q}{C}_{Wind} = A * \exp\left[\frac{(\ln(A_{site}) - B)^2}{C}\right]$$

where A_{site} is the areal extent of the site or site contamination (acres), and A, B, and C are equivalent to those described in Section 3.3.3. As described in Section 3.3.2, Q/C pertains to particulate concentrations at the *center* of a square source area. The site-specific constants are included in the spreadsheet that accompanies this guidance. The definitions and default values for V, the fraction of vegetative cover (unitless), U_m, the mean annual wind speed (m/s), U_t, the equivalent threshold value of windspeed at 7 m (m/s), and $F(x)$ are also equivalent to those described in Section 3.3.3.

The inverse of $PEF_{Onsite\ resident}$ can then be taken to give the outdoor ambient air dust concentration ($D_{Onsite\ resident}$; kg/m^3) for on-site residents:

[Eq. 29]

$$D_{Onsite\ resident} = \frac{1}{PEF_{Onsite\ resident}}$$

3.4 Approaches for Calculating Asbestos-Related Risk

The mathematical models describing the relationship between exposure and disease endpoints for calculating ARR are described in USEPA (1986) and summarized in Appendix E of USEPA (2008a). The model for lung cancer estimates *relative* risk, meaning that the risk of death is proportional to the cumulative exposure to asbestos and to the underlying lung cancer risk in the absence of exposure. For mesothelioma, the model estimates *absolute* risk meaning that the risk of death is proportional to the cumulative exposure to asbestos in a given period and to the time from first exposure.

The 1986 *Airborne Asbestos Health Assessment Update* (USEPA 1986) estimates of lung cancer and mesothelioma potency were based on human epidemiological studies of worker mortality. EPA's lung cancer potency estimate was based on ten epidemiological studies of workers in textile production, friction product manufacturing, insulation production, and mixed product manufacturing. The mesothelioma potency estimate was based on four of those studies for which USEPA judged that the data were sufficient to allow estimation of duration and intensity of asbestos exposure. The calculations to estimate an inhalation unit risk factor (IUR) based on lung cancer and mesothelioma potencies in USEPA (1986) are based on the following assumptions:

- Equal potency for chrysotile and amphibole forms of asbestos.
- Equal potency for all asbestos fibers longer than 5 µm.
- A multiplicative interaction between asbestos exposure and cigarette smoking for lung cancer.
- Relative risks for lung cancer that vary linearly with cumulative exposure, lagged by 10 years.

- Death rates for mesothelioma that vary as a linear function of concentration and a cubic function of time since first exposure.

Apart from calculating parameters for specific disease endpoints, ARR relies on parameters that characterize the intensity and duration of asbestos exposure. These parameters are used to estimate the total time of exposure and are determined on a scenario-specific basis. Exhibits 4-1 and 5-1 in *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (USEPA 2002) provide the most commonly used exposure factors outlined by exposure receptor and receptor age class.

3.5 Characterizing Asbestos-Related Risk

The basic equation for assessing inhalation cancer risk for asbestos is analogous to that recommended by USEPA for other inhalation carcinogens. As shown in Equation 11 of *Risk Assessment Guidance for Superfund, Part F* (USEPA 2009), inhalation cancer risk is the product of an IUR and an exposure concentration. For ARR, the exposure concentration is a function of the asbestos air concentration, the length of time an individual is exposed, and the averaging time for which carcinogenic effects are evaluated. The ARR equation used in performing an asbestos inhalation risk assessment is referenced to USEPA (2008a):

[Eq. 30]

$$ARR = C_{air} \times IUR \times TWF$$

where:

C_{air} is air concentration of asbestos (f/cm^3) (fibers per centimeter cubed)
IUR is inhalation unit risk factor (risk per f/cm^3)
TWF is Time Weighting Factor

The TWF is essentially the fraction of the exposure duration time during which asbestos exposure related to C_{air} occurs. As described below, when applying *Framework for Investigating Asbestos-Contaminated Superfund Sites* (USEPA 2008a), each exposure scenario will have an associated age of onset and exposure duration and therefore a unique IUR because the IUR is described as a function of these two variables. Each exposure activity may also have a unique combination of exposure time (hr/day) and exposure frequency (day/yr), resulting in a unique TWF. The full equation for ARR is then:

[Eq. 31]

$$ARR = C_{air} \times IUR \times \left(ET_{out} + (ET_{in} \times ATT_{in})\right) \times EF \Big/ 8760\ hour/year$$

where:

ET_{out} is exposure time outdoors (hours/day)

ATT_{in} is indoor air particulate attenuation factor (unitless)
ET_{in} is exposure time indoors (hours/day)
EF is exposure frequency (days/year)

The IUR is based on the estimated additional deaths from lung cancer or mesothelioma due to aggregate lifetime exposure, calculated according to the methods described in USEPA (1986) and summarized in Appendix E of USEPA (2008a). The cancer potency factors for lung cancer and mesothelioma, expressed as mortality risk per PCM fiber concentration in air for one year of exposure, from USEPA (1986), are:

