# 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
BMI – Basic Management, Incorporated
CSM - Conceptual Site Model
DQOs - Data Quality Objectives
EPC – Exposure Point Concentration
IRIS _ Integrated Risk Information System
OLM – Ordinary Light Microscopy
OSWER – Office of Solid Waste and Emergency Response
PCM - Phase Contrast Microscopy
PEF - Particulate Emission Factor
TEM - Transmission Electron Microscopy
URF - Unit Risk Factor
USEPA - United State Environmental Protection Agency

# 1.0 Overview

There are several guidance documents that discuss approaches for the estimation of cancer potency factors associated with asbestos inhalation exposure (United States Environmental Protection Agency (USEPA), 1986, Berman and Crump 2001; 2003). Other documents provide guidance for modeling the transport of particulates from specific emission and dispersion processes for various exposure scenarios (USEPA, 2002). However, guidance that effectively combines information for sampling asbestos in soils, modeling the transport of asbestos, and calculating asbestos-related risks (ARR) from soil contamination in a straightforward and logical manner does not yet exist. This guidance document describes a process for characterizing ARR in soils for the Basic Management, Inc. (BMI) Complex and Common Areas in the State of Nevada. This document is intended to provide methodological direction to human health risk assessors, contractors, consultants, and managers who are involved in, or evaluate, soil disturbing activities with known or suspected presence of asbestos contamination in soils at the BMI Complex and Common Areas sites.

This Nevada Division of Environmental Protection (NDEP) guidance is based on the 2003 draft protocol for assessing ARR prepared for USEPA's 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 it's application (Berman 2003a; 2003b; 2005). This guidance document is also accompanied by a spreadsheet that can be used as a template for estimating ARR following this guidance. At present, the inhalation cancer potency factor for asbestos fibers provided by USEPA in the Integrated Risk Information System (IRIS) electronic database[1] is based on dose-response information summarized in USEPA (1986). The NDEP has chosen to utilize the methodology for assessing ARR proposed in Berman and Crump (2003). NDEP has used this approach consistently since 2003, when the first ARR evaluations were performed for the BMI Complex and Common Areas.

This guidance is based on methods for assessing ARR described in Berman and Crump (2003), and associated examples of the implementation of these methods as described in Berman (2003a; 2003b; 2005). Users are advised to employ this guidance only after fully understanding the equations and methods upon which it is based.

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 DQO process and development of a conceptual site model (CSM), and then proceeds to outline the methods and equations used for calculating risk. However, NDEP first discusses more recent guidance that USEPA OSWER has released regarding ARR.

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

## 2.0 Activity Based Sampling for Asbestos Related Risk.

NDEP recognizes that USEPA OSWER is currently investigating alternative approaches for estimating cancer potency factors for inhalation exposure to asbestos, as described in USEPA, 2008. These approaches differ 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, September 2008). Key differences between the Berman and Crump approach and the more recent OSWER guidance relate to:

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

The Berman and Crump approach relies on collection of soil samples that are suspended in an elutriator, in which filters collect particles. The recent USEPA OSWER guidance introduces activity-based sampling (ABS), whereby filter samples are collected directly in the breathing zone at the site as a consequence of specific activities, such as raking. In both cases, the filters are analyzed for asbestos structures, but the asbestos fiber dimensions of importance for each ARR approach differ. For the Berman and Crump method, the asbestos counts are translated directly to estimates of asbestos concentrations in soil. A dust particle resuspension model must be used to predict outdoor air concentrations from the soil concentrations. For ABS, breathing zone air concentrations are measured directly. In addition, the two methods use different approaches for estimating unit risk factors that are used to translate air concentration in air to ARR.

A consideration for NDEP is that the Berman and Crump approach has been used consistently at the BMI Complex and Common Areas since 2003, which has led to various remediation decisions for removing asbestos in surface soils. For consistency, there is clear benefit in continuing this approach until the BMI Complex and Common Areas are restored for their planned re-use. Consequently, NDEP has conducted a virtual side-by-side study on the potential differences between the two approaches, which is presented in Appendix C. In terms of overall ARR, the results are sufficiently similar that NDEP is confident that reasonable ARR results are provided by the Berman and Crump methods, and, hence that consistency in approach should be maintained as the site development approaches its conclusion.

