REPORT ON DEVELOPMENT OF A MEDIA SPECIFIC SOIL STANDARD FOR ASBESTOS

GTAC-2 Requisition 20-051
GTAC-3 Requisition 30-051

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1.0 INTRODUCTION

The Land Recycling Program (Title 25 of the Pennsylvania Code Chapter 250) provides for Media-Specific Concentrations (MSC) for soil, which are based on protecting public health for populations (users of residential or industrial property) exposed to chemicals though the ingestion and direct contact, or the inhalation of soil (entrained as dust) containing potentially toxic chemicals.

The Pennsylvania Department of Environmental Protection (PADEP) tasked Ogden Environmental and Energy Services Company, Inc. (Ogden) with an evaluation of whether the standard algorithms for soil entrainment would be applicable to the case of asbestos fibers mixed with the soil, and what MSC should apply (using the standard algorithms or some alternative). Additionally, PADEP asked Ogden to consider what analytical method should be applied to the evaluation of soil-asbestos under Title 25, Chapter 250.

2.0 THE ENTRAINMENT ALGORITHM

The standard algorithm for entrained carcinogenic compounds[1] is provided at Pennsylvania Code Chapter 250, Section 250.307 (Inhalation Numeric Values) and is as follows:

$$MSC = \frac{TR\ x\ AT_c\ x 365d\ /\ y\ x TF}{CSF_i\ x\ Abs x\ ET\ x\ EF\ x\ If_{adj}}$$

(Equation 1)

[1] Asbestos is rated as a "human carcinogen" by the U.S. Environmental Protection Agency and no toxicity factors for the non-cancer actions of the fibers are listed in the Integrated Risk Information Service (IRIS) files on asbestos. As such, the carcinogenic action of the fibers will be the only consideration in this evaluation.

Where:

TR = Target risk (unitless, 10^{-5})
AT_c = Averaging time for carcinogens (70 years)
TF = Transport Factor (10^{10} (mg/kg)/(mg/m^3))
CSFi = Inhalation Cancer Slope Factor (mg/kg day)
Abs = Absorption (unitless, 1.0)
ET = Exposure Time (24 hours/day for residential exposure; 8 hours/day for industrial exposure)
EF = Exposure Frequency (250 days/year for residential exposure; 180 days/year for industrial exposure)
If_{adj} = adjusted inhalation factor (0.5 m^3 yr/kg hr for residential exposure; 0.4 m^3 yr/kg hr for industrial exposure)

The basic premise of the model is that contaminants may be sorbed to soil particles. Entrainment and subsequent dispersion of the soil particles as a dust provides a "carrier" for inhalation exposure. The contaminant concentration in the air is simply represented by the fraction of the dust mass that is contaminant. In this regard, the parameter of particular importance is "TF", the transport factor. The TF specified in 250.307 is actually the inverse product of two factors; a particle emission rate (ER) and an atmospheric dispersion factor (DF):

$$TF = (DF \ x \ ER)^{-1} \quad \textit{Equation 2)}$$

In the special case of asbestos, the "sorption" concept may be inappropriate. Rather, it might be assumed that individual fibers of asbestos may be mixed with the surface soil and entrained separately. If this an appropriate conceptual model, it would be important to consider whether entrainment is equivalent for fibers as it is for dust, and how one would account for the fraction of the total entrained mixture that is represented by asbestos fibers. The next sections consider the applicability of the individual parameters of TF for the case of asbestos, and are followed by a consideration of how to adjust equation (1) for this contaminant.

However, another consideration is whether the conceptual model for distribution of asbestos at a regulated will be correct in all cases. It would seem that it is equally likely or more likely that asbestos would be a component of construction material (such as insulation) and may exist as “mixed” large pieces unless substantial degradation over time had occurred. Large pieces of construction debris would not be subject to entrainment (or at least not to entrainment as it is modeled by ER). Thus, an MSC based on equation 1 might not be applicable to all site.

2.1 The Dispersion Factor (DF)

The dispersion factor used in 250.307 (12 (mg/m^3)/(mg/kg second)) is derived from the U.S. Environmental Protection Agency *Soil Screening Guidance. Technical Background Document (EPA, 1996)*[2] and is generic to any gas or small particle, if one ignores particulate settling. Therefore, the value should be generally applicable to small fibers as well as particulate. The specific modeling parameters used (one-half acre source size, dispersion as calculated from the AREA-LT dispersion model using meterologic data from Harrisburg, PA) are as applicable in the case of asbestos fibers as for contaminants sorbed to dust particulate.