Lung Cancer: 0.01 per PCM f/cc-year (with an estimated uncertainty range of between 0.001 and 0.01 f/cc-year when applied in diverse exposure conditions)

Mesothelioma: 1E-08 per PCM f/cc-year (with an estimated uncertainty range of between 5E-10 and 2E-07 f/cc-year when applied in diverse exposure conditions)

Table 6-3 of USEPA (1986) shows lifetime lung cancer and mesothelioma mortality risks for males and females according to age and duration of exposure. These risks are based on the general U.S. population in the year 1977 and reflect the prevalence of smoking at that time. The male and female mortality rates shown in Table 6-3 were averaged for lung cancer (111.5) and mesothelioma (234), and then these values were summed, resulting in a total lifetime mortality risk per 100,000 persons of 345.5 results. This equates to an IUR of 0.3455 per f/cc for continuous lifetime exposure from birth.

As described in USEPA (1986), the values shown in Table 6-3 were derived from the occupational data of 40 hours/week exposures by multiplying the values by a factor of 4.2 (168 hours/week / 40 hours/week). In IRIS, and in Section 3 of Appendix E of USEPA (2008a), USEPA describes a further adjustment factor to account for an assumed total daily breathing volume (20 m^3/day) relative to breathing volume in an 8-hr occupational setting and a 5-day work week. This adjustment factor is calculated as:

[Eq. 32]

$$(20\ m^3/day / 10\ m^3/day) \times (7\ days/week / 5\ days/week) = 2.8$$

On this basis, the IRIS IUR for continuous asbestos exposure from birth until death is calculated as:

[Eq. 33]

$$0.3455\ per\ f/cc \times (2.8 / 4.2) = 0.23\ per\ f/cc$$

In Appendix E of USEPA (2008a), USEPA describes how IUR values were developed for asbestos exposures of durations and ages of onset other than those shown in Tables 6-1, 6-2, and 6-3 of USEPA (1986). The residential unit risk values in Table E-3 of USEPA (2008a) were plotted and fit to an equation of the following form:

[Eq. 34]

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

where:

$IUR_{a,d}$	is IUR for a continuous exposure beginning at age of onset "a" and extending for a duration of "d" years
k1 and k2	are empirically derived fitting parameters

Both k1 and k2 depend on the age of onset (a), and are defined as follows:

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

k2 = b4 + b5 exp(-a / b6)

Values of b1 through b6 are:

b1 = -0.0176401
b2 = 0.2492567
b3 = 24.07806941
b4 = 0.0415839
b5 = 0.0039973
b6 = -18.2212632

The adjustment factor of 2.8/4.2, and the equations and parameters described above, were applied to calculate the IUR values shown in Table 1 below for each exposure scenario defined in the EXCEL® spreadsheet "asbestos_guidance_riskcalcs.xls" that supports and implements this guidance.

The IUR for asbestos was derived from asbestos air data generated by PCM. Therefore, the IUR must be used in conjunction with analogous asbestos air concentration. The IUR may be used in conjunction with PCM data, but more commonly is used with PCM-equivalent (PCMe) data, which refers to the practical equivalent of the resolution of PCM using a TEM instrument. As described in USEPA (2008a), for use with the asbestos IUR, USEPA recommends a fiber counting protocol where PCMe fibers are defined as having a length greater than 5 µm, a width between 0.25 µm and 3 µm, and a length:width aspect ratio of 3:1 or greater.

Table 1. Values of IUR (risk per f/cm^3) for the Residential[1], Construction[2], and Commercial/Industrial[3] Worker Exposure Scenarios.

	Residential	Construction)	Commercial/Industrial
IUR	0.16	0.0051	0.073
[1] 26-year exposure duration and exposure onset at birth. [2] 1-year exposure duration and exposure onset at age 18 years. [3] 25-year exposure duration and exposure onset at age 18 years.			

The air concentration term (fibers/m^3) is derived from soil concentrations (fibers/gram) by applying the PEF values derived by Eqs. 19, 23, and 26, where the PEF is the inverse of the atmospheric respirable dust concentration:

[Eq. 35]

$$C_{air} = C_{soil} \times 1/PEF$$

Soil concentrations are reported in f/g (fibers/gram), and are based on the number of fibers observed in a sample multiplied by the analytical sensitivity of the measurement:

[Eq. 36]

$$C_{soil} = f \times AS$$

where f is the number of fibers observed (unitless) and AS is the analytical sensitivity (f/g). If more than one asbestos sample is collected, then the analytical sensitivity is pooled across the *n* samples. Analytical sensitivity is of further interest, because it plays a role in the calculation of the concentration term for estimates of risk.