NDEP also notes some concerns with the ABS approach. The ABS approach is based on direct breathing zone sampling 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. 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). The ABS approach seems unnecessary given the similarity in ARR results for the Berman and

Crump method and the new USEPA OSWER method (Appendix C). In effect, the sampling and analysis differences between the two approaches amounts to modeling air concentrations from soil concentrations, compared to measuring breathing zone concentrations directly using activities that might not be applicable and might exhibit a lot of variability. In effect, the question of interest is in the uncertainty of the modeling versus the uncertainty in the applicability of the ABS activity.

NDEP acknowledges, however, that direct comparison of the two methods has not been performed. The study presented in Appendix C is a virtual-side-by-side study. It does not involve ABS. Instead, it predicts ABS concentrations based on the available data from the elutriator samples at four different sub-areas of the BMI Complex and Common Areas. The difference is in the counting methods, which leads to different concentrations. Further differences come from application of alternative unit risk factors. Although NDEP concludes that the virtual side-by-side study indicates sufficiently similar ARR results between the two approaches, NDEP acknowledges the limitations of the virtual side-by-side study presented in Appendix C. The remainder of this guidance applies the Berman and Crump approach to ARR.

# 3.0 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 (asbestosis). The correlation between asbestos exposure and these effects has been supported by clinical observation and analysis of epidemiological data collected from exposed cohorts. The latter effect (asbestosis) is the result of exposure to high concentrations of asbestos in air, and is not applicable to the conceptual site model (CSM) for the BMI Complex and Common Areas where exposure concentrations are anticipated to be relatively low. This section sets the stage for ARR assessment, including a brief overview of asbestos toxicity issues, and approaches to sample design, quality control and site assessment.

## 3.1 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 also be found with other fibers 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, lung cancer, and non-malignant respiratory effects (asbestosis) (Bourdes et al., 2000; Metintas et al., 2005; Pira et al., 2005).

## 3.2 Asbestos Toxicity

There is ongoing debate addressing differences in the degree of potency among asbestos types and the contribution to associated disease endpoints. The carcinogenic effects of asbestos on humans have been supported by various animal laboratory experiments. It is generally agreed that amphibole fibers are more potent than chrysotile in the initiation of mesothelioma while there is weaker, limited evidence supporting a key mineralogical association in initiating lung cancer (ERG, 2003; Berman and Crump, 2008a and 2008b). Berman and Crump (2001) defined biologically active asbestos structures as being longer than 5 µm and thinner than 0.5 µm. More recent analyses conducted by Berman and Crump (2003; 2008a and 2008b) have suggested that longer fibers (e.g., > 10 µm) are more potent than shorter fibers for both mesothelioma and lung cancer. Much of the epidemiological evidence suggests that the potency of long fibers on the initiation of pulmonary disease increases with length up to approximately 20 µm (and perhaps up to approximately 40 µm). While there has been ongoing debate about fiber size and associated disease endpoints, USEPA interim guidelines (Berman and Crump, 2003) suggest that fibers longer than 10 µm and thinner than 0.4 µm are most responsible for asbestos related disease. Similar findings are reported in Berman and Crump (2008a and 2008b). As such, the equations and parameters in this guidance document will follow these guidelines.

Estimating ARR can be accomplished on a receptor-specific basis. Obtaining data for estimating ARR involves obtaining samples from site soils, suspension of soil samples in air, elutriation (that separates out potential asbestos structures from the soil), and analysis by microscopy (Berman and Kolk, 2000). 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 dust emission and dispersion models to predict airborne exposures and associated risks. Dust emission and dispersion estimates are calculated for each type of human receptor of interest (construction worker, offsite resident, commercial and industrial workers) 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 model rather than by the estimate of soil asbestos concentrations or the application of the dust models to asbestos fibers.

## 3.3 Site Assessment, Sampling Design, and Quality Control

A CSM is used in risk assessment to provide an overall picture of site conditions and assure 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 provided in Appendix A. 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 describing how the data will be used for evaluating ARR. The DQO 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 DQO 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 are often few or no asbestos fibers found in a samples or collections of samples, especially post-remediation. 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 5.0 of this guidance, implementation of the DQO process can help by ensuring that the number of samples is sufficient that the uncertainty in the outcome does not drive an unacceptable ARR. The DQO 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.

# 4.0 Risk Characterization

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

## 4.1 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 gastrointestinal cancer, laryngeal and pharyngeal cancer, and renal cancer. However,

many of these disease endpoints could not be directly linked to a cancer endpoint because of insufficient data (NAS, 2006). The USEPA publishes a maximum contaminant level (MCL) drinking water standard for asbestos fibers with length >10µm 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 risk to human health 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.