2.2 The Emission Rate (ER)

The emission rate, is based on an empirical model of entrainment of particles less than 10 µm in aerodynamic diameter (“PM-10”), as a function of wind speed and frequency[3]. The emission rate used in Section 250.307 (8.25 x 10^{-12} (mg/m^2 sec)/(mg/kg)), was also taken from an evaluation conducted by EPA (1996) for the meteorology of Harrisburg, PA.
It is of interest to consider whether a model for PM-10 entrainment should be applied to asbestos fibers. We believe the use of the ER for PM-10 will tend to overstate the expected rate of release of asbestos fibers from contaminated ground surfaces to the air by wind entrainment. This belief is derived from the literature on the forces acting on small particles:

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[2] EPA. 1996. *Soil Screening Guidance. Technical Background Document*. EPA 540/R-95/128. May. Appendix D provides an inverse dispersion term (Q/C) of 81.9 (g/m2 sec)/(kg/m3) for the Area ST dispersion code applied to a one-half acre site for meteorological data obtained from Harrisburg, PA. Converting to the typical dispersion term (C/Q) and appropriate units yields approximately 12 (mg/m3)/(mg/kg second).

[3] The model is presented in EPA, 1996, as cited in footnote 2, but is developed more completely in Cowherd, C., Muleski, G.E., Englehart, P.J. and Gillette, D.A. 1985. Rapid assessment of exposure to particulate

1. A particle is entrained from a surface into a moving air stream when the aerodynamic forces from the air exceed the forces holding the particle onto the surface. Hinds (1999)[4] describes three adhesive forces that cause small particles to stick to surfaces and resist being entrained into air blowing over a surface. For most particles, van der Waals forces, which involve molecular attractive forces, and surface tension forces associated with adsorbed liquid on particle surfaces dominate. However, for insulating materials, like asbestos, which tend to retain electrostatic charges, the attractive electrostatic forces can be the strongest. Thus, charged asbestos fibers will have a stronger tendency to stick to a surface than other materials. The effect of gravity is relatively small for small particles. Complicating this effect is the fact that surface charges for the variety of asbestos types may differ.

2. The balance of forces on a particle is such that a critical wind speed must be exceeded for the particle to detach from the surface. The key parameter in the determination of the forces that work to entrain a particle from a surface into an air stream is the equivalent aerodynamic size of the particle. Within the range of particles that may entrained by the wind, it is the "larger" particles (i.e., with larger aerodynamic diameters) that are affected at lower wind speeds.

   The "equivalent aerodynamic diameter" is a measure to account for the net effects of differences in size and shape on the wind forces on a particle. There are two steps in the estimation of aerodynamic diameters. The first is the determination of the "equivalent volume diameter". In the case of an asbestos fiber, this is calculated by equating the volume of the long particle to a spherical particle having the same volume. The smaller diameter of the fiber is the more important dimension for a long fiber. For example, the equivalent volume diameter for a fiber with a 30:1 aspect ratio would be about 3.5 times the small diameter[5].

emissions from surface contamination sites. Paper 85-66.5 in *Proceedings of the 78th Annual Meeting of the Air Pollution Control Association*. June. 16 pages.

[4] Hinds, W.C., 1999. *Aerosol Technology*. Properties, Behavior, and Measurement of Airborne Particles. John Wiley & Sons, Inc. New York

[5] This is a relevant aspect ratio for toxic asbestos fibers, which are typically viewed as being 5 μm or longer and have diameters of approximately 0.4 μm or less.

The second step is to estimate the effect of the elongated shape on the aerodynamic drag on the particle. This "dynamic shape factor" also depends upon the ratio of the aspect ratio of the length to diameter of the fiber. Hinds (1999) states that this factor, averaged over all possible orientations of the fiber to the flow, is only 1.43 for an aspect ratio of 10. Thus, the aerodynamic diameter of asbestos particles is much smaller than the length of the fibers. In the context of fibers long enough to be in the toxic range (i.e., greater than 5 μm, but perhaps only 0.4 μm in diameter), the fibers are in the category of "small particles" that will need significant gusts of wind to cause them to be entrained into the air.