Analytical sensitivity for a sample, as defined for the FBAS method, is related to a number of factors, including the total and scanned area of the filter that traps respirable particulates, and the mass of soil loaded in the instrument. Section 10 of the FBAS test method (USEPA 2018) shows the following calculation of AS:

[Eq. 37]

$$AS = A_f / (A_s \times M_s \times Q_R)$$

where:

A_f is total area of the filter (mm^2)
A_s is area of the scanned part of the filter (mm^2); calculated as the product of the area of one grid cell and the number of grid cells counted
M_s is mass of soil loaded on the FBAS (g)
Q_R is flow ratio; calculated as the volume of air passed through the air filter (V_{filter}) divided by the volume of air passed through the soil sample (V_{total}).

The number of fibers used to define AS is usually set to one, implying the intent is for the instrumentation to be sufficiently sensitive that one fiber will be detected. In practice, a target value of AS is often set, and the equation is used to define the number of grid openings that should be scanned during laboratory analysis.

The pooled analytical sensitivity for all sample results is used for the summation of sample results, where results are based on counts of PCMe fibers that are assumed to come from a Poisson distribution. If the sample result is represented as X_i, then X_i is distributed as a Poisson random variable with parameter λ [$X_i \sim Poisson(\lambda)$]. The parameter λ is the mean and the variance of the Poisson distribution. The sum of independent and identically distributed (i.e., data that all come from the same population) Poisson random variables is also Poisson, but with parameter $n\lambda$. That is:

[Eq. 38]

$$Y = \sum_{i=1}^{n} X_i \approx Poisson(n\lambda)$$

That also means that the sum of the observations has a mean and variance of $n\lambda$.

The pooled analytical sensitivity changes as individual sample results are summed. This is true in part because factors such as A_s and M_s in Eq. 37 may vary among samples. Using a simplifying assumption that these factors are constant among samples, the analytical sensitivity for two samples is ½ the analytical sensitivity of one sample. The analytical sensitivity for n samples is $1/n$ times the analytical sensitivity for one 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 $n\lambda$. 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:

[Eq. 39]

$$Pooled\ AS = 1 * \frac{1}{\sum_{i=1}^{n} AS_n}$$

The individual Poisson random variables might have different λ parameters, but they can still be summed if the results are assumed to be independent:

[Eq. 40]

$$Y = \sum_{i=1}^{n} X_i \approx Poisson(\sum_{i=1}^{n} \lambda_i) = Poisson(\kappa),\ say$$

where κ represents the sum of the λ s. Given this situation, as the sample size increases, the analytical sensitivity decreases, and the mean (and variance) of the Poisson

distribution increases. The confidence interval of interest is now the confidence interval for κ, which is then adjusted by the observed pooled or summed analytical sensitivity. Estimation of an upper confidence limit (UCL) for the parameter of a Poisson distribution is presented in Appendix A. The UCL of the number of fibers (f_{UCL}), given the number of fibers observed in all the samples combined (for a given sub-area or project), is multiplied by the pooled analytical sensitivity to provide an RME-based estimate of asbestos concentration in soil. Asbestos risk assessment should then proceed with the estimated mean fiber count for the central tendency exposure (CTE) estimate of ARR, and the UCL for the RME estimate of ARR. For a single sample, the CTE-based estimate of soil asbestos concentration is given in Eq. 36, and the RME-based estimate of soil concentration is given by Eq. 41:

[Eq. 41]

$$C_{soil} = f_{UCL} \times AS$$

If multiple samples are involved, which is the most likely case when evaluating ARR for a site or sub-area, then the CTE-based estimate of soil asbestos concentration is given by Eq. 42:

[Eq. 42]

$$C_{soil} = pooled(AS) \times \sum_{i=1}^{n} f_i$$

and the RME-based estimate of soil asbestos concentration is given by Eq. 43:

[Eq. 43]

$$C_{soil} = pooled(AS) \times \left(\sum_{i=1}^{n} f_i \right)_{UCL}$$

4.0 Sample Size Calculations

The previous sections provide guidance for ARR assessment. ARR depends on the number of fibers counted and the analytical sensitivity, which is a function of the number of samples as well as parameters including the area of the scanned part of the filter, total area of filter, and mass of soil loaded on the FBAS instrument. For fixed instrument parameters, analytical sensitivity can be controlled by the number of samples. This provides a mechanism for determining the number of samples needed to meet risk thresholds for a given total number of fibers.

Collecting enough data is essential so that the analytical sensitivity (discussed below) is represented adequately for a given site. As more samples are collected, the pooled analytical sensitivity decreases. If too few samples are collected, the pooled analytical sensitivity can be high enough that the risk thresholds are exceeded even if few or no asbestos fibers are detected. In these cases, the risk assessment results are directly

affected by the 95% upper confidence bound calculation, which returns a value of 3 fibers/gram even when no fibers are detected. If risk estimates are not to routinely result in an asbestos cancer risk exceeding a target cancer risk threshold (TR), such as 10^{-6}, then analytical sensitivity must be controlled in sample design. That is, analytical sensitivity must at a minimum be low enough that an upper confidence bound of 3 fibers/gram of soil does not result in an unacceptable risk. In order to perform a calculation of the pooled analytical sensitivity that is needed, a TR value must be established, the dominant receptor scenario identified (which is usually the construction worker scenario at the BMI Complex and Common Areas), and a PEF must be calculated or estimated prior to asbestos sampling. Then the required pooled AS can be estimated. The number of samples required to achieve the pooled AS can then be estimated by assuming, *a priori*, that all analytical results have the same analytical sensitivity (minor differences are usually observed). This process should be implemented as part of the DQOs process for asbestos concentration data collection.