## 4.2 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. 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 Area 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 modified elutriator method (Berman and Kolk, 2000) provides bulk measurements of asbestos structures that can be used for the prediction of airborne asbestos exposure. This method is a modified version of an earlier USEPA method (USEPA, 1997) that was developed to improve performance and reduce analysis costs. 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. This modified elutriator method is referenced for the acquisition of soil asbestos data to calculate ARR in Berman (2003a; 2003b; 2005).

Three main forms of microscopy have been used for measuring asbestos: ordinary light microscopy (OLM); phase contrast microscopy (PCM); and transmission electron microscopy (TEM). OLM is the most limited method as there can be no distinction made between mineralogies or morphologies. OLM is generally limited to detecting particles that are much larger than those detected using phase contrast and electron microscopy, which makes it the least useful of the readily available methods.

In the 1980s, the USEPA developed an approach for assessing ARR (Asbestos Health Effects Assessment Update, USEPA, 1986), which assumes no differences between the potencies of different asbestos types (amphibole and chrysotile). At the time, the most likely analytical method used for asbestos analysis was PCM. Unlike OLM, PCM is able to measure smaller asbestos structures and also determine their shape. However, PCM can only measure particles greater than 0.25 µm in diameter and 0.5 µm in length. This can result in underestimation of narrow asbestos particles, which may be important for accurately quantifying asbestos cancer risk (Berman and Crump 2003; Berman and Crump 2008a and 2008b). 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. Used in conjunction with the cancer potency factors described in Berman and Crump (2003), 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.

## 4.3 Exposure Concentration Estimation

Asbestos soil measurements derived using the modified elutriator method can be combined with dust 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 detail in Berman and Kolk (2000), and examples are provided in Berman (2003a; 2003b; 2005). The USEPA Particulate Emission Factor (PEF) model is used to estimate annual average concentrations of respirable particulates (approximately

10 µm and less) in ambient air (USEPA, 2002). The suitability of these generic particulate emission and dispersion models for predicting concentrations of asbestos fibers in air that are longer than 10 µm is defended in Berman and Kolk (2000) by reference to a study of dust emissions from two roads surfaced with asbestos-containing serpentine material.

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]

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

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, offsite resident, onsite resident, and commercial / industrial exposure scenarios are outlined in the following subsections.

### 4.3.1 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 calculated according to Equation E-26 of USEPA (2002):

[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]

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

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]

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

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):

[Eq. 5]

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

In Equation 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 PM10 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[2]. 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]

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

where $V$ is the fraction of vegetative cover (unitless – default is set to 0 for construction), $U_m$ is the mean annual wind speed (default is 4.69 m/s), $U_t$ is the equivalent threshold of windspeed at 7m (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 (default is 4.9 m/s), $M$is the gravimetric soil moisture content (default is 12%), $\rho_{soil}$ is the wet soil bulk density (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 (default is 2).

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

[Eq. 9]

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

where $s$ is the percent weight of silt in the soil (default is 6.9%), $M$is the gravimetric soil moisture content (default is 7.9%), $S_{doz}$is the mean vehicle speed (default is 11.4 km/hr), and $VKT_{doz}$ is the sum of dozing kilometers traveled (km). A calculation $VKT_{doz}$ 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]

$$VKT_{doz} = \frac{\frac{A_{surf}{}^{0.5}}{2.44} * A_{surf}{}^{0.5} * 3}{1000\ m/km}$$

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

[Eq. 11]

$$M_{grade} = 0.60 * 0.0056 * S_{grade}{}^2 * VKT_{grade} * 10^3 g/kg$$

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

*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 percent weight of silt in the soil (default is 18%), $A_{till}$ 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 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]

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

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 Equation 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]

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

where $s$ is the road surface silt content (default 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 $VKT_{road}$ is the sum of fleet vehicle kilometers traveled during the exposure duration (km) in which:

[Eq. 17]

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

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 $L_R$)[3].