This being said, because the ER term is an empirical one, it is difficult to offer an alternative that is applicable to asbestos fibers. A search of the literature, as well as contact with several researchers and regulatory staff, revealed no entrainment factor that could be applied to the special case of asbestos. PADEP may therefore wish to use the typical TF for asbestos as an "only alternative", but acknowledge that this may be conservative relative to other Inhalation Numeric Values developed on the same basis. This would alert the Respondent that further site-specific study (e.g., monitoring ambient air for asbestos fibers) might be fruitful for sites with soil concentrations in excess of the Inhalation Numeric Value.

2.3 Adjustment of the Entrainment Algorithm

Even if the TF is maintained, it is necessary to adjust parameters in equation (1) to account for the nature of the toxicity factor provided for asbestos fibers. Specifically, the toxicity factor given in the Integrated Risk Information Service (IRIS) database for asbestos is based on fibers rather than the typical units of mass. Two adjustments are required:

1. The cancer factor for asbestos given in IRIS is a "unit risk" value and must be converted to an inhalation cancer slope factor (CSF_i) to be compatible with equation (1). Using a unit risk of 0.23 per f/ml, and the typical exposure assumptions (i.e., risk is due to continuous inhalation at 20 m^3/day in a 70 kg adult), the CSF_i can be calculated as:

$$CSF_i = 0.23 / [(f\ /\ ml)\ x\ (20000000\, ml\ /\ day)\ x\ (1/70 kg)] = 0.0000008 / (f\ /\ kg - d)\ \textit{(Equation 3)}$$

Note that this factor still does not have the typical units of a $CSF_{i,}$ rather it is in units of risk per bodyweight and time corrected-fiber count. Should one wish to convert this value into the typical units of risk per dose, it would be necessary to estimate the mass of a fiber.

For fibers of the dimensions assumed to produce toxicity (a "cylinder" at least 5 μm long and 0.4 μm in diameter), the volume of a fiber is at least ($\pi * (0.4/2)^2 * 5) \cong 0.6\ \mu m^3 = 6 \times 10^{-13}\ cm^3$. Assuming a density[6] of approximately 3 g/cm^3, the idealized fiber would have a mass of approximately 2×10^{-12} g, and equation (3) would convert to approximately 400/(mg/kg-day). U.S. EPA[7] has provided an "rough" estimate of density for the fibers visible by polarized light microscopy. This value, 1 mg/33 x 10^6 fibers equates to a single fiber weight of 3×10^{-11} g and a CSF of 27/(mg/kg day). The latter estimate may be more realistic than assuming all fibers are ideal.

2. The TF term in equation (1) might be converted from a factor that calculates contaminant concentration based on the mass fraction of contaminant in the dust to one that corrects for the proportion of fibers in the entrained particulate. One way to do this would be to assume the number of fibers per mass unit of soil is equivalent to the fraction of fibers that makes up the overall level of entrained dust. In this case, the TF factor is simply substituted with the fiber count per mass of soil, i.e., the TF becomes 10^{10} (f/kg)/(f/m^3). Alternatively, one might make the assumption that the proportional mass of fibers in soil is equivalent to their proportional mass in entrained dust. This causes the TF factor to retain its numeric value and units, but should not be confused with the better-founded assumption that a sorbed contaminant is proportional by mass in both soil and dust. To maintain the units of TF, a calculation of the mass of an asbestos fiber would have to be performed, as shown above for the CSF_i estimation. These calculation approaches use complimentary adjustments and will therefore yield identical answers.

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[6] According to the *Manual of Mineralogy, 19th Edition (*C.S. Hurlbut and C. Klein. John Wiley, New York, 1977), chrysotile asbestos, the primary fiber of exposure in several of the cancer epidemiology studies underlying the asbestos unit risk has a density ranging from 2.5 - 2.6 g/cm^3, while crocidolite asbestos, the primary fiber of exposure in other epidemiology studies has a density ranging from 3.2-3.3 g/cm^3

[7] EPA, 1986. Airborne Asbestos Health Assessment Update. EPA 600/8-84/0035.