For planning purposes, it is reasonable to assume that the analytical sensitivity for each sample is the same. In which case, pooled analytical sensitivity is simply sample analytical sensitivity divided by the number of samples. Consequently, Equation 43 can be stated as:

[Eq. 44]

$$C_{soil} = \frac{AS}{n} \times \left(\sum_{i=1}^{n} f_i \right)_{UCL}$$

Equation 44 can be restructured to calculate the number of samples:

[Eq. 45]

$$n = \frac{AS}{C_{soil}} \times \left(\sum_{i=1}^{n} f_i \right)_{UCL}$$

The concentration term (C_{soil}) is obtained from Equation 46 for a specified TR such as 1×10^{-6}:

[Eq. 46]

$$C_{soil} = \frac{TR \times PEF}{\frac{(ATT_{in} \times ET_{in}) + ET_{out}) \times EF}{8760 \frac{hr}{year}}} \times IUR$$

Equations 45 and 46 can be used together to calculate the number of samples needed to satisfy a target risk constraint for a given set of exposure parameters, a particular PEF, and a target number of fibers. This approach can be used to determine how many samples are needed to reasonably ensure that a total of zero fibers from *n* samples does not result in exceeding a TR.

5.0 Baseline Concentration Levels for Asbestos

The derivation of an optimal sample size for achieving risk goals can also be used to determine a baseline concentration level (BCL) for asbestos. The baseline concentration can only be given in terms of soil or air concentration, and not also in terms of the number of fibers detected, because the latter depends on the number of samples collected and the pooled analytical sensitivity. Equation 46 can be used directly to provide an asbestos concentration in soil BCL for a given set of exposure parameters, particulate emission factor, and target risk level. Exposure parameters are fixed for specific scenarios. Default values are also available for many parameters that are inputs to the PEF equations. However, areal size of surface contamination is site specific, in which case the BCL depends on the site-specific value for this factor.

6.0 Asbestos Calculations Spreadsheet

This guidance document is supported by an EXCEL® spreadsheet "asbestos_guidance_riskcalcs.xls". There are nine worksheets in the EXCEL® file covering risk calculations, PEF calculations, data input, IUR and analytical sensitivity calculations, and calculation of the optimal number of asbestos samples for a range of input conditions. This spreadsheet brings together data, transport, and risk into one program, facilitating characterization of ARR in accordance with this guidance and review of documents that use this spreadsheet for ARR. The spreadsheet can also be used to calculate PEFs for the four scenarios under consideration, which might also be used in chemical risk assessment.

The spreadsheet is constructed so that all input values can be changed. However, recommendations are made on which parameters can be changed because of site-specific factors, and which parameter value changes would require NDEP concurrence before using in a risk assessment. The data table that is used as part of the spreadsheet is an example. Site-specific data can be entered in the same worksheet, but the formulas will need to be adjusted to accommodate a new dataset. The "Data and Analytical Sensitivity" worksheet provides a mechanism for calculating the number of relevant fibers and the pooled analytical sensitivity, which is read directly into the "Risk_Calculations" worksheet. The values for number of fibers and pooled analytical sensitivity could also be entered directly into the "Risk_Calculations" worksheet if that approach is preferred.

The "BCL Asbestos" worksheet supports calculation of the optimal number of asbestos samples needed to satisfy risk target concentrations. This is intended as a planning tool as described in Section 4.0.

This guidance document and the attached EXCEL® spreadsheet file are intended to be used in tandem. However, use of other calculational tools that follow this guidance is not precluded.

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Appendix A

Exact Confidence Intervals for the Poisson Distribution

The Poisson distribution is a discrete distribution used commonly to model count data. In this situation it is being used to model the number of asbestos fibers found in a sample. The probability distribution function of the distribution is shown below:

$$f(x) = \frac{\lambda^x e^{-\lambda}}{x!},\ x = 0,1,2,3,...$$

Note that the parameter λ is both the mean and standard deviation of the Poisson distribution. The Poisson distribution can be modeled by the normal distribution for sufficiently large means. Consequently, normal confidence bounds can be constructed to approximate the Poisson confidence bounds. However, this can be fairly inaccurate in situations when the mean of the distribution is expected to be small. In this situation it may be beneficial to create "exact" 95% confidence bounds for the mean. This can be done by viewing the Poisson distribution as a function of λ given *x* as opposed to viewing it as a distribution of *x* given λ. 2-sided confidence intervals can then be established as follows using the chi-square distribution:

$$\left(\frac{\chi^2_{0.025}(2 \cdot x)}{2}, \frac{\chi^2_{0.975}(2 \cdot (x+1))}{2} \right)$$

and, 1-sided confidence intervals are given by:

$$\left(\frac{\chi^2_{0.95}(2 \cdot (x+1))}{2} \right)$$

The following table shows confidence limits for λ given data, *x*, for values of *x* up to 5.