### *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]

$$PEF_{sc\_total} = \frac{1}{\frac{1}{PEF_{sc_{road}}} + \frac{1}{PEF_{sc}}}$$

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]

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

## 4.3.2 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) 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:

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

[Eq. 20]

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

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

[Eq. 21]

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

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 Equation 7, $M_{excav}$ is defined in Equation 8, $M_{doz}$ is defined in Equation 9, $M_{grade}$ is defined in Equation 11, $M_{till}$ is defined in Equation 12, and $M_{road}$ is defined in Equation 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 Equation 7, but the ED parameter is changed to reflect the exposure duration of an off-site receptor (typically assumed to be about 30 years) 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 offsite residents:

[Eq. 23]

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

### 4.3.3 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]

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

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

[Eq. 25]

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

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 3.2.2, 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 (m/s; location specific), $U_t$ 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]

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

### 4.3.4 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]

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

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

[Eq. 28]

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

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 3.2.3. As described in Section 3.2.2, 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 $V$ is the fraction of vegetative cover (unitless), $U_m$ is the mean annual wind speed (m/s), $U_t$ is the equivalent threshold value of windspeed at 7 m (m/s), and $F(x)$ are also equivalent to those described in Section 3.2.3.

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 onsite residents:

[Eq. 29]

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

## 4.4 Approaches for characterizing risk

Approaches for characterizing ARR have been outlined in previous guidance documents (USEPA, 1986; Berman and Crump, 2001, 2003). All of these guidance documents use the same general structure for the mathematical models to describe the relationship between exposure and disease endpoints.

These models characterize risk as being a product of a specific cancer risk coefficient (i.e., specific to lung cancer, mesothelioma, or both) and a function that is dependent upon the level and frequency of exposure and time. The cancer risk coefficients are estimated by two models that characterize the relative risk of lung cancer and the absolute risk of mesothelioma. 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. It is given in Equation 7-2 of Berman and Crump (2003):

[Eq. 30]

$$RR = \alpha\ (1 + K_L * CE10)$$

where RR is the relative risk (i.e., mortality) of lung cancer for a worker with a specified level of asbestos exposure measured by PCM (f-yr/ml), α is the baseline relative risk of lung cancer in unexposed members compared to the reference population, $K_L$ is the lung cancer potency factor for asbestos particles (f/cc-years)$^{-1}$, and CE10 is the cumulative

exposure to asbestos lagged by 10 years (f/cc-yrs) which depends on the time since first exposure *t* and the duration of exposure *D* where:

| | |
|---|---|
| $CE10 = 0$ | for $t < 10$ |
| $CE10 = C \times (t - 10)$ | for $10 < t < 10 + D$ |
| $CE10 = C \times D$ | for $10 + D < t$ |

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. It is given in Section 7.3 of Berman and Crump (2003):

[Eq. 31]

$$I_M(t) = C * Q * K_M$$

where $I_M(t)$ is the mortality rate per year at year *t* after the beginning of exposure, C is the concentration of asbestos in air (f/cc), $K_M$ is the mesothelioma potency factor for asbestos particles $(f/cc\text{-}yrs^3)^{-1}$, and Q is a cumulative exposure factor ($yrs^3$) which depends on the time since first exposure *t* and the duration of exposure *D* where:

| | |
|---|---|
| $Q = 0$ | for $0 \le t < 10$ |
| $Q = (t - 10)^3$ | for $10 \le t < 10 + D$ |
| $Q = (t - 10)^3 - (t - 10 - D)^3$ | for $10 + D \le t$ |

The 1986 method (USEPA, 1986) is based on human epidemiological studies of worker mortality resulting from asbestos. The risk calculations are based on fiber sizes that are detectable by PCM (e.g., longer than 0.5 µm and wider than 0.25 µm). No consideration was made for distinguishing between amphibole and chrysotile asbestos. The original cancer and mesothelioma coefficients outlined in the USEPA (1986) methodology were revised by Berman and Crump (2001; 2003) to address the potential importance of different mineral classes (i.e., amphibole and chrysotile) and different fiber size classes on disease endpoints. The Berman and Crump methodologies for characterizing asbestos risk (Berman and Crump, 2001; 2003) benefit from more recent mortality data and updated epidemiological studies. Both Berman and Crump protocols anticipate data from TEM analysis, which allows for the treatment of amphibole and chrysotile fibers separately, as well as allowing better resolution of finer fiber sizes. The conclusion of Berman and Crump (2003) is that almost all cancer risk comes from fibers that are greater than 10 µm in length and less than 0.4 µm in width.

Apart from calculating parameters for specific disease endpoints, ARR relies on parameters that characterize the level and extent of asbestos exposure. The frequency and duration of exposure to asbestos is an integral part of asbestos risk assessment calculations. These parameters are used to estimate the total time of exposure and are determined on a site-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.

