United States
Environmental Protection
Agency

RCRA Draft Supplemental Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway (Vapor Intrusion Guidance)

December 2001

SUPPLEMENTAL GUIDANCE
FOR
EVALUATING THE VAPOR INTRUSION TO INDOOR AIR PATHWAY
(Vapor Intrusion Guidance)

Partial Response to "Question 3" of 02/05/99 RCRA Corrective Action
Environmental Indicator (EI) RCRIS Code (CA725)
"Current Human Exposures Under Control"

INTRODUCTION

This document provides guidance for assessing if the subsurface vapor intrusion to indoor air pathway for human exposure is complete under current site conditions. This pathway is illustrated in Figure 1. For the purposes of this document, a "complete pathway" is defined to be one that results in exposures above levels of concern. This assessment may be required to answer Question 3 (Are there complete pathways?) of the Human Exposures Environmental Indicator (EI) determinations under the Resource Conservation and Recovery Act (RCRA) as specified in the February 5, 1999 EI Guidance Document. This supplemental guidance is intended to provide a national benchmark for consistent evaluation of this pathway and is not intended to supercede existing state-specific guidance or regulations. The lead regulatory authority should determine the appropriate use of this guidance.

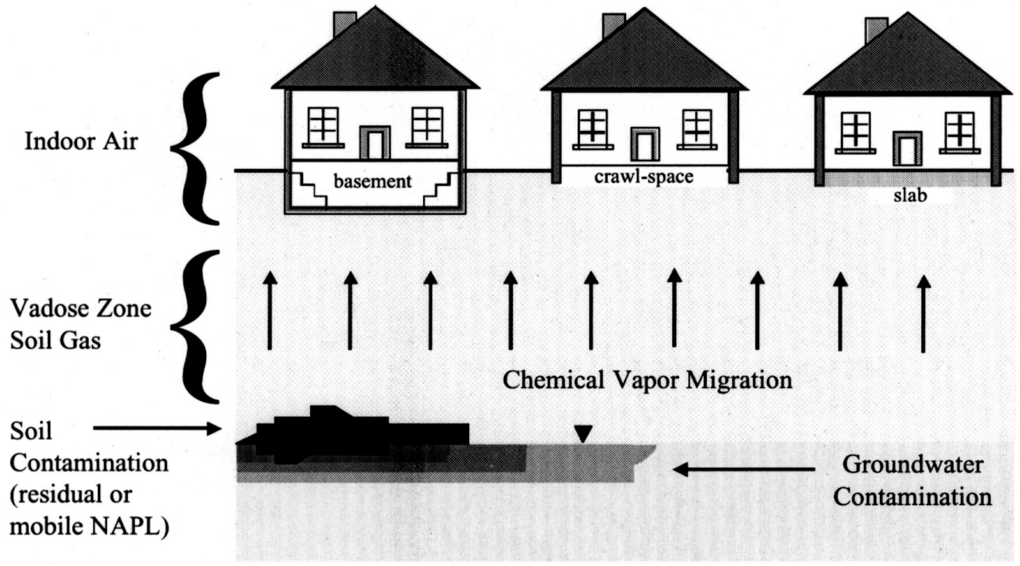

Figure 1: Generalized schematic of the pathway for subsurface vapor intrusion into indoor air.

The implementation of the approach presented here is generally similar to that of the original 1999 EI guidance. Record sheets containing a series of questions lead users through an analysis to determine if the subsurface vapor intrusion into indoor air pathway is complete. Those who implement this guidance should use professional judgement, consider the technical objectives and attempt to assess the completeness of the vapor intrusion pathway in a fair, practical, and technically defensible fashion. Users may find the discussions included in Appendix A to be useful when factoring in professional judgement.

At sites where soils or groundwater contain volatile or semi-volatile chemicals of concern, there is the potential for chemical vapors to migrate from the subsurface to overlying buildings. In extreme cases, these vapors may accumulate at concentrations that pose near-term safety hazards (e.g., explosions or acute health effects) or aesthetic problems (i.e. odors). More commonly, the chemical concentrations are low, if detectable at all, and the main concern is whether there is an unacceptable risk of acute or chronic health effects. This pathway may be important regardless of whether there is a basement or not.

This inhalation exposure pathway is different from other pathways for several reasons. First, assessment of the subsurface vapor to indoor air pathway has a much shorter history than the assessment of other pathways (e.g., groundwater ingestion, direct exposure to impacted soils, etc.) and consequently the key issues and technical challenges are not as well understood. Second, response options are more limited. For example, if the groundwater ingestion pathway is complete, people can drink bottled water or can be connected to other potable sources. In comparison, one has little choice over the air they breathe, and it is impractical to breathe bottled air. Third, the assessment of this pathway is more complex than other pathways because it often involves the use of indirect measurements and modeling (e.g. using soil gas or groundwater data to assess indoor air quality). Exposure levels attributable to this pathway can be lower than, comparable to, or even higher than exposures due to groundwater ingestion, and therefore, target groundwater concentrations for this pathway are sometimes lower and sometimes higher than Maximum Contaminant Levels (MCLs), as shown on Tables 2 and 3. This is attributable to differences in exposure factors (e.g., an average person inhales about 20,000 liters of air per day but only drinks about 2 liters of water), and differences in transport mechanisms (e.g., subsurface vapors are typically diluted by 100 to 10,000 times before they enter indoor air).

In addition, this pathway differs from others because ambient background concentrations can exceed target breathing concentrations for some common chemicals of interest, especially in urban areas where air quality is often affected by a large number of atmospheric emissions. Indoor vapor sources (cleaners, paints, glues, etc.) may also contribute to increased indoor air concentrations of some chemicals. In fact, there are typically dozens of detectable chemicals in indoor air even in the absence of subsurface contributions. Vapors attributable to ambient and indoor sources need to be considered when assessing the completeness of this pathway. Air concentrations from the scientific literature can be used initially, and if necessary, a more site-specific survey can be conducted later. This is necessary to ensure that the subsurface vapor intrusion pathway is not falsely concluded to be complete when using indoor air quality data.

SUMMARY OF TIERED ASSESSMENT FOR PATHWAY COMPLETENESS

The approach adopted in this guidance is summarized in the flowchart given in Figure 2. There are three tiers of assessment (Primary Screening, Secondary Screening, and Site-Specific Pathway Assessment) with increasing levels of complexity and specificity, as described in the paragraphs that follow.

The **Primary Screening** step is designed to quickly identify if the subsurface vapor intrusion to indoor air pathway is incomplete (i.e. currently poses no unacceptable exposures for the purpose of the EI) or if it is complete and immediate action is appropriate. Criteria for each of these conditions are identified in Questions 1 through 3, which focus on identifying: a) if chemicals of sufficient volatility and toxicity are present (Question 1), b) if inhabited buildings are above or in close proximity to subsurface contamination (Question 2), and c) if current conditions warrant immediate action (Question 3). The Primary Screening can be conducted with general knowledge of a site and the chemicals known or reasonably suspected to be present in the subsurface; it can be conducted without necessarily having specific media concentrations available (i.e. groundwater and/or soil gas concentrations, indoor air concentrations). If, at the end of the Primary Screening, the pathway is not conclusively incomplete, or immediate actions have not been initiated, the evaluation proceeds to the Secondary Screening.

The **Secondary Screening** involves comparing measured or reasonably estimated concentrations of target chemicals in various media (groundwater, soil gas, and/or indoor air) to numerical criteria identified in Questions 4 and 5. The first criteria discussed in Question 4 are conservative enough that they can be applied even if little is known about the subsurface conditions affecting vapor transport at the site. These “generic criteria” are biased towards worst-case conditions and are likely to be overly protective at most sites. Question 5 provides the opportunity to link the target criteria to depth and soil type. If measured or reasonably estimated media concentrations are judged to be less than the target numerical criteria, the pathway can be considered to be incomplete. If indoor air samples have been collected and these concentrations are greater than the target criteria used in Question 4, then exposure controls should be implemented unless it can be demonstrated that the concentrations result from ambient air or indoor sources of the chemicals. If soil gas or groundwater concentrations are available, and these are judged to be considerably higher than the criteria used in Question 5, then interim exposure control measures should be considered, or further assessment involving more direct sampling and analysis should be conducted as soon as possible. If soil gas or groundwater concentrations are only moderately higher than the criteria (and indoor air data is not available), the evaluation should proceed to the third level of screening, the Site-Specific Pathway Assessment.

Vapor migration and potential exposures are examined in more detail in the **Site-Specific Pathway Assessment** (Question 6). The assessment could be as simple as using the same equations employed to develop the Secondary Screening criteria but with revised inputs that are defended with site-specific data. It could involve measuring vertical soil gas profiles for the purpose of developing and defending a site-specific vapor attenuation factor. It could also be as complex as a comprehensive mapping of subsurface vapor distributions and measurement of subsurface material properties affecting gas flow and transport, combined with the development of a site-specific vapor transport model. The data needs are greater here than in the Primary and Secondary Screening; however, the necessary data might already be available from previous site characterization work. A conceptual model of the site and subsurface vapor transport and vapor intrusion mechanisms will be needed to defend the Site-Specific Pathway Assessment. Model inputs and assumptions that are different than the generic assumptions in Questions 4 and 5 criteria must be supported with site-specific data.