x	**2-sided Lower Limit**	**2-sided Upper Limit**	***x***	**1-sided Upper Limit**
0	0.000	3.6889	0	2.996
1	0.0253	5.5716	1	4.744
2	0.2422	7.2247	2	6.296
3	0.6187	8.7673	3	7.754
4	1.0899	10.2416	4	9.154
5	1.6235	11.6683	5	10.513

Appendix B

Comparison of Asbestos-Related Risk Results Using Berman and Crump Toxicity Criteria with Results Using the Toxicity Criterion Published in IRIS

This appendix was originally published with NDEP's 2011 *Technical Guidance for the Calculation of Asbestos Related Risk in Soils for the Basic Management Incorporated (BMI) Complex and Common Areas*. The appendix was then titled *Comparison of Berman and Crump and Activity Based Sampling methods for Asbestos Related Risk*, but this was a misnomer since no activity-based sampling results were evaluated. The appendix has been retitled for clarity. Also, as described in the paragraphs below, some text in Sections 1.0 through 6.0 has been edited for consistency with this technical guidance.

The NDEP 2011 guidance for calculating asbestos-related risk (ARR) for soil contamination recommended evaluating ARR based on a draft protocol (Berman and Crump 2003) that assigned different cancer inhalation unit risk (IUR) factors to chrysotile and amphibole forms of asbestos, and associated inhalation carcinogenicity with fibrous structures longer than 10 µm and with a diameter less than 0.4 µm. The 2011 guidance also recommended a modified elutriator method to separate respirable asbestos fibers from bulk soil samples (Berman and Kolk 2000.) As discussed in the main text, this updated NDEP 2024 technical guidance for ARR recommends the asbestos IUR values and fiber dimension counting protocols described in USEPA's *Framework for Investigating Asbestos-Contaminated Superfund Sites* (USEPA 2008), and also recommends the fluidized bed asbestos segregator (FBAS) to replace Berman and Kolk's modified elutriator.

Throughout Sections 1.0 through 6.0 of this appendix, text has been edited to reference the asbestos IUR values and FBAS instrument recommended in this guidance. These edits are made to maintain consistency between the main text of the guidance and this appendix, but they do not alter the comparisons of ARR calculated using Berman and Crump (2003) and USEPA (2008) asbestos IUR values and fiber counting protocols. The result of this comparison is that the risk results using the mean and 95UCL of asbestos air concentrations based on Berman and Crump (2003) bound the risk results calculated using the USEPA (2008) methods. The results described in this appendix indicate that changing from the asbestos IUR values described in Berman and Crump (2003) to the IUR values discussed in Appendix E of USEPA (2008) should not have a significant effect on the comparability of ARR results over time at the BMI Complex and Common Areas.

1.0 Problem Statement. The Nevada Division of Environmental Protection (NDEP) first published guidance for calculating ARR for soil contamination in April 2009. This guidance was based on a 2003 draft protocol for assessing ARR prepared for the United

States Environmental Protection Agency (USEPA) Office of Solid Waste and Emergency Response (OSWER) (Berman and Crump 2003), as well as several reports by one of the authors of the draft protocol describing its application (Berman 2003a; 2003b; 2005). NDEP has followed the basic approach laid out in this guidance for sites at the BMI Complex and Common Areas in Henderson, Nevada, since 2003. A few months prior to the publication of the NDEP guidance on ARR, OSWER released *Framework for Investigating Asbestos-Contaminated Superfund Sites* (USEPA 2008). This approach differs from the approach proposed in Berman and Crump (2003) in some important ways. The relevant publication on ARR is *Framework for Investigating Asbestos-Contaminated Superfund Sites* (USEPA 2008). Key differences between the Berman and Crump approach and the more recent OSWER guidance relate to:

- asbestos cancer risk potency values,
- protocols for counting carcinogenic asbestos fibers, and
- protocols for estimating breathing-zone asbestos air concentrations.

Due to different sources of mined asbestos, different processing, and the effects of weathering in the environment, there may be significant variability in fiber types and dimensions in soil at different contaminated sites. Therefore, the effect of these key differences on estimated cancer risks will also vary on a site-by-site basis. This addendum compares asbestos cancer risks using NDEP and USEPA methodologies for the first and second key differences described above, using asbestos soil sample data from the BMI Complex and Common Areas.