## 4.5 Characterizing Asbestos-related Risk

The basic equation for assessing inhalation cancer risk for asbestos is analogous to that recommended by EPA 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 inhalation unit risk factor 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 for the unit risk factor. This calculation of ARR is also consistent with application of Berman and Crump (2003) to risk calculations described in Berman (2003a; 2003b; 2005). The risk equation used in performing an asbestos inhalation risk assessment is:

[Eq. 32]

$$ARR = \frac{C_{air} \times URF \times ET \times EF \times ED}{AT}$$

where:

$C_{air}$ – air concentration of asbestos (f/cm$^3$) (fibers per centimeter cubed)
ET – Exposure time (hours/day)
EF – Exposure frequency (days/year)
ED – Exposure duration (years)
AT – Averaging time (hours)
URF – Unit risk factor (risk per f/cm$^3$)

The URF is based on the estimated additional deaths from lung cancer or mesothelioma due to constant lifetime exposure. It is calculated according to the methods described in Berman and Crump (2003; Section 8). Based on this guidance, the URF is calculated as follows:

[Eq. 33]

$$URF = \frac{10^{-5}}{0.0001} R = \frac{1}{10} R$$

where R is a factor calculated according to Equation 8-1 of Berman and Crump (2003) as follows:

[Eq. 34]

$$R = 0.5((0.786(NSM + NSF)) + (0.214(SM + SF)))$$

and R is the "Estimated Additional Deaths from Lung Cancer or Mesothelioma per 100,000 persons from Constant Lifetime Exposure to 0.0001 TEM f/cc Longer than 10 µm and Thinner than 0.4 µm" (Berman and Crump, 2003; Table 8-2 – combined lung cancer and mesothelioma risk). In Equation 33, the numerator value ($10^{-5}$) and denominator value (0.0001) reflect the fact that the numbers shown in Table 8-2 refer to risk per 100,000 persons for exposure to an asbestos air concentration of 0.0001f/cc.

The approximations of population averaged risk derived by Equation 31 are valid as long as the projected risk is no greater than 1,000 per 100,000, otherwise risk is likely to be overestimated (Berman and Crump, 2003).

*NSM* and *NSF* in Equation 34 represent the risk for populations of non-smoking males and non-smoking females, respectively. *SM* and *SF* represent the risk for populations of smoking males and smoking females, respectively. In essence, R is a weighted average of the combined risks to the general population. This value of R is appropriate for a general population of adult receptors that includes smokers. For child receptors in the off-site and on-site residential scenarios, the same R value may be used in order to be protective of exposure to second hand smoke.

The parameter values for *NSM*, *NSF*, *SM*, and *SF*, which can be found in Table 8-2 of Berman and Crump (2003), are based on "optimized" risk coefficients for pure fiber types. Berman and Crump (2003; Table 8-3) also provide parameter values based on "conservative" risk coefficients for pure fiber types, however these parameters are derived from a single study that focused on exposure at a South Carolina textile mill. As such, these parameters are not considered appropriate for assessing ARR from soil at the BMI Complex and Common Areas. NDEP therefore recommends that the optimized parameters for combined lung cancer and mesothelioma in Table 8-2 of Berman and Crump (2003) be used for calculating the URF. These values are provided in Table 1 of this guidance.

**Table 1**. Values of NSM, NSF, SM, and SF for optimized risk coefficients, combined for lung cancer and mesothelioma (from Berman and Crump, 2003; Table 8-2).

| Fiber Type | non-smoker males (NSM) | non-smoker females (NSM) | smoker males (SM) | smoker females (SF) |
|---|---|---|---|---|
| Chrysotile | 0.269 | 0.303 | 1.65 | 1.57 |
| Amphibole | 62.9 | 72.5 | 38.3 | 55.1 |

By application of Equations 33 and 34, the following URFs for lung cancer and mesothelioma risks are computed for chrysotile and amphibole fibers:

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

The air concentration term (fibers/$m^3$) is derived from soil concentrations (fibers/gram) by applying the PEF values derived by equations 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 1 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 elutriator method described in Berman and Kolk (2000), is related to a number of factors including the total and scanned area of the filter that traps respirable particulates, and the mass of respirable particulates acquired. Equation 10-1 of Berman and Kolk (2000), rearranged to solve for AS shows:

[Eq. 37]

$$AS = \frac{S_d \times A_f}{A_s \times M_f}$$

where:

$S_d$ = number of structures required to define detection (1 fiber)
$A_f$ = total area of the filter ($mm^2$)
$A_s$ = area of the scanned part of the filter ($mm^2$)
$M_f$ = mass of respirable dust collected on the filter (g)