2.4 Calculation of the MSC Inhalation Numeric Value

Table 1 provides calculations of entrainment-based MSCs for both residential and industrial Inhalation Numeric Values. Differences in the fiber per kilogram MSC calculations using the different formulations of CSF_i are solely due to rounding errors.

3.0 FIBER ANALYSIS

Of course, an analytical procedure will be required to determine compliance with the MSC. Due to the fact that a significant aspect of the toxicity of asbestos lies in the fibrous nature of the minerals, analytical methods for asbestos content typically employ quantitative microscopic techniques. There is an automated technique known as X-ray powder diffraction, which is reported to provide results in mass of asbestos per mass of bulk sample. However, the documentation for this technique[8] indicates the detection limit is 1 percent by weight, which would only be minimally sufficient for demonstrating compliance with the calculated Inhalation Numeric Values (see the MSC calculation based on mass in Table 1). Further, the method was developed for analysis of asbestos in bulk samples so that potential interferences produced by components of soil are not discussed but may be significant[9].

Difficulty is likely to be encountered in applying the standard microscopic techniques to a health-based soil standard. This is because, although the IRIS citation for asbestos indicates the unit risk is based on fibers counted by phase-contrast microscopy (PCM), laboratories we contacted[10] indicated that interference would prevent the application of this technique to soil samples. Other standard techniques for fiber analysis are polarized light microscopy (PLM) and transmission electron microscopy (TEM).

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[8] EPA, 1982. Test Method. Interim Method for the Determination of Asbestos in Bulk Insulation Samples. EPA 600 M4-82-020. December.

[9] For instance, the method identifies as a problem interference from kaolinite carbonates and iron in bulk samples.

[10] Fibertec (Holt, MI); Microanalytical Laboratories (Emeryville, CA); MAS (Atlanta, GA). EMSL (NJ) was contacted but did not provide a technical response

3.1 Polarized Light Microscopy (PLM)

U.S. EPA has a protocol for PLM analysis of fibers in soil, however, the Test Method (attached to this report) is, in fact, for the determination of asbestos in bulk insulation. While this Test Method might be applied to soil, at least one laboratory we contacted reported that PLM in many cases only allows the identification of "bundles" not individual fibers, and that, in any case, some number of fibers may be obscured by particles of soil. Thus, an opportunity for underestimation of actual fiber count exists for this method. This may or may not constitute a problem, since it should be recognized that the PCM method used to develop the unit risk factor also fails to count certain fibers. The question becomes how comparable the methods are and we found no information on this point.

Quantitative PLM applies a "point counting" method, in which a reticle is inserted into the ocular of the microscope to provide a grid or points above a portion of the optical field. The method then requires scoring how many counting points over an asbestos fiber versus non-abestiform structures (e.g. soil particles). Results are then reported as a "per cent asbestos" where the percentage is calculated as the quotient of the number of points with asbestos fibers over the total number of non-empty points counted. This is thus a per cent by "area" and bears no relation to a per cent by mass.

Presuming one knows the total mass of sample applied to the preparation and can assure that the applied material is reasonably homogeneous, the point counting technique could be converted to fiber number per mass of soil. While the PLM method is probably applied to only a few milligrams of soil, the lowest calculated Inhalation Numeric Value (approximately 10^{12} f/kg for residential exposures) can be converted to 10^{9} f/mg. This suggests that for fibers discernable using PLM, if interferences could be overcome, it should not be difficult to determine compliance with the MSC.

3.2 Transmission Electron Microscopy (TEM)

TEM methods can quantify the number of fibers, "bundles" or other particles in a given sample mass and therefore may represent a more unambiguous analytical method. The limitation of this method, as outlined in the IRIS citation, is that the increased resolution of TEM leads to counts of fibers well in excess of those that can be discerned by PCM. While it is satisfying to reveal the total fiber content of a sample, the TEM results may represent an overestimate of the fiber content relevant to the unit risk factor, because the factor was based on PCM measurements. Conceivably, a Respondent could specify that the analyst should count only fibers of greater than a certain length (e.g., greater than 5 µm) to partially account for this problem. IRIS reports that the fraction of fibers greater than 5 µm long detected by TEM that would also have been detected by PCM ranges from 0.22 to 0.53. Thus, although imprecise, one might apply a correction factor to the TEM results (where fibers greater than 5 µm are specified) to be consistent with fiber analysis method underlying the toxicity factor.