2.0 Introduction. The key differences between Berman and Crump (2003) and USEPA (2008) are discussed in the following subsections. With one exception, the effect of these differences on calculated asbestos cancer risks using BMI asbestos soil sample data are explored in detail in this appendix. The exception is evaluation of the differences in estimated asbestos air concentrations using an air elutriation method for soil samples and personal air sampling for the "activity-based sampling" approach described in USEPA (2008).

2.1 Quantifying Asbestos Carcinogenicity. The IUR used in the USEPA (2008) framework is based on combined cancer and mesothelioma risk coefficients originally published in USEPA (1986) and currently available on the Integrated Risk Information System (IRIS). This IUR is based on fiber sizes that are detectable by phase contrast microscopy (PCM) — longer than 5 µm and wider than 0.25 µm[3]. The IUR applies to all six asbestos mineral types that meet the fiber size criteria. The cancer and mesothelioma risk coefficients published by Berman and Crump (2003) and applied in the 2011 NDEP guidance distinguish risk based on different mineral classes (i.e., amphibole and chrysotile) and different fiber size classes. The IURs in Berman and Crump (2003) incorporate more recent epidemiological data and anticipate data from transmission electron microscopy (TEM) analysis, which allows for the treatment of amphibole and chrysotile fibers separately and provides better resolution of finer fiber sizes. Berman and Crump (2003) concluded that ARR is dominated by fibers that are greater than 10 µm in

[3] More details of the PLM and TEM methods are provided in Section 3.2 of the main text.

length and less than 0.4 µm in width, and that the potency of amphibole asbestos is far greater than that of chrysotile asbestos.

2.2 Collecting and Counting Asbestos Fibers. The NDEP ARR guidance instructs users to collect soil samples, suspend the soil samples in air using a dust generator (elutriation) to separate and concentrate the respirable fraction of the sample on a filter, and finally analyze the filter for asbestos using TEM. The USEPA (2008) framework instead recommends an "activity-based sampling" approach, which involves mechanical disturbance of soil by sampling personnel and simultaneous collection of asbestos air samples with a personal sampler. USEPA (2008) also recommends that TEM be used to analyze the particulates captured on a filter in order to distinguish the six mineral types of asbestos from other fibers.

For using TEM data with the IUR values derived from USEPA (1986), which are based on PCM fiber measurements, USEPA (2008) recommends that the analytical laboratory count only PCM-equivalent (PCMe) fibers of dimensions consistent with the limitations of PCM to detect asbestos fibers. This fiber count protocol includes fibers longer than 5 µm, with width ≥0.25 µm and ≤3 µm, and having at least a 3:1 length to width (aspect) ratio.

For using TEM data with the IUR values obtained from Berman and Crump (2003), separate fiber counts (fibers per gram of respirable particulate) are made for chrysotile and amphibole asbestos, and a fiber count protocol is applied that includes fibers that are greater than 10 µm in length and less than 0.4 µm in width.

2.3 Estimating Asbestos Air Concentrations. USEPA (2008) recommends that the "simple average" of site asbestos data be used for the exposure point concentration (EPC), rather than a 95% upper confidence limit of the mean (95UCL), and that non-detect samples be represented using a value of zero when calculating the average. This recommendation was made pending development and approval of methods for calculating the UCL for asbestos, which is complicated by the presence of both inter-sample and Poisson counting variability. This NDEP ARR guidance recommends an approach for calculating an asbestos 95UCL on the basis of pooled analytical sensitivity.

Various forms of the USEPA Particulate Emission Factor (PEF) model are used in the NDEP ARR guidance to estimate annual average air concentrations of asbestos from soil measurements. For long-term residential and industrial exposures, these models are based on wind resuspension of particulates. For exposures during construction, both wind and mechanical disturbances are modeled. Under USEPA (2008), air concentrations are measured directly subsequent to mechanical disturbance of soil. A screening method for this type of sampling is described in Section 3 (Step 4) of USEPA (2008), involving raking of soil under dry conditions. The applicability of the activity-based sampling data to estimating EPCs for long-term exposures (such as in a residential or industrial scenario) is not directly addressed in USEPA (2008).

3.0 Methods. The comparison of asbestos cancer risks using IUR values from Berman and Crump (2003) and the USEPA (2008) framework was conducted in the following manner:

1. Obtain BMI asbestos soil fiber count data sets based on TEM measurements from Basic Remediation Company (BRC),
2. Perform separate fiber counts using NDEP protocol (length >10 µm, width < 0.4 µm) and USEPA (2008) PCMe protocol (length >5 µm, width ≥0.25 and ≤3 µm, aspect ratio ≥3:1),
3. Calculate mean PCMe asbestos fibers soil concentrations according to USEPA (2008), and mean and 95UCL chrysotile and amphibole soil concentrations,
4. Use mean PCMe asbestos fibers soil concentrations and the IRIS IUR for continuous lifetime exposure, in conjunction with PEF models, to calculate USEPA (2008) framework asbestos cancer risks,
5. Use mean and 95UCL chrysotile and amphibole soil concentrations and Berman and Crump (2003) IURs, in conjunction with PEF models, to calculate asbestos cancer risks.