The number of fibers used to define detection is usually set to 1, implying the intent is for the instrumentation to be sufficiently sensitive that 1 fiber will be detected. NDEP recommends use of 1 fiber for this parameter. In practice, a target value of AS is often set and the equation is used to define the area of filter that should be scanned during laboratory analysis. Berman and Kolk (2000; Section 2.4) state that a target AS of $3 \times 10^6$ f/g "is likely to adequately bound the range of concentrations of potential concern for the vast majority of emission and dispersion scenarios of interest for risk management. Assuming a filter area of 385 $mm^2$ and dust loading on the filter of 0.0001 g (Berman and Kolk, Equation 10-1), this corresponds to a filter area of 1.5 $mm^2$ that must be scanned for fibers in the laboratory analysis. If a larger area of the filter is scanned, $A_s$, during the laboratory analysis the AS value decreases, resulting in a corresponding decrease in the estimated concentration of asbestos fibers in soil.

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). If the sample result is represented as $X_i$, then $X_i$ is distributed as a Poisson random variable with parameter $\lambda$ [$X_i \sim \text{Poisson}(\lambda)$]. The parameter $\lambda$ 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 nλ.

The pooled analytical sensitivity changes as individual sample results are summed. This is true in part because factors such as $A_s$ and $M_f$ in Equation 37 may vary among samples. 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 *n*λ. 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 represent the sum of the $\lambda$ '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 B. 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 a 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 Equation 36, and the RME-based estimate of soil concentration is given by Equation 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 Equation 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 Equation 43:

[Eq. 43]

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

## 5.0 Sample Size Calculations

The previous sections provide guidance for ARR assessment. ARR can be estimated for both chrysotile and amphibole using the procedures described. ARR for both asbestos types depends on analytical sensitivity, which is a function of the number of samples as well as instrument parameters of area of scanned part of the filter, total area of filter, and mass of respirable dust collected on the filter. 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 such 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 such that the risk thresholds are exceeded even if few or no asbestos fibers are detected. This is a common issue for amphibole fibers at the BMI Complex and Common Areas. There have often been few or no amphibole fibers longer than 10 µm and thinner than 0.4 µm found at a site. In these cases, the risk assessment results are directly affected by the 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 threshold, 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 in soil does not result in an unacceptable risk. In order to perform a calculation of the pooled analytical sensitivity that is needed, a threshold risk 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 DQO 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 as a function of the number of samples:

[Eq. 45]

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

The concentration term is obtained from Equations 32 and 35:

[Eq. 46]

$$C_{soil} = \frac{ARR \times AT}{URF \times ET \times EF \times ED} \times PEF$$

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, particular emission factor, and target number of fibers. Given the issues regarding the potential for identification of zero amphibole fibers to produce an unacceptable risk, this approach can be used to determine how many samples are needed to reasonably ensure that a total of zero amphibole fibers from *n* samples does not result in exceeding a target risk threshold.

## 6.0 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.

## 7.0 Asbestos Calculations Spreadsheet

This guidance document is supported by an EXCEL spreadsheet 'asbestos_guidance_riskcalcs.xls'. There are 8 worksheets in the EXCEL file covering risk calculations, PEF calculations, data input and analytical sensitivity calculations, and calculation of optimal number of asbestos samples for a range of input conditions. This spreadsheet brings together data, transport and risk into one program, facilitating asbestos risk assessment and review of documents that use this spreadsheet for asbestos risk assessment. The spreadsheet can also be used to calculate PEFs for the 4 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 those parameter value changes that 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. However, the values for number of fibers and pooled analytical sensitivity could 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 5.0.

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:

# Data Validation Steps for Reported Asbestos Data

1. Compare the samples reported with any Chain-of-Custody (COC) information. Make sure the report is complete and consistent with the COC.
2. Ensure the method used is documented and the method citation is sufficient to retrieve the method from the USEPA or other applicable source.
3. Verify that the date of analysis (start and completion) along with the analysts name is included. If the data were reviewed at the laboratory, the person(s) performing the review should also be included in the report. Batch identifier information should also be reported with each sample.
4. Make note of any quality assurance issues described in the laboratory report and include these in the DVSR.
5. Verify that the analytical sensitivity reported for each sample meets the Work Plan and NDEP requirements for Risk Assessment. Analytical sensitivity units should be consistent with the method, (e.g. $S/g_{PM10}$).
6. For the Elutriator Method for the Determination of Asbestos in Soils and Bulk Materials, verify that the laboratory report includes the relative flow rates through the IST and ME openings of the elutriator and estimated total air flow during each run of the dust generator for each sample.
7. Verify that asbestos measurements are consistent with the method. If the Draft Modified Elutriator Method for the Determination of Asbestos in Soils and Bulk Materials dated May 23, 2000, Revision 1 is used, be sure that biologically relevant structures are counted in terms of mineralogy and dimensions.
8. If any field or lab preparation technique was performed this should be reported. Ensure any mechanical steps used in laboratory sample preparation are included in the reports such as drying, splitting.
9. Verify that dimensions of the sample (filter) are provided in applicable units (e.g. square millimeters) and that the grid opening and magnification is reported.
10. Verify that all reported structures include the asbestos type: Amphibole, Chrysotile, Amisite, or Actinolite.
11. Appropriate blanks, as described in the asbestos laboratory method, should be reported with each laboratory report. Compare the blank values with the criteria in the method and Work Plan. If values exceed these criteria this should be identified and the associated data should be qualified in the DVSR.
12. Replicates should also be reported in the laboratory report. The results from these replicate analyses should be reported in the DVSR. If the precision limit found in the method or Work Plan is exceeded the effect on the data quality should be discssued.

# Appendix B

## 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 (Hogg and Craig). 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 C

# Comparison of Berman and Crump and Activity Based Sampling methods for Asbestos Related Risk

**1.0 Problem Statement**. The Nevada Division of Environmental Protection (NDEP) first published guidance for calculating asbestos-related risk (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 it's application (Berman 2003a; 2003b; 2005). NDEP has followed the basic approach laid out in this guidance for sites at the Basic Management Incorporated (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, September 2008). These approaches differ 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, September 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 the NDEP ARR guidance 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 the elutriator method and the "activity-based sampling" approach described in USEPA (2008).

2.1 Quantifying Asbestos Carcinogenicity. The inhalation unit risk factor (URF) 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 URF is based on fiber sizes that are

detectable by phase contrast microscopy (PCM) – longer than 5 µm and wider than 0.25 µm[4]. The URF applies to all 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 NDEP guidance distinguish risk based on different mineral classes (i.e., amphibole and chrysotile) and different fiber size classes. The URFs 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) conclude that ARR is dominated by fibers that are greater than 10 µm in 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, and finally analyze the respirable material for asbestos using TEM. Consistent with the asbestos URFs obtained from Berman and Crump (2003), separate fiber counts (fibers per gram of respirable particulate) are obtained for chrysotile and amphibole asbestos, and only fibers that are greater than 10 µm in length and less than 0.4 µm in width are counted. The USEPA (2008) framework 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. Like the NDEP ARR guidance, USEPA (2008) also recommends that TEM be used to analyze the particulates captured in the air sampling, in anticipation of improved asbestos risk models to distinguish the potencies of different mineral types and fiber dimensions. For using the TEM data with the current IRIS URF, which is based on PCM measurement, 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.

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 (UCL), and that non-detect samples be represented using a value of zero when calculating the average. This recommendation is 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. The NDEP ARR guidance recommends an approach based on Berman and Crump (2003) and Berman (2003a) to calculate an asbestos UCL 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

[4] More details of the PLM and TEM methods are provided in Section 4.2 of the main text.

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 NDEP ARR guidance 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 total asbestos fibers soil concentrations according to USEPA (2008), and mean and 95% UCL (95UCL) chrysotile and amphibole soil concentrations according to NDEP guidance,
4. Use mean total asbestos fibers soil concentrations and the IRIS URF, in conjunction with PEF models, to calculate USEPA framework asbestos cancer risks,
5. Use mean and 95UCL chrysotile and amphibole soil concentrations and Berman and Crump URFs, in conjunction with PEF models, to calculate NDEP guidance asbestos cancer risks.

Risk assessment calculations were performed utilizing the asbestos calculations EXCEL workbook 'asbestos_guidance_riskcalcs.xls' described in Section 6.0 of NDEP ARR guidance. To support these comparisons the following modifications to the workbook were made:

a. 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.
b. Input cells for USEPA method PCMe fiber concentrations and IRIS URF 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.
c. Asbestos risk calculation cells using USEPA PCMe fiber concentrations and URFs 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 4 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 onsite residential scenario. Table 1 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 1. 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 PM10

The analytical sensitivity for each sample is always slightly less than $3 \times 10^6$ fibers/gram PM10. 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 1 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 NDEP and USEPA 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 2.