TEM method is preferable to the PLM method based on the low probability that fiber counts would be underestimated and the availability of a correction factor for comparison to PCM-based toxicity factors (albeit crude). However, the method is expensive: the one lab we spoke to who provided a cost estimate indicated a sample price of $500 (price could be reduced for large orders), as compared to quotes for PLM of approximately $30 to $200 per sample (we have no explanation for the variance in the latter quotes). As such, if PADEP selects the TEM method, you may wish to consider allowing Respondents to use PLM where it can be demonstrated that there is reasonable concordance with TEM results (as corrected to be compatible with the unit risk factor).

4.0 SUMMARY AND CONCLUSIONS

It is possible to make calculations of Inhalation Numeric Values for residential and industrial soils (values shown in Table 1) only by using the TF factor provided in Section 250.307 because this was the only value we found available. Such a computation implies the assumptions that asbestos at a site is in a form subject to entrainment and that the entrainment factors for asbestos are similar to small soil particles. However, asbestos may be present in bulk samples and the physics of air entrainment suggest that the TF is quite conservative for charged fibers such as asbestos (more so than the conservatism built into the application of the TF to soil-borne compounds).

It appears that analytical methods for asbestos are limited to microscopic techniques, which will report fibers per mass of soil. The microscopic method used for deriving asbestos toxicity factors, PCM, is not available for the analysis of soil due to interference difficulties. The most reliable fiber analysis technique for demonstrating compliance with the MSC is likely to be TEM, but the raw results of this analysis would have to be corrected to be compatible with fiber counts used to derive toxicity factors for asbestos. This may or may not be an accurate procedure. TEM is more expensive than PLM, the only other technique likely to be applicable to soil, but significant modifications would need to be made to current PLM methods to provide reporting units compatible with the soil MSC.

In view of the uncertainties of the entrainment model in the special case of asbestos, as well as the technical difficulties of finding an adequate analytical method to demonstrate compliance, PADEP may wish to consider an alternative approach for asbestos. Because the type of protection implied by the particular MSC derived here is limitation of risk due to inhalation of airborne asbestos, PADEP may wish to consider if air measurements could be used *in lieu* of a soil standard. This avoids the uncertainty of the model and makes the most relevant analytical techniques (PCM) available to the respondent. The mechanics of this approach would need to be discussed with PADEP and the Cleanup Standards Science Advisory Board, but could be viewed as (1) compatible with the requirements of Act 2 to provide an accurate site characterization prior to remediating (i.e., the finding of no airborne asbestos above a background level could be justification for no further action in relation to asbestos); (2) a site-specific standard (a risk assessment of the observed air concentrations is shown to be less than target risks specified in Chapter 250); or (3) an attainment demonstration (post-remediation sampling demonstrates that a reduction of airborne asbestos to background or a target risk has been achieved).

Table 1
Derivation of Soil MSCs for Asbestos
Based on Air Entrainment of Fibers

Basis of Conversion mass fraction	**Target Risk unitless**	**Averaging Time years**	**TF (mg/kg)/(mg/m^3)**	**CSF_i kg day/mg**	**Absorption Fraction unitless**	**Exposure time hr/day**	**Exposure Frequency d/y**	**Inhalation Factor m^3 yr/kg hr**	**MSC mg/kg**	**Fiber Mass mg/fiber**	**MSC f/kg**
Residential	1.00E-05	70	1.00E+10	2.70E+01	1	24	250	0.5	3.15E+04	3.00E-08	1.05E+12
Industrial	1.00E-05	70	1.00E+10	2.70E+01	1	8	180	0.4	1.64E+05	3.00E-08	5.48E+12
Basis of Conversion fiber fraction	**Target Risk unitless**	**Averaging Time years**	**TF (f/kg)/(f/m^3)**	**CSF_i kg day/f**	**Absorption Fraction unitless**	**Exposure time hr/day**	**Exposure Frequency d/y**	**Inhalation Factor m^3 yr/kg hr**			
Residential	1.00E-05	70	1.00E+10	8.00E-07	1	24	250	0.5			1.06E+12
Industrial	1.00E-05	70	1.00E+10	8.00E-07	1	8	180	0.4			5.54E+12