Risk assessment calculations were performed utilizing the asbestos calculations EXCEL® workbook "asbestos_guidance_riskcalcs.xls" described in NDEP's ARR guidance. To support these comparisons the following modifications to the workbook were made:

1. Connections from the worksheet "Data and Analytical Sensitivity" to "Risk_Calculations" were severed. Values for pooled analytical sensitivity and fiber counts (NDEP method) were input for each data set in "Risk_Calculations" using the Scenario Manager tool.
2. Input cells for USEPA method PCMe fiber concentrations and IRIS IUR were added to the worksheet "Risk_Calculations" and fiber count values were input for each data set in "Risk_Calculations" using the Scenario Manager tool.
3. Asbestos risk calculation cells using USEPA PCMe fiber concentrations and IURs were added to the worksheet "Risk_Calculations."

4.0 Data Sources and Preparation.

Four sampling events from the First Eight Rows and Mohawk sites are utilized in this comparison of ARR methods: First Eight Rows, Mohawk, Mohawk Rescrape, and Mohawk Supplemental. These datasets were selected only on the basis of availability of data. Across the BMI Complex and Common Areas there is evidence of low levels of asbestos contamination. The First Eight Rows and Mohawk sub-areas of the BMI Common Areas fall into this category. Both of these areas are proposed for residential development. Consequently, residential and construction worker scenarios are most relevant.

The First Eight Rows and Mohawk laboratory worksheets serve as the starting point of the quantitative comparison of risk. The asbestos samples for these sites were prepared using the elutriator method and asbestos fibers were counted using TEM analysis. PDF versions of the laboratory worksheets were obtained from BRC. Electronic data deliverables (EDDs) were created from the laboratory worksheets, following ISO

guidance (ISO 1995), for all four sampling events that contain asbestos fiber classifications and dimensions, as well as all metadata for all asbestos fibers.

The next step of the comparison was to use the Berman and Crump and USEPA guidance counting methods to create asbestos count tables for each of the four sampling events. Count files were produced for all four sampling events using both counting methods and the count data were used to calculate analytical sensitivities for both the Berman and Crump and the PCMe approaches.

The counts were used directly in estimates of mean concentrations of asbestos, and in subsequent risk calculations for the on-site residential scenario. Table B1 shows the counts that were obtained from the First Eight Rows and Mohawk data. The number in parentheses is the number of samples collected.

Table B1. Asbestos Counts

Soil Data Set	Pooled AS	PCMe	amphibole	chrysotile
First Eight Rows (42)	0.071	22	0	25
Mohawk (42)	0.070	90	1	29
Mohawk Supplemental (8)	0.373	7	0	6
Mohawk Rescrape (8)	0.373	4	0	0

PCMe: phase contrast microscopy equivalent
Pooled analytical sensitivity presented in units of 10^6 fibers/gram PM_{10}

The analytical sensitivity for each sample is always slightly less than 3×10^6 fibers/gram PM_{10}. As a rough rule of thumb, the pooled analytical sensitivity (AS) is the analytical sensitivity divided by the number of samples. However, the pooled AS presented in Table B1 uses the more accurate formula (Eq. 39 in the main text). The range of concentrations and range of samples collected seems reasonable to evaluate the difference in Berman and Crump (2003) and USEPA (2008) methods for the BMI Complex.

5.0 Results. Mean and 95UCL asbestos fiber soil concentrations measured by TEM, and calculated as described in Sections 3.0 and 4.0, are shown in Table B2.

Table B2. Asbestos Soil Concentrations (10^6 fibers / g PM_{10})

Soil Data Set	PCMe (mean)	amphibole (mean / 95UCL)	chrysotile (mean / 95UCL)
First Eight Rows	1.56	0.0 / 3.00	1.77 / 34.9
Mohawk	6.37	0.070 / 4.74	2.04 / 39.5
Mohawk Supplemental	2.62	0.0 / 3.00	2.24 / 11.8
Mohawk Rescrape	1.49	0.0 / 3.00	0.0 / 3.00

PCMe: phase contrast microscopy equivalent
PM_{10}: particulate matter ≤ 10 μm aerodynamic diameter

Cancer risks calculated as described in the main text are shown in Table B3. Cancer risks calculated according to USEPA (2008) guidance employ a single asbestos IUR for all fiber types and for mesothelioma and lung cancer combined. This IUR is 0.23 $(\text{fibers/cm}^3)^{-1}$ (http://www.epa.gov/ncea/iris/subst/0371.htm). Separate mesothelioma and lung cancer IURs for amphibole and chrysotile are described in Berman and Crump (2003). For this comparison, asbestos mesothelioma and lung cancer risks for both amphibole and chrysotile fibers have been summed to facilitate comparison to the IRIS IUR results. Results are shown for the on-site Residential exposure scenario. The relative risks using these two protocols are identical for the other exposure scenarios described in NDEP's ARR guidance.