**Table 2. 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 Section 3.0 are shown in Table 3. As discussed in Section 2, cancer risks calculated according to USEPA (2008) guidance employ a single asbestos URF for all fiber types and for mesothelioma and lung cancer combined. This URF is 0.23 $(\text{fibers/cm}^3)^{-1}$ (http://www.epa.gov/ncea/iris/subst/0371.htm). Separate mesothelioma and lung cancer URFs for amphibole and chrysotile are employed in NDEP's ARR guidance. For this comparison, asbestos mesothelioma and lung cancer risks for both amphibole and chrysotile fibers have been summed to facilitate comparison to the USEPA results. Results are shown for the on-site Residential exposure scenario. The relative risks using USEPA and NDEP protocols are identical for the other exposure scenarios described in NDEP's ARR guidance.

**Table 3. Asbestos Risk Assessment Results**

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

USEPA (mean): asbestos risk calculated using mean PCMe soil concentrations and the IRIS URF, as suggested in USEPA (2008)
NDEP (mean): asbestos risk calculated using mean soil concentrations according to NDEP ARR guidance
NDEP (95UCL): asbestos risk calculated using 95UCL soil concentrations according to NDEP ARR guidance

Table 3 indicates that asbestos cancer risks calculated according to USEPA (2008) guidance for all four data sets lie between the mean and 95UCL risks calculated according to NDEP guidance. Risk management decisions based on asbestos risk results calculated using NDEP guidance at these sites are therefore considered to be consistent with current USEPA recommendations for asbestos risk assessment. 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 $1 \times 10^{-6}$ to $1 \times 10^{-4}$ risk management range. These risk estimates in the absence of detected fibers would not be generated using current USEPA guidance (USEPA, 2008).

However, the USEPA approach is based on a mean concentration, which contains no uncertainty. This makes it difficult to perform sample size calculations. The NDEP approach addresses sample size by considering the UCL of the mean concentration. 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. This sample size, or data quality assessment, evaluation cannot be performed with the USEPA approach.

The similarity of results bears some discussion regarding sources of asbestos risk. The NDEP approach distinguishes between amphibole and chrysotile risks, whereas the

USEPA approach does not. Asbestos-related risks calculated using the NDEP approach are usually dominated by the amphibole risks. USEPA uses a unit risk factor that is between the amphibole and chrysotile URFs 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 URFs, it will take large differences in fiber concentrations for the NDEP mean and 95UCL risk estimates to not bound the USEPA risk estimates.

USEPA (2008; Appendix C) recognizes there is some uncertainty associated with using PCMe fiber counts to calculate risk with the IRIS URF 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 NDEP and USEPA methods 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 mean and 95UCL from the NDEP ARR method will bound the risk results for the USEPA methods. 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.

Although there are shortcomings of this side-by-side study because BAS concentrations are not directly available, the overall results suggest that continuing to follow the Berman and Crump methodology leads to reasonable risk-based decisions.

**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 NDEP risk result and the USEPA result were a factor of 4 (First Eight Rows), 2 (Mohawk) and 12 (Mohawk Supplemental).

When no fibers are detected, the response from the USEPA OSWER approach is that the human health risk is zero. This does not account for sample size. At a site where asbestos fibers have been observed, it does not seem reasonable to conclude that there is zero risk when zero PCMe fibers are observed. Also, the USEPA OSWER approach underestimates risk if the observed fibers are primarily amphibole. This results from a comparison of the URFs for PCMe and amphibole. At a site where amphibole is a factor in observed asbestos concentrations, such comparative underestimation might not be sufficiently protective of human health.

NDEP concludes that use of the 95UCL for asbestos risk results following the Berman and Crump approach is appropriate for making remedial decisions at BMI Complex sites. However, risk managers may also choose to acknowledge that current USEPA guidance (USEPA, 2008) does not recommend the use of a 95UCL for asbestos and 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.

In drawing this conclusion, NDEP has also considered the long history of following the Berman and Crump approach (since 2003), the relatively recent introduction of USEPA's new guidance, and concerns that NDEP has concerning the practicality of using the ABS method, and the benefit of the results. NDEP also recognizes that USEPA guidance will be changed as new information is gathered on ABS and other possible approaches that involve soil disturbance. The USEPA Asbestos Working Group continues to work on these issues. Given the comparison described above, and these other related concerns, NDEP recommends continued use of the Berman and Crump method at the BMI Complex and Common Areas.

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