Implementation of **Performance Monitoring** and **Pathway Monitoring** programs is considered in Question 7. **Performance Monitoring** should be conducted when engineered systems are used for exposure controls and should be sufficient to confirm their effectiveness in making the pathway incomplete. This may be limited to monitoring of pressure differentials, and does not necessarily need to include confirmatory indoor air quality monitoring. **Pathway Monitoring** should be conducted to confirm the persistence of an incomplete pathway, in cases where measured or reasonably estimated media concentrations are less than, but potentially comparable (within site-specific ranges of variability) to levels that would correspond to a complete pathway. Pathway monitoring is probably unnecessary in most cases where the pathway is judged to be incomplete in Question 1 or Question 2, and the same would probably be true when measured or reasonably estimated media concentrations were more than an order of magnitude lower than Question 4 or Question 5 criteria. In any case, the need for, and scope of a monitoring program is decided by the lead regulatory authority.

This guidance is intended to begin with simple and conservative screening, and then allow a gradual progression toward more complex and accurate assessment. While the flowchart presents a logical and linear progression, the user is not strictly constrained to the sequence of events depicted in Figure 2. For example, if at any time it is more cost-effective to invoke proactive exposure controls than to proceed with further assessment, the guidance allows for this option, provided that performance monitoring is conducted to assure effectiveness. Similarly, users might elect at any time to collect additional soil gas, groundwater, or indoor air data. Question 4 should be reconsidered whenever indoor air data is collected.

This guidance relies on the use of three tables (Table 1, Table 2, and Table 3) containing a list of chemicals and target media concentrations for each. This guidance is not intended to supercede existing guidance and the lead regulatory authority may determine that criteria other than the ones provided in this guidance are appropriate in their area. Thus, the user should consult with their lead regulatory authority to identify the appropriate criteria to use. Furthermore, it should be understood that references to use of “Table 1”, “Table 2” and “Table 3” in this guidance should be interpreted to mean use of the criteria tables selected by the lead regulatory authority.

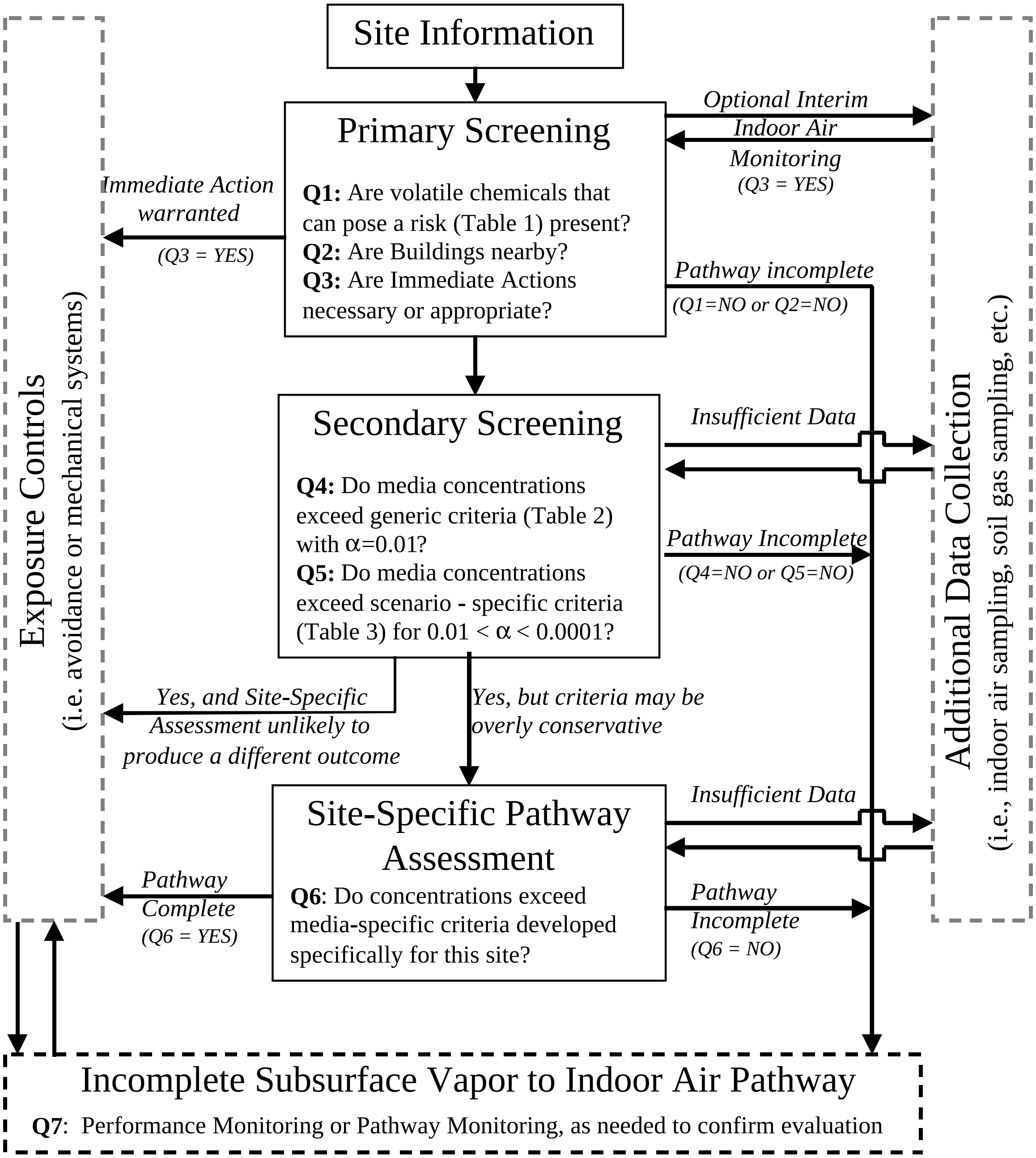

Figure 2. Flowchart of the vapor intrusion pathway assessment process. While the flowchart presents a logical and linear progression, the user is not strictly constrained to the sequence of events depicted here. Questions 1, 2, and 3 are answered for most sites, but beyond that the user may elect to collect indoor air samples or implement exposure controls at any time. Indoor air sampling is not required however as soil gas concentrations or groundwater concentrations can also be used for pathway assessment. Exposure controls are needed when indoor air quality criteria are known to be exceeded, or when comparison of groundwater or soil gas concentrations with their respective target media concentrations suggest that indoor air quality criteria are exceeded, and there is no indoor air quality data to confirm the absence of a complete pathway.

Primary Screening – Question #1

Q1: **Are chemicals of sufficient volatility and toxicity** (Table 1) known or reasonably suspected to be present in subsurface soils, soil gas, or ground water; the presence of these chemicals having resulted from releases subject to RCRA Corrective Action (e.g., from Solid Waste Management Units (SWMU), Regulated Units (RU), or Areas of Concern (AOC))?

_____ If YES - check here, check the relevant chemicals on Table 1, and continue with Question 2 below;

_____ If NO - check here, provide rationale and references below, and skip to the Pathway-Specific EI Summary Page and document that the subsurface vapor to indoor air pathway is incomplete; or

_____ If sufficient data are not available, skip to the Pathway-Specific EI Summary Page and enter "IN" (more information needed) status code.

Criteria:

Table 1 provides a list of chemicals and indicates whether they are sufficiently volatile and toxic to pose an incremental lifetime cancer risk greater than 10^{-5} or a hazard index (HI) greater than 1, assuming continuous exposure to the maximum possible vapor concentration. This is an extremely conservative criterion, corresponding to an infinite supply of the pure chemical (e.g., NAPL pool), and no indoor air dilution, which is highly unlikely to occur. The exposure assumptions and calculations are documented in Appendix B.

Note: Table 1 may not include all possible chemicals of concern; it can be revised to include other chemicals according to the methods described in Appendix B, if the necessary chemical property and toxicity data is available.

Rationale and References:

Primary Screening – Question #2

Q2: **Are inhabited buildings located near** subsurface contaminants having sufficient volatility and toxicity?

_____ If YES - check here, identify buildings below, and continue with Question 3 below.

_____ If NO – check here and skip to the Pathway-Specific EI Summary Page and document that the subsurface vapor to indoor air pathway is incomplete, or

_____ If sufficient data are not available - check here and skip to Pathway-Specific EI Summary Page and enter "IN" (more information needed) status code.

Criteria:

The goal of this question is to identify buildings that could potentially have a complete pathway, i.e., indoor air concentrations above levels that would pose a lifetime incremental cancer risk of 10^{-5}, or a hazard index of >1. For the purposes of this question:

- **"inhabited buildings"** are structures with enclosed air space that are designed for human occupancy.
- **"subsurface contaminants having sufficient volatility and toxicity"** are defined by Table 1 and were discussed above in Question 1.
- An inhabited building is considered **"near"** subsurface contaminants if it is located within 100 ft laterally of known or interpolated soil gas or groundwater concentrations in excess of the criteria in Table 2.

A distance criterion is necessary to focus the assessment on buildings most likely to have a complete pathway. Vapor concentrations generally decrease with increasing distance away from a subsurface vapor source, and at some distance, the concentrations become negligible. The distance at which concentrations are negligible is a function of the mobility, toxicity and persistence of the chemical, as well as the geometry of the source, subsurface materials, and characteristics of the building of concern. Definitive studies on this topic have yet to be conducted, but 100 feet is a reasonable criterion when considering vapor migration fundamentals, typical sampling density, and uncertainty in defining the actual contaminant spatial distribution.

Identify Inhabited Buildings Within Distances of Possible Concern:

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Primary Screening Stage-– Question #3

Q3. Is **immediate action warranted** to mitigate current risks to residents of those buildings identified in Question 2 to be located within the area of concern?

_____ If YES – check here and proceed with immediate actions to verify or eliminate imminent risks, which may include indoor air quality monitoring, engineered containment or ventilation systems, or relocation of receptors[1]. The immediate action(s) should be appropriate for the situation.

_____ If NO – check here and then continue with Question 4 below.

Criteria:

Here we focus on those buildings identified in Question 2 to be located within the areas of concern. The following qualitative criteria are considered sufficient to justify immediate actions:

Odors reported by occupants, particularly if described as “chemical”, or “solvent”, or “gasoline”. The presence of odors does not necessarily correspond to adverse health and/or safety impacts and the odors could be the result of indoor vapor sources; however, it is prudent to investigate any reports of odors as the odor threshold for some chemicals exceeds their respective acceptable target breathing zone concentrations.

Physiological effects reported by occupants (dizziness, nausea, vomiting, confusion, etc.).

Wet basements, in areas where chemicals of sufficient volatility and toxicity (see Table 1) are known to be present in groundwater and the water table is shallow enough that the basements are prone to groundwater intrusion or flooding, especially if there is evidence of light, non-aqueous phase liquids (LNAPLs) floating on the water table directly below the building, and/or any direct evidence of contamination (liquid chemical or dissolved in water) inside the building.

Short-term safety concerns are known, or are reasonably suspected to exist - for example: a) explosive or acutely toxic concentrations of vapors have been measured in the building or connected utility conduits; b) explosive or acutely toxic levels of vapors are likely to be present in utility conduits, sumps, or other subsurface drains directly connected to the building. Lower explosive limits are typically in the range of 1 to 5% by volume (10,000,000 ppbv to 50,000,000 ppbv).

There may be circumstances in which the Responsible Party elects to initiate indoor air quality monitoring and/or pro-actively eliminate exposures through avoidance or mechanical systems, rather than pursue continued assessment of the pathway. In some cases this may be a cost-effective option as it leads directly to an incomplete subsurface vapor to indoor air pathway. This option is available at any time in the assessment. Furthermore, some buildings are positively pressurized as an inherent design of the heating, ventilating and air conditioning system, and it may be possible to show that the pathway is incomplete by demonstrating a significant pressure differential from the building to the subsurface. Proactive indoor air quality monitoring may also be initiated at any time, although it is not necessary if the pathway can be confirmed to be incomplete using other data.

Rationale and Reference(s):

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Secondary Screening – Question #4

Q4: Do measured or reasonably estimated indoor air, soil gas, or ground water concentrations[2] exceed the target media-specific concentrations given in Table 2?

_____ If NO, and there is no reason to believe that the conservative attenuation factor of 0.01 is inappropriate – document representative media concentrations on Table 2 and check here. Go to the Pathway-Specific EI Summary Page and document that the subsurface vapor to indoor air pathway is incomplete.

_____ If YES – check here. If indoor air concentrations are known and these are greater than the target indoor air concentrations, then the pathway is complete and engineering controls or avoidance measures need to be implemented. If only soil gas or groundwater data are available, and these exceed the target criteria, document representative media concentrations on Table 2 and then proceed to Question 5.

_____ If sufficient data are not available - check here and skip to Pathway-Specific EI Summary Page and enter “IN” (more information needed) status code.

Criteria:

Question 4 is intended to allow a rapid screening of available site data, which may include soil gas, groundwater, or indoor air concentrations. Concentrations in the three media are assumed to be correlated, so that data from any of the three media can be used. If data are available for more than one media, all of the data should be considered in answering Question 4. As discussed in Appendix A, confidence in the assessment increases with multiple lines of evidence, so additional data may be collected for consideration in Question 4, at the discretion of either the responsible party or the lead regulatory authority, to the extent that this may be necessary and appropriate.

Note that it is important to segregate the buildings of interest into two categories: a) buildings lying above areas where contaminated groundwater is the only source of contaminant vapors, and b) buildings lying above areas where contaminated vadose (unsaturated) zone vapor sources are present. While indoor air quality data can be used to judge the pathway completeness in either case, the appropriate use of groundwater and soil gas data is different for these two cases. In case (a) either the soil gas or groundwater criteria in Table 2 can be used at this step, while in case (b) only soil gas criteria and soil gas samples collected above the vapor source zone can be used. This is because the groundwater criteria have been derived assuming no other vapor sources between the water table and the building foundation. This also applies for Question 5.

The term “measured or reasonably estimated” is used above (and throughout this document) as it is recognized that measurements at all buildings of concern may not be practical or necessary. For example, groundwater concentrations beneath buildings are commonly estimated from concentrations collected in wells distributed about a larger area of interest. Likewise, one might reasonably estimate upper bound indoor air concentrations for a group of buildings based on the measurements taken from those buildings expected to have the highest concentrations.

In the case of soil gas concentrations, measured or reasonably estimated soil gas concentrations at any depth in the subsurface may be used in Question 4, provided that this depth falls below the foundation depth. As there are concerns about the integrity of shallow soil gas samples, it is recommended that samples collected at depths <5 ft below ground surface (BGS) not be used for this analysis, unless they are collected immediately below the building foundation several feet in from the edge. Samples from fixed probes are also preferable, but not required. With respect to the spatial distribution of sampling points, close proximity to the building(s) of concern is preferred; however, it may be possible to reasonably estimate concentrations based on data from soil gas samples collected about a larger area. Users should

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also consider that, in general, samples collected at depth closer to the vapor source are much less likely to be dependent on the surface cover (i.e. pavement, lawn, foundation) than shallow soil gas samples.

In the case of groundwater concentrations, these should be measured or reasonably estimated using samples collected from wells screened at, or across the top of the water table. This is necessary to be consistent with the derivation of the target groundwater criteria in Table 2. Samples from groundwater monitoring wells may be a blend of groundwater from different levels across the screened interval. Confidence in the results can be increased through use of a more narrowly screened interval across the water table, or a variety of other depth-discrete sampling protocols. These issues, and others to be considered during data collection, are discussed in Appendix A.

Question 4 calls for comparison with the target criteria given in Table 2; however, this guidance is not intended to supercede existing state-specific guidance or regulations. Thus, the lead regulatory agency will determine the appropriate criteria to be used here and in Questions 5 and 6. If target criteria are not available, then the tables provided with this guidance should be used. A regulatory agency may have already developed acceptable indoor air concentrations, but they might not have derived vapor intrusion pathway-specific target media concentrations. In this case, the methods discussed in Appendix B can still be used to derive target soil gas and dissolved groundwater concentrations consistent with those existing target indoor air concentrations. Where pathway-specific media concentrations already exist, the values provided in this guidance should be considered national benchmarks, and the governing regulatory authority should compare the methods and assumptions used to derive their criteria with the methods used in this guidance. In any case, users of this guidance should review the methods used to derive the tables presented in this guidance, and consider whether or not the assumptions and methods are appropriate for their application. These assumptions are discussed briefly below, and in more detail in Appendix B.

The target media-specific concentrations given in Table 2 correspond to indoor air concentrations calculated to cause an incremental lifetime cancer risk of 10^{-5} or a Hazard Index of 1.0 (whichever is more restrictive). In the case of the soil gas criteria, a conservative soil gas to indoor air attenuation factor of 0.01 is used. For the groundwater criteria, there is an additional conservative assumption that the partitioning of chemicals between groundwater and soil vapor is assumed to obey Henry’s Law. Table 2 may not include all possible chemicals of concern; it can be revised to include other chemicals of concern according to the methods described in Appendix B, if chemical property and toxicity data is available.

The soil gas to indoor air attenuation factor represents the ratio of the indoor air concentration to the soil gas concentration at some depth. The 0.01 value is considered to be a reasonable upper-bound value for the case where the soil gas concentration immediately beneath a foundation is used (e.g., the indoor air concentration would not be expected to exceed 1/100 of the concentration immediately below the foundation). This value is based on available data from sites where paired indoor air and soil gas samples immediately below a foundation were available, and also theoretical considerations. It is a conservative enough criterion that it should be protective even in settings where the building has significant openings to the subsurface. In addition, since it has been argued that the 0.01 value is conservative for deriving near-foundation soil gas criteria, the soil gas criteria derived using this value would be even more conservative if applied to soil gas concentrations measured or reasonably estimated at any other deeper depth. For reference, attenuation factors as low as 0.00001 have been determined from data at some sites. There may be some settings where the 0.01 attenuation factor is not a conservative upper-bound value; however, most of these settings would presumably be identified and addressed in Question #3.

The authors of this guidance felt that the uncertainties associated with soil partitioning calculations as well as the uncertainties associated with soil sampling and soil chemical analyses (see EPA/600/SR-93/140) were so great that use of soil concentrations for assessment of this pathway is not technically defensible. Thus, soil concentration criteria were not derived and the use of soil criteria is not encouraged. However, as discussed above, this guidance is not intended to supercede existing State guidance, and users should follow the appropriate guidance as determined by the lead regulatory authority. Furthermore, proponents may elect to defend the use of soil concentration data in the Site-Specific Pathway Assessment, Question 6.

The soil gas and groundwater target concentrations were derived from the target indoor air criteria, without consideration of ambient outdoor air quality or other chemical sources internal to the building. The target concentrations should therefore be interpreted as target incremental concentrations above background levels. To be consistent with that definition, background concentrations should be subtracted from measured or reasonably estimated indoor air concentrations before comparison against the Table 2 (or other appropriate) criteria.

Values appearing in Table 2 were derived for an incremental lifetime cancer risk (R) of 1 x 10^{-5} and hazard index (HI) of 1. The risk-manager or decision-maker should consider a number of variables when comparing site data to the Table 2 criteria, including: the number and locations of samples, the spatial and temporal variability of concentrations, the frequencies of accedences of Table 2 criteria, the magnitude of accedences of Table 2 criteria, and the degree of conservatism built into Table 2 values. The Table 2 criteria are not intended for use as "bright-line criteria", below which any measured or reasonably estimated concentrations are acceptable and above which any concentrations are unacceptable. Instead, professional judgment should be used when applying the criteria. For example, if eight out of ten samples satisfy Table 2 criteria and the other two exceed the criteria, but only by a factor of two or three, the risk-manager might decide that the pathway is incomplete, even though two of the samples exceed the criteria. This is because the risk estimate is still in the same order-of-magnitude as the target risk level and there is some conservatism built into the Table 2 values.

Rationale and Reference(s):

Secondary Screening – Question #5

Q5: Using the appropriate scenario-specific attenuation factor (from Figure 1), do measured or reasonably estimated soil gas or ground water concentrations exceed the target media-specific concentrations given in Table 3?

_____ If NO, and there is no reason to believe that the scenario-specific attenuation factor is inappropriate, check here and document the Rationale and References for the scenario-specific attenuation coefficient below. Go to the Pathway-Specific EI Summary Page and document that the subsurface vapor to indoor air pathway is incomplete.

_____ If YES – check here, and if representative measured or reasonably estimated soil gas and/or groundwater concentrations are considerably (i.e. greater than 100 times) higher than the values in Table 3 then interim exposure controls and/or measurement of indoor air quality monitoring should be conducted as soon as practicable; and when representative media concentrations are less than 100 times the appropriate Table 3 values proceed to further analysis and modeling in Question 6.

_____ If sufficient data are not available - check here and skip to Pathway-Specific EI Summary Page and enter "IN" (more information needed) status code.

Criteria:

Soil gas or groundwater to indoor air attenuation factors are expected to depend on building characteristics, chemical type, soil type, and depth of the source (which is defined as either a measured soil gas concentration at the specified sample collection depth below the building, or the ground water concentration at the depth of the water table). The 0.01 attenuation factor value used in Question 4 is representative of expected upper bound values for vapors located immediately below the building, and therefore does not depend on soil type or depth. Question 5 considers the site-specific soil type and depth of source to allow for a more representative vapor attenuation factor, and consequently the target media concentrations. The target indoor air concentrations remain the same (unchanged from Table 2), but target soil gas and groundwater concentrations will vary with changes in the vapor attenuation factor.

Attenuation factors have been calculated for some combinations of source depth, soil type, and building characteristics using the Johnson and Ettinger (1991) model. Reasonable building characteristics were selected and held constant in these calculations and the chemicals were assumed not to degrade. To capture the effect of changes in soil properties, the U.S. Soil Conservation Service (SCS) soil texture classifications were considered, and a subset of these were selected. This subset was chosen so that their relevant properties (porosity and moisture content) would collectively span the range of conditions most commonly encountered in the field. Then, plots of attenuation factor vs. depth were calculated and these results are presented below in Graphs 1a (for use of soil gas data) and 1b (for use of groundwater data). The two graphs are different because the first does not have to account for transport across the capillary fringe. Details of these calculations are included in Appendix B.

The depth used should be: a) the vertical separation between the soil gas sampling point and the building foundation for use of Graph 1a, or b) the vertical separation between groundwater and the building foundation for use of Graph 1b. Samples collected near to, but at depths shallower than the building foundation should not be used. Table 4 should be used to help select the most appropriate soil texture classification as discussed below.

The site characterization should include collection of soil samples at various depths between the building foundation elevation and contamination source (i.e., vertical soil gas and/or groundwater quality profiling) and description of soil lithology. The preferred method for determining the SCS soil class is to use lithological information combined with the results of grain size distribution tests on selected soil samples. Procedures for conducting grain size distribution tests are provided in American Society for Testing and Materials (ASTM) Standard Test Method for Particle Size Analysis of Soils (D422-63) and U.S. Natural Resources Conservation (NRCC) Soil Survey Laboratory Methods Manual, Soil Survey Laboratory Investigations Report No. 42.

The U.S. SCS soil texture classes are based on the proportionate distribution of sand, silt and clay sized particles in soil. It does not include any organic matter. The grain size boundaries are as follows:

Sand: 0.05 mm to 2 mm
Silt: 0.002 mm to 0.05 mm
Clay: <0.002 mm

The soil textural classes are displayed in the SCS soil textural triangle. The soil texture class is determined by plotting the grain size distribution results on the soil texture triangle. If a soil texture class is not intersected based on the five classes included in the guidance, the nearest soil class is chosen. The selection of the soil texture class should be biased towards the coarsest soil type of significance, as determined by the site characterization program.

There are sites where different soil classifications systems have been used, and where information on soil lithology and grain size distribution is limited. Most engineering soil classification systems are either based on grain size, or a combination of grain size and engineering properties (e.g., Unified Soil Classification System (USCS), ASTM D2488-84, NAVFAC DM7.2 (1982)). For several soil classification systems, soil is divided into a coarse-grained fraction consisting of sand and gravel (or larger) particles (greater than 0.075 mm size) and fine-grained fraction consisting of silt and clay (less than 0.075 mm size). Soils are characterized as fine-grained if more than 50 percent is less than 0.075 mm in size. Various descriptors of particle size proportions such as trace, few, little, some, or use of the grain size class as an adjective or noun are often used to describe different soil types. In some cases engineering properties are also used to determine the appropriate soil type description. Unfortunately, there are widespread differences in both the soil classification systems used to describe soils and differences in the quality of lithological descriptions incorporated in boring logs.

To assist users of guidance in cases where lithological and grain size information is limited, Table 4 below provides guidance that can be used to select, in appropriate terms, the appropriate soil texture class.

Table 4. Guidance for selection of soil type curves in Graphs 1a and 1b.

If your boring log indicates that the following materials are the predominant soil types …	Then you should use the following texture classification when obtaining the attenuation factor
Sand or Gravel or **Sand and Gravel**, with less than about 12 % fines, where “fines” are smaller than 0.075 mm in size.	Sand
Sand or Silty Sand, with about 12 % to 25 % fines	Loamy Sand
Silty Sand, with about 20 % to 50 % fines	Sandy Loam
Silt and Sand or Silty Sand or Clayey, Silty Sand or Sandy Silt or Clayey, Sandy Silt, with about 45 to 75 % fines	Loam
Sandy Silt or Silt, with about 50 to 85 % fines	Silt Loam

We note that there is no soil texture class represented as consisting primarily of clay. Exclusion of clay was deliberate since homogenous, unfractured clay deposits are rare. Users of this guidance have the option to refine selection of soil properties as part of the Site Specific Pathway Assessment.

The user must defend their scenario choice with site-specific data. Given the approximate nature of this approach, users should round their attenuation factor to the nearest half order-of-magnitude (0.01, 0.003, 0.001, 0.0003, or 0.0001), selecting the higher number if the best estimate is between two increments. Then, the columns in Table 3 can be used to determine the appropriate target media concentrations. Values in Table 3 were derived as discussed in Appendix B.

Interim exposure controls and/or measurement of indoor air quality should be conducted as soon as practicable if measured or reasonably estimated soil gas and/or groundwater concentrations are considerably (i.e. greater than 100 times) higher than the values in Table 3 since the Site-Specific Assessment step is very unlikely to result in an attenuation factor that is 100 times smaller than the attenuation factor determined at this stage. This is especially true for any chemical (degradable or not) when shallow (e.g., <2 ft beneath the building foundation) soil gas concentrations are being used for assessment.

If the media concentrations being used are from a significant depth and the chemicals of concern are known to degrade aerobically, it is possible for the actual attenuation factor to be considerably less than the value determined in this step. However, this issue should be addressed through vertical soil gas profile sampling involving shallower samples in this question (or other direct empirical evidence and supporting data to show the profile of oxygen, carbon dioxide, or other indicators of microbial activity are adequate to validate conceptual models based on analogous case studies in similar settings, in Question 6). Again, if shallow soil gas samples are being used, it is unlikely that degradation will contribute significantly to increased attenuation between the sampling point and the building.

It should also be recognized that it may be less expensive (or more desirable for other reasons) to install and operate exposure controls than to conduct further assessment. This guidance neither requires nor precludes such an approach, and it is left to the discretion of the responsible party to decide if proactive exposure controls are cost-effective.

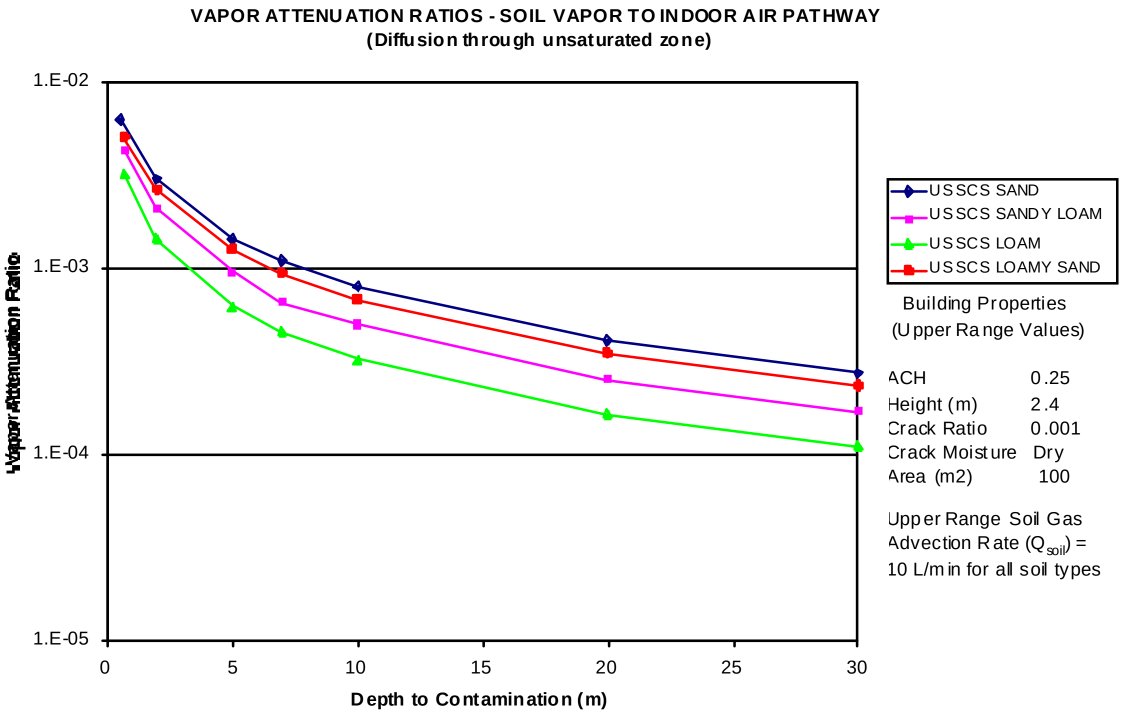

FIGURE 1

Graph 1a. For use with soil gas monitoring data.
(future edits to add: units of feet, ½ order-of-magnitude lines, and clarify y-axis is “Vapor Attenuation Ratio”)

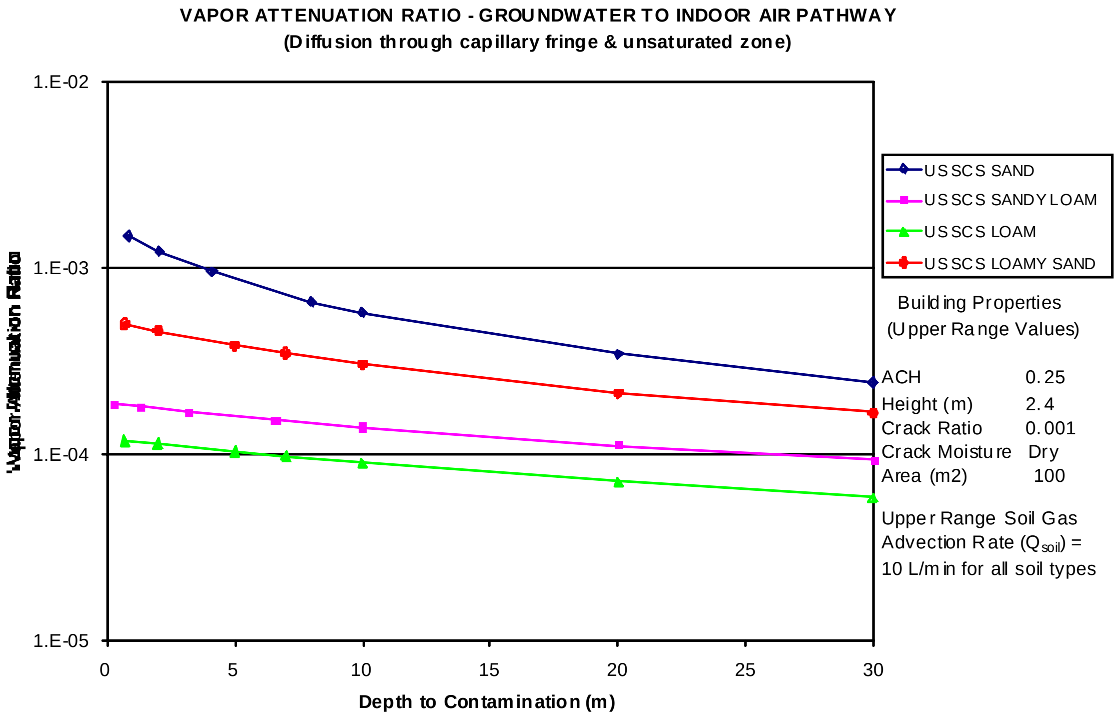

FIGURE 2

Graph 1b. For use with groundwater monitoring data.
(future edits to add: units of feet, ½ order-of-magnitude lines, and clarify y-axis is "Vapor Attenuation Ratio")

Rationale for Selecting Site-Specific Attenuation Factor and Reference(s):

Site-Specific Assessment – Question 6

Q6: Do measured or reasonably estimated soil gas or ground water concentrations exceed media-specific criteria developed specifically for this site?

_____ If YES - check here and implement exposure controls (avoidance or mechanical systems with appropriate monitoring to demonstrate their effectiveness) to prevent possible human exposures to subsurface vapors migrating into indoor air. Prepare a performance monitoring plan and proceed to Question 7;

_____ If NO – check here and provide documentation of Site-Specific Assessment for regulatory review.

_____ If sufficient data are not available - check here and skip to Pathway-Specific EI Summary Page and enter "IN" (more information needed) status code.

Criteria:

The Site-Specific Pathway Assessment is intended to be used where site-specific conditions warrant further consideration prior to concluding either that the pathway is incomplete, or that some form of exposure control is required. The assessment could be as simple as using the same equations employed to develop the Secondary Screening criteria but with revised inputs that are defended with site-specific data. It could also be as complex as a comprehensive mapping of subsurface vapor distributions and measurement of subsurface material properties affecting gas flow and transport, combined with the development of a site-specific vapor transport model. The data needs are greater here than in the Primary and Secondary Screening; however, the necessary data might already be available from previous site characterization work. A conceptual model of the site and subsurface vapor transport and vapor intrusion mechanisms will be needed to defend the Site-Specific Pathway Assessment. Model inputs and assumptions that are different than the generic assumptions in Questions 4 and 5 criteria (and others to be added to the appendices) must be supported with site-specific data.

The site-specific conceptual model should be developed in the source-pathway-receptor framework, and it should identify how the site-specific conceptual model is similar to, and different from, the generic conceptual model used in developing Table 3. Key components of the conceptual model may need to be justified with site-specific data, including, but not limited to the source (chemical constituents, concentrations, mass, phase distribution, depth, and aerial extent), pathway (soil texture, moisture, and layering) and receptor (building design, construction, and ventilation). The indoor air concentrations may be simulated with a mathematical model, which the user must be prepared to document and defend as appropriate for the site-specific conceptual model. The user must also defend model inputs (different than those (to be added to) the appendices) by validated site-specific data. The discussion above in Appendix A concerning data sufficiency is also applicable here. Indoor air quality sampling and analysis is neither required, nor precluded; however, if indirect data (e.g. soil gas data) are to be used exclusive of indoor air quality data, the vapor attenuation factor must be assigned either using site-specific data (e.g. the building ventilation rate, pressure differentials, soil gas permeability), or using conservative assumptions.

If the pathway is not judged to be incomplete during the Primary, Secondary, or Site-Specific Screening, it is considered to be complete, unless some action is taken. Possible actions include:

- engineered containment systems (subslab de-pressurization, soil vacuum extraction, vapor barriers)
- ventilation systems (building pressurization, indoor air purifiers)
- avoidance (temporary or permanent receptor relocation) or
- removal actions to reduce the mass and concentrations of subsurface chemicals to acceptable levels (i.e., remediation efforts).

Rationale and Reference(s):

Post-Assessment Monitoring – Question 7

Q7: Will temporal monitoring data or performance monitoring data (for a mechanical exposure control system) be collected to assess whether the pathway remains incomplete?

_____ If YES - check here and provide a brief summary of the monitoring requirements, or reference monitoring workplan.

_____ If NO – check here and provide justification.

Criteria:

Performance Monitoring is necessary to ensure that the pathway remains incomplete for sites relying on exposure control systems. **Pathway Monitoring** is recommended for sites where the measured or reasonably estimated media concentrations are at, or marginally less than the target media concentrations for that site, or when temporal trends cannot be reasonably predicted with existing data. This could involve repeated sampling of groundwater, soil gas, or indoor air on some appropriate frequency. The need for pathway monitoring is decided by the lead regulatory authority; however, one should consider the derivation of the target media concentrations and differences between those and measured or reasonably estimated values when determining monitoring requirements. Presumably, monitoring is less important in cases where measured or reasonably estimated media concentrations are an order of magnitude less than the more conservative media criteria (Table 2), and monitoring is more important when measured or reasonably estimated media concentrations are only marginally less than criteria selected at Question 5 (Table 3) or Question 6. As additional data becomes available, it should be compared with previous data as well as the target media-specific concentrations. If accedences occur, or are projected to occur, appropriate actions (usually engineering controls) should be taken, or continued. If monitoring demonstrates that the pathway is incomplete and will remain so under current site conditions, then other actions are not necessary.

Rationale and Reference(s):

Pathway-Specific EI Summary Page

Facility Name: ____

Facility Address: ____

Facility EPA ID #: ____

Below, check the appropriate status codes for the Subsurface Vapor to Indoor Air Pathway evaluation on the EI determination and attach appropriate supporting documentation as well as a map of the facility.

Is there a Complete Pathway for subsurface vapor intrusion to indoor air?

____ NO - the "Subsurface Vapor Intrusion to Indoor Air Pathway" has been verified to be incomplete, based on a review of the information contained in this EI Determination of the ____ facility, EPA ID #_______________, located at ________________________ under current and reasonably expected conditions, or based on performance monitoring evaluations for engineered exposure controls. This determination will be re-evaluated when the Agency/State becomes aware of any significant changes at the facility.

____ YE – Yes, The "Subsurface Vapor to Indoor Air Pathway" is Complete.

____ IN - More information is needed to make a determination.

Locations where References may be found:

____

____

____

____

____

Contact telephone and e-mail numbers:

(name) ______________________________________

(phone #) ____________________________________

(e-mail) ______________________________________

This document is dedicated to the late Craig Mann, who was a member of the authoring committee, a prominent researcher in the field and programmer of the widely-used spreadsheet version of the Johnson and Ettinger (1991) model available at www.epa.gov/superfund/programs/risk/airmodel/johnson_ettinger.htm. He was a friend and inspiration to us all.

FINAL NOTE: THE HUMAN EXPOSURES EI IS A QUALITATIVE SCREENING OF EXPOSURES AND THE DETERMINATIONS WITHIN THIS DOCUMENT SHOULD NOT BE USED AS THE SOLE BASIS FOR RESTRICTING THE SCOPE OF MORE DETAILED (E.G., SITE-SPECIFIC) ASSESSMENTS OF RISK.

ATTACHMENTS

Table 1:	**Question 1 Summary Sheet**
Table 2:	**Question 4 Numerical Criteria and Summary Sheet**
Table 3:	**Soil Gas and Groundwater Criteria for Scenario-Specific Soil Gas to Indoor Air Attenuation Factors (α)**
Appendix A	**Technical Considerations**
Appendix B	**Derivation of Tables 1, 2 and 3 and Graphs 1a and 1b.**

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All errors, and particularly those of formatting this version, are the responsibility of Henry Schuver.

APPENDIX A – TECHNICAL CONSIDERATIONS

The assessment of possible human health exposures to subsurface vapors migrating into indoor air is a complex process. Professional judgment plays an important role, and a wide variety of issues must be considered to perform the assessment reliably. The relative importance of the various issues will change from site to site, so it is not possible to provide a single unique discussion of the issues that will be universally applicable. Nevertheless, this appendix briefly identifies many of the most significant issues for consideration, the details of which will depend on site-specific factors. Each site will have different issues and not all issues will be relevant at all sites.

DATA SUFFICIENCY

First, a brief discussion of data sufficiency is warranted. The data are sufficient if media concentrations in the vicinity of buildings can be estimated with reasonable certainty, considering the target concentrations in Table 2. A higher level of certainty is necessary when media concentrations are close to target levels and a lower level of certainty is acceptable when media concentrations are considerably lower than target levels (assuming the data you have are representative). The level of certainty can be increased in many ways, including:

- multiple sampling events to assess temporal variability and trends
- collecting data for more than one media (i.e soil gas and groundwater concentrations, or indoor air and groundwater concentrations) and
- sampling from different depths.

The best way to increase one’s confidence in the use of data is to employ multiple independent lines of evidence, and employ a degree of caution in interpreting the results. While collection of data for one media (indoor air, soil gas, or groundwater) is in theory adequate, having data for more than one media greatly increases one’s confidence in the interpretation and use of the results. Users of this guidance are urged to sample more than one media and to look for consistency in these multiple lines of evidence. This involves consistency in qualitative aspects of the data (e.g., are the same chemicals present in both media?) as well as quantitative aspects (e.g., are concentrations in soil gas greatest above locations having the greatest groundwater concentrations?)

MEDIA-SPECIFIC SAMPLING AND DATA INTERPRETATION ISSUES

Indoor air sampling and analysis provides the most direct estimate of inhalation exposures, but even the best indoor air quality (IAQ) data are subject to homeostatic fluctuations, temporal trends, and superposition of several dozen compounds that are typically present in indoor air from ambient outdoor air or ancillary indoor sources. Ambient outdoor air contains detectable concentrations of many volatile chemicals, particularly in urban areas, and the ambient concentrations can be similar to or higher than levels that are calculated to pose an unacceptable chronic risk. The pathway assessment should be designed to identify incremental exposures, so the background concentrations should be characterized and subtracted from the indoor air concentrations to limit the assessment to only those vapors that may be attributable to subsurface vapor sources. This is typically very challenging and may require an extensive monitoring program, which may not be cost-effective compared to other management options, such as proactive exposure controls.

An indoor air quality survey has several components, and must comply with data quality protocols appropriate for risk assessment (see RAGS). An excellent guide (in-draft) has been prepared by the Massachusetts Department of Environmental Protection and is available for free download at:

http://www.state.ma.us/dep/new.htm

Soil gas sampling and analysis results tend to be more reliable at locations and depths where high concentrations are present and where the soils are relatively permeable (note: we use the term “reliable” here to express a degree of confidence in how well the sampling result reflects the true concentration at a given point). Reliability of the results tends to be lower in lower permeability settings and when sampling shallow soil gas. In both cases, leakage of atmospheric air into the samples is a valid concern. Also, soil gas sampling reliability may be less at lower concentrations as sample carry-over from sampling of higher concentration areas is a possibility. Parallel analysis of oxygen, carbon dioxide, and nitrogen in soil gas samples can often be used to help assess the reliability of a given sample result. In addition, reliability can be assessed by: a) measuring a vertical profile and inspecting to see if measured concentrations decrease in moving up from the vapor source, and b) checking to see if vapor concentrations correlate qualitatively and quantitatively with available groundwater concentration data. For example, with groundwater sources the highest soil gas concentrations should correlate with the highest groundwater concentrations and vapor concentrations collected immediately above groundwater would not be expected to exceed the value calculated using Henry’s Law. Even with reliable soil gas sample results, there is some uncertainty in selection of the soil gas to indoor air attenuation factor. Therefore, when making management decisions based solely on soil gas data one should consider the potential uncertainty in both the soil gas data and the attenuation factor estimate.

Soil sampling and analysis by SW846 Method 8240 may have negative biases of one to three orders of magnitude because of loss of volatiles (EPA/600/SR-93/140). In addition, there are significant uncertainties in estimating soil to soil gas partitioning. The authors of this guidance do not recommend use of soil data when assessing whether or not this pathway is complete, unless the soil samples are preserved immediately upon collection with methanol or hexane and the assessment of phase partitioning is supported by site-specific data. Soil concentration data could be used in a qualitative sense for delineation of sources. For example, high soil concentrations (e.g. >1000 mg/kg TPH) would definitely indicate impacted soils; unfortunately, the converse is not always true and non-detect analytical results should not be interpreted to conclude the absence of a vapor source.

Groundwater sampling and analysis is relatively reproducible when the same sampling method is used consistently. Groundwater data is usually a very reliable indicator of the presence of contaminants of concern. The main limitation of groundwater data is the fact that the sample represents a blended average of concentrations across the well screen interval. At some sites, concentrations are highest near the water table, and the in-well blending will provide data with a negative bias (concentrations lower than representative values). Examples include sites with LNAPL floating at or near the water table with low recharge rates, and sites where there is an interface-zone plume (fluctuating water table facilitates interactions between a vapor plume and the shallow groundwater). At other sites, shallow groundwater has relatively low concentrations, and in-well blending will provide data with a positive bias (concentrations higher than representative). Examples include sites with a high rate of recharge from above, which can create a layer of shallow groundwater with little or no contamination that acts as a barrier to volatilization of vapors from deeper groundwater. This becomes important when estimating attenuation factors as diffusion resistances across near-water saturated regions are great. The groundwater to soil gas attenuation factors are derived starting at the top of the water table; therefore, for the purposes of this pathway assessment, groundwater concentrations measured or reasonably estimated at the top of the aquifer are needed.

Detection Limits should always be considered when choosing which media to sample and how to interpret the results. The properties of some chemicals and the biases in the analytical methods may be such that the sensitivity of detection is higher in one media than another. For example, a high Henry’s constant ($H>1$) chemical might be detectable in soil gas when the concentration in groundwater falls below the detection limit (e.g., vinyl chloride).

Transformation products should also be considered when selecting the chemicals of concern. For example, 1,1,1-trichloroethane (111TCA) may be abiotically converted to 1,1-dischloroethene (11DCE) in groundwater, so that both chemicals should be looked for at 111TCA spill sites.

FATE AND TRANSPORT CONSIDERATIONS

The processes affecting the fate and transport of subsurface vapors should be considered in the exposure assessment.

Inhalation exposures are not limited to buildings with basements, but can occur for slab-on-grade and suspended floor (or crawl-space) designs as well. Construction quality is a very important issue, since one relatively small crack can transmit as much gas as an otherwise integral structure.

To be conservative, the criteria used for Questions 4 and 5 have been established assuming that the chemicals do not degrade as they migrate through the vadose zone. It should be recognized that many chemicals of interest do biodegrade. For example, petroleum hydrocarbon vapors will biodegrade in the presence of oxygen, and field studies have shown this biodegradation to be very significant in some settings. Unfortunately, the significance of the biodegradation has also been highly variable, and the factors that determine its significance are not yet fully understood. In a very general sense it is expected that aerobic biodegradation will have limited effect in settings where oxygen re-supply is limited, and also will have little effect on the attenuation factors used for soil gas samples collected near a building. Therefore, the significance of biodegradation is best determined at this time through collection of vertical soil gas profiles beneath the buildings of concern. The occurrence of aerobic biodegradation will be reflected qualitatively in the oxygen and contaminant soil vapor profiles, and the quantitative effects can be estimated by the methods described in Johnson et al. (1999), or other defensible analysis methods. To date, analysis of data from sites impacted with chlorinated solvents suggest that degradation is insignificant in determining soil gas to indoor air attenuation factors.

Geologic stratification can significantly affect vertical vapor migration, particularly where there are laterally extensive fine-grained layers and where infiltration rates are high, since water-filled pores provide significant resistance to vapor migration. These settings can also encourage significant lateral vapor migration.

If the recharge rate is high relative to seasonal water table fluctuations, a layer of groundwater may develop near the water table that acts as a barrier to off-gassing of VOCs from deeper intervals. The vertical stratification of chemicals in groundwater can be a very significant issue and may require specialized sampling to adequately represent the small-scale variations in VOC concentrations near the water table. The vertical profile of soil gas concentrations may also be important.

Seasonal effects must often be considered. Some argue that a frozen ground surface is significantly less permeable to gas flow. Combined with the heating of buildings that creates a “stack effect” from the rising of heated air, this may result in a worst case conditions for indoor air quality. Alternatively, Henry’s constant is very sensitive to temperature, and it is possible that vapor migration is exacerbated in the late summer when soil temperatures are highest and the maximum mass fraction of VOCs are in the gas phase.

Gas production (e.g. methane generation by biological activity at a landfill) can cause advection of subsurface vapors and significantly increase subsurface vapor travel distances.

APPENDIX B:
DERIVATION OF TABLES 1, 2, AND 3 AND GRAPHS 1a AND 1b

1.0 Introduction

This appendix briefly summarizes the derivation of the entries appearing in Tables 1, 2, and 3, and the curves appearing in Graphs 1a and 1b.

2.0 Derivation of Tables 1, 2, and 3

2.1 Chemical Property Data

The source of chemical data used in the calculations necessary to create Tables 1, 2, and 3 comes from the original USEPA Johnson and Ettinger (1991) Model Excel Spreadsheets that can be down-loaded from:

http://www.epa.gov/superfund/programs/risk/airmodel/johnson_ettinger.htm

The only exception to this was the addition of the chemical methyl-tert-butyl-ether (MTBE). The inhalation reference concentration for that chemical comes from the USEPA IRIS Database (value obtained 10/6/01) and other relevant properties (e.g., solubility, vapor pressure, molecular weight) come from:

www.chemfinder.com

2.2 Calculations

Entries in Tables 1, 2, and 3 follow from the calculations and logic discussed below.

2.2.1 Maximum Pure Component Vapor Concentration at T=25 C (C_{max})

The maximum possible vapor concentration is that corresponding to the pure chemical at the temperature of interest. In this case, all calculations were done at the reference temperature corresponding to the chemical property data table (25 C) using the equation:

$$C_{max} = S \text{ x } H \text{ x } 10^3 \text{ ug/mg x } 10^3 \text{ L/m}^3$$

where C_{max} = maximum pure component vapor concentration at 25 C [ug/m^3], S = pure component solubility at 25 C [mg/L] and H = Henry's Law Constant at 25 C [(mg/L-vapor)/(mg/L-H_2O)].

Target Breathing Zone Concentration to Satisfy both the Prescribed Risk Level and the Target Hazard Index [ug/m^3]

This calculation is composed of three steps. In the first, the target breathing zone concentration corresponding to an incremental carcinogenic risk of 1 x 10^{-5} is calculated for all chemicals having inhalation unit risk factors (URF) in the database:

$$C_{cancer} = 10^{-5}/URF$$

where C_{cancer} = the target breathing zone concentration corresponding to an incremental carcinogenic risk of 1 x 10^{-5} [ug/m^3], and URF = the inhalation unit risk factor [risk/(ug/m^3)].

In the second calculation, the target breathing zone concentration corresponding to a hazard index (HI) of 1 is calculated for all chemicals having inhalation reference concentrations (Rfc) in the database:

$C_{non\text{-}cancer}$ = Rfc x 10^3 ug/mg

where $C_{non\text{-}cancer}$ = the target breathing zone concentration corresponding to a hazard index of 1 [ug/m^3], and Rfc = the inhalation reference concentration [mg/m^3].

In the final step, C_{cancer} and $C_{non\text{-}cancer}$ are compared and the target breathing zone concentration C_{target} is set to be equal to the smaller value of the two.

Target Breathing Zone Concentration to Satisfy both the Prescribed Risk Level and the Target Hazard Index [ppbv]

This calculation involves a simple unit conversion of the value calculated above in 2.2.2:

C_{target} [ppbv] = C_{target} [ug/m^3] x 10^9 [ppbv/atm] x 10^{-3} [m^3/L] x R x T/(MW x 10^6 [ug/g])

where R = gas constant (0.0821 L-atm/mole-K), T = absolute temperature (298 K), and MW = molecular weight (g/mole).

Is There a Potential for Unacceptable Risks?

For this Table 1 entry, the purpose is to assess if a given chemical's vapors could create unacceptable breathing zone concentrations under the worst case conditions of pure chemical and no ventilation in the breathing space. The values calculated in 2.2.1 and 2.2.2 are compared; if the target breathing zone concentration from 2.2.2 exceeds the maximum possible pure chemical concentration from 2.2.1 then the answer is "NO"; otherwise the answer is "YES".

Target Soil Gas Concentration Corresponding to Target Breathing Zone Concentration Where the Soil Gas to Indoor Air Attenuation Factor is 0.01, 0.003, 0.001, 0.0003, or 0.0001

The "soil gas to indoor air attenuation factor" (a.k.a. the attenuation factor, or α) represents the ratio of the indoor air concentration divided by the soil gas concentration at some depth below the building. The attenuation factor can be determined empirically or calculated using an appropriate model (e.g., the Johnson and Ettinger 1991 model was used to derive Graphs 1a and 1b). Therefore, once the appropriate attenuation factor is determined, then the target soil gas concentration is calculated:

$C_{soil\text{-}gas}$ [ug/m^3] = C_{target} [ug/m^3]/α

and

$C_{soil\text{-}gas}$ [ppbv] = C_{target} [ppbv]/α

where C_{target} is the target breathing zone concentration derived in 2.2.2.

If C_{target} exceeds the maximum possible pure chemical vapor concentration at 25 C, then "NA" is entered in the table. If C_{target} does not exceed the maximum possible pure chemical vapor concentration at 25 C, but $C_{soil\text{-}gas}$ for that attenuation factor does exceed the maximum possible pure chemical vapor concentration, then "**" is entered in the table. In both cases the pathway is "incomplete" as defined in the introduction to this guidance.

1.1.2 Target Groundwater Concentration Corresponding to Target Breathing Zone Concentration Where the Soil Gas to Indoor Air Attenuation Factor is 0.01, 0.003, 0.001, 0.0003, or 0.0001

The target groundwater concentration corresponding to the target breathing zone concentration for given values of the attenuation factor (i.e. α=0.01, 0.003, 0.001, 0.0003, and 0.0001) are calculated assuming equilibrium between the soil gas and groundwater at the water table (diffusion resistances across the capillary fringe are accounted for in the α calculation below). This equilibrium is assumed to obey Henry's Law so that:

C_{gw} [ug/L] = $C_{soil\text{-}gas}$ [ug/m^3] x 10^{-3} m^3/L x 1/H

where C_{gw} = the target groundwater concentration, and H = Henry's Law Constant at 25 C [(mg/L-vapor)/(mg/L-H_2O)].

If C_{target} exceeds the maximum possible pure chemical vapor concentration at 25 C, then "NA" is entered in the table (as this would also require the dissolved concentration to exceed the pure component solubility). If C_{target} does not exceed the maximum possible pure chemical vapor concentration at 25 C, but $C_{soil\text{-}gas}$ for that attenuation factor does exceed the maximum possible pure chemical vapor concentration, then "**" is entered in the table. In both cases the pathway is "incomplete" as defined in the introduction to this guidance.

1.03 Derivation of Graphs 1a and 1b

Upper bound or conservative vapor attenuation ratios are estimated using the Johnson and Ettinger (J&E) (1991) model for the Groundwater to Indoor Air Pathway (Figure B1) and Soil Vapor to Indoor Air Pathway (Figure B2). Based on the site-specific contaminant scenario, soil type and depth to contamination, the vapor attenuation ratios can be estimated from these figures. The Groundwater to Indoor Air Pathway assumes that contaminated groundwater is the only source of contaminant vapors while the Soil Vapor to Indoor Air Pathway assumes vadose zone vapor sources are present. Fate and transport processes incorporated in the J&E model are diffusion through soil, soil gas advection and diffusion through the building foundation, and mixing of VOCs in the building airspace. Fate and transport processes and derivation of important input parameters are discussed below.

Diffusive transport of VOCs in soil is primarily a function of the air-filled and total porosity of soil. The air-filled porosity decreases with increasing soil moisture content. Prediction of soil moisture content is complex, but below a building the moisture content is likely to be primarily a function of the soil water retention characteristics. Surface water infiltration and evapotranspiration would generally be of lessor importance below buildings. For this guidance, the U.S. Soil Conservation Service (SCS) soil texture classification system is the basis for the estimation of soil properties. The US SCS soil classification system is also referred to as the USDA soil textures or soil series. This system is widely used, and water retention curve parameters have been derived for different SCS soil textures using the Van Genuchten (VG) model, for a relatively large data set. This is also the approach incorporated in the "*User's Guide for the Johnson and Ettinger (1991) Model for Subsurface Vapor Intrusion into Buildings ("User's Guide")*", which was prepared by Environmental Quality Management (EQM, 2000) for U.S. EPA.

As shown in Figures B1 and B2, vapor attenuation ratios are provided for five of twelve U.S. SCS soil texture classes. This subset of soil textures was chosen so that their relevant properties (porosity and moisture content) would collectively span the range of conditions most commonly encountered in the field.

For the Groundwater to Indoor Air Pathway, the soil is divided into the Capillary Zone and Unsaturated Zone. The air-filled porosity in the Capillary Zone corresponds to the air-entry pressure for the SCS soil type, as estimated using the class average water retention curve parameters for VG Model, computed by Schaap and Leij (1998). When the air-filled porosity is greater than the air-filled porosity corresponding to the air-entry pressure, vapor-phase diffusion starts to become a significant transport process. The height of the capillary zone was estimated using a capillary tube model, where it is assumed that the average capillary rise can be estimated using the mean grain size as represented by the centroid composition of each soil texture class (Fetter, 1994). The air-filled porosity in the Unsaturated Zone is taken to be the value half way between the residual saturation and field capacity of the soil. This air-filled porosity is considered a reasonable approximation for soil below a building. For the Soil Vapor to Indoor Air Pathway, there is only one (i.e., constant) air-filled porosity, which is taken to be the value half way between the residual saturation and field capacity of the soil. The total porosity of the soil is the saturated volumetric water content predicted using the VG model. Additional details on the methods described above are provided in the "Users' Guide".

Soil gas advection through the building foundation can have a significant effect on vapor attenuation ratios for shallow to moderate depths to contamination. While mathematical models can be used to estimate the soil gas advection rate (Qsoil) as a function of soil properties (soil-air permeability) and building characteristics, these models are relatively uncertain. Furthermore, relatively permeable fill is often placed directly below the building floor slab and adjacent to the below-grade walls, and subsurface utility lines and backfill may extend from the building foundation to ground surface. It is important to recognize that the soil properties encountered at boreholes adjacent to buildings, which are used to estimate diffusive transport, may not be representative of the soil and utility properties directly adjacent to the foundation, which have the greatest effect on Qsoil. To simplify the guidance and to ensure for conservative predictions of vapor intrusion, a constant Q_{soil} of 10 L/min was assumed for all U.S. SCS soil types. A Qsoil equal to 10 L/min is considered a reasonable upper bound value for coarse soils based on field measurements for residential single family dwellings. The building properties shown in Figures 1 and 2 are considered conservative (upper bound?) values based on field measurements and best professional judgement.

The above approach represents a simplified and approximate method for prediction and selection of vapor attenuation ratios. The uncertainty and potential limitations inherent in the approach are recognized; nevertheless, it is considered to provide for reasonably (conservative?) estimates. At some sites there may be conditions that preclude the use of the Secondary Screening vapor attenuation ratios (e.g., highly fractured soil and/or rock).

Selection of U.S. SCS Soil Texture Class

The site characterization should include collection of soil samples at various depths between the building foundation elevation and contamination source (i.e., vertical soil profiling) and description of soil lithology. The preferred method for determining the SCS soil class is to use lithological information combined with the results of grain size distribution tests on selected soil samples. Procedures for conducting grain size distribution tests are provided in American Society for Testing and Materials (ASTM) Standard Test Method for Particle Size Analysis of Soils (D422-63) and U.S. Natural Resources Conservation (NRCC) Soil Survey Laboratory Methods Manual, Soil Survey Laboratory Laboratory Investigations Report No. 42. The U.S. SCS soil texture classes are based on the proportionate distribution of sand, silt and clay sized particles in soil. It does not include any organic matter. The grain size boundaries are as follows:

Sand:	0.05 mm to 2 mm
Silt:	0.002 mm to 0.05 mm
Clay:	<0.002 mm

The soil textural classes are displayed in the SCS soil textural triangle. The soil texture class is determined by plotting the grain size distribution results on the soil texture triangle. If a soil texture class is not intersected based on the five classes included in the guidance, the nearest soil class is chosen. The selection of the soil texture class should be biased towards the coarsest soil type of significance, as determined by the site characterization program.

We recognize that there are sites where different soil classifications systems from the U.S. system have been used, and where information on soil lithology and grain size distribution is limited. Most engineering soil classification systems are either based on grain size, or a combination of grain size and engineering properties (e.g., Unified Soil Classification System (USCS), ASTM D2488-84, NAVFAC DM7.2 (1982)). For several soil classification systems, soil is divided into a coarse-grained fraction consisting of sand and gravel (or larger) particles (greater than 0.075 mm size) and fine-grained fraction consisting of silt and clay (less than 0.075 mm size). Soils are characterized as fine-grained if more than 50 percent is less than 0.075 mm in size. Various descriptors of particle size proportions such as trace, few, little, some, or use of the grain size class as an adjective or noun are often used to describe different soil types. In some cases engineering properties are also used to determine the appropriate soil type description. Unfortunately, there are widespread differences in both the soil classification systems used to describe soils and differences in the quality of lithological descriptions incorporated in boring logs.

To assist users of guidance in cases where lithological and grain size information is limited, we provide guidance below that can be used to select, in appropriate terms, the appropriate soil texture class.

If your boring log indicates that the following materials are the predominant soil types …	Then you should use the following texture classification when obtaining the attenuation factor
Sand or Gravel or Sand and Gravel, with less than about 12 % fines	Sand
Sand or Silty Sand, with about 12 % to 25 % fines	Loamy Sand
Silty Sand, with about 20 % to 50 % fines	Sandy Loam
Silt and Sand or Silty Sand or Clayey, Silty Sand or Sandy Silt or Clayey, Sandy Silt, with about 45 to 75 % fines	Loam
Sandy Silt or Silt, with about 50 to 85 % fines	Silt Loam

We note that there is no soil texture class represented as consisting primarily of clay. Exclusion of clay was deliberate since homogenous, unfractured clay deposits are rare. Users of this guidance have the option to refine selection of soil properties as part of the Site Specific Pathway Assessment.