Table B3. Asbestos Risk Assessment Results

Soil Data Set	USEPA (mean)	NDEP (mean)	NDEP (95UCL)
First Eight Rows	5×10^{-8}	1×10^{-8}	2×10^{-7}
Mohawk	2×10^{-7}	8×10^{-8}	3×10^{-7}
Mohawk Supplemental	9×10^{-8}	2×10^{-8}	1×10^{-6}
Mohawk Rescrape	5×10^{-8}	0.0	1×10^{-6}

USEPA (mean): asbestos risk calculated using mean PCMe soil concentrations and the IRIS IUR, as suggested in USEPA (2008)
NDEP (mean): asbestos risk calculated using mean soil concentrations according to Berman and Crump protocols
NDEP (95UCL): asbestos risk calculated using 95UCL soil concentrations according to Berman and Crump protocols

Table B3 indicates that asbestos cancer risks calculated according to USEPA (2008) guidance for all four data sets lie between the mean and 95UCL risks calculated using Berman and Crump protocols. Risk management decisions based on asbestos risk results calculated using these protocols at these sites are therefore considered to be consistent with USEPA (2008) recommendations for the asbestos IUR. The Mohawk Rescrape results indicate that reliance on 95UCL estimates of asbestos soil concentrations when no fibers are detected may produce risk estimates within the 1×10^{-6} to 1×10^{-4} risk management range. These risk estimates in the absence of detected fibers would not be generated using current USEPA guidance (USEPA 2008), where only the simple average of asbestos air concentrations is recommended.

However, because USEPA (2008) recommends use of the simple mean concentration there is no associated measure of uncertainty in the average and this makes it difficult to perform sample size calculations. The use of pooled analytical sensitivity and calculation of the 95UCL of the mean concentration allow for determination of an appropriate number of samples. For example, in the case of the Mohawk Rescrape and Supplemental data sets, the risk associated with the 95UCL indicates that enough data have been collected to support the decision.

The similarity of results bears some discussion regarding sources of asbestos risk. Asbestos-related risks calculated using Berman and Crump (2003) are usually dominated

by the amphibole fiber risks. The lifetime exposure USEPA IUR value lies between the amphibole and chrysotile IURs from the Berman and Crump method:

- PCMe: 0.23 $(f / cm^3)^{-1}$
- Chrysotile: 0.057 $(f / cm^3)^{-1}$
- Amphibole: 6.3 $(f / cm^3)^{-1}$

Given these IURs, it will take large differences in fiber concentrations for the Berman and Crump mean and 95UCL risk estimates to not bound the USEPA risk estimate.

USEPA (2008; Appendix C) recognizes there is some uncertainty associated with using PCMe fiber counts to calculate risk with the IRIS IUR because PCMe is only an approximation of actual PCM measurements. However, USEPA considers the uncertainty in this approximation to be "relatively small" compared to other sources.

It should be noted that the results are presented here for a range of asbestos concentrations from four sampling campaigns. This subset of studies suggests that the Berman and Crump (2003) and USEPA (2008) IURs provide similar risk results from a risk-based decision-making perspective. The counts are of the same basic order of magnitude in each case (the biggest difference is at Mohawk where the PCMe count is 90 fibers, and the chrysotile count is 29). If the counts are of roughly the same magnitude, then it seems that the risk results for the Berman and Crump (2003) mean and 95UCL will bound the risk results using the USEPA IRIS IUR. At least to the extent of considering sample size, extrapolation to other sites should be evaluated site-specifically to confirm that the counts for these different fiber sizes are sufficiently close that the same conclusions will hold.

6.0 Summary and Recommendations. When one or more fibers are detected, asbestos cancer risk calculated using the USEPA (2008) framework for Mohawk, Mohawk Supplemental, and First Eight Rows data sets is always in between the mean and 95UCL values calculated using NDEP guidance. The differences between the 95UCL risk result using Berman and Crump (2003) IURs and the USEPA IUR result were a factor of 4 (First Eight Rows), 2 (Mohawk), and 12 (Mohawk Supplemental).

When no asbestos fibers of countable dimensions are detected, use of the simple average to represent the EPC results in an estimated human health risk of zero. This approach does not account for sample size, such that counting no fibers with relatively few samples and with very many samples is equivalent. At a site where asbestos releases are known or suspected, it does not seem reasonable to conclude that there is zero risk when zero PCMe fibers are observed.

NDEP concludes that use of the 95UCL for asbestos risk results is appropriate for making remedial decisions at BMI Complex sites. However, risk managers may also choose to acknowledge that current USEPA guidance for ARR (USEPA 2008) does not recommend the use of a 95UCL for asbestos, and to consider use of mean asbestos soil concentrations for calculating asbestos risks and supporting remedial decisions. This is

particularly relevant in situations where no asbestos fibers are detected, and only the 95UCL provides a non-zero estimate of fiber concentrations and cancer risk.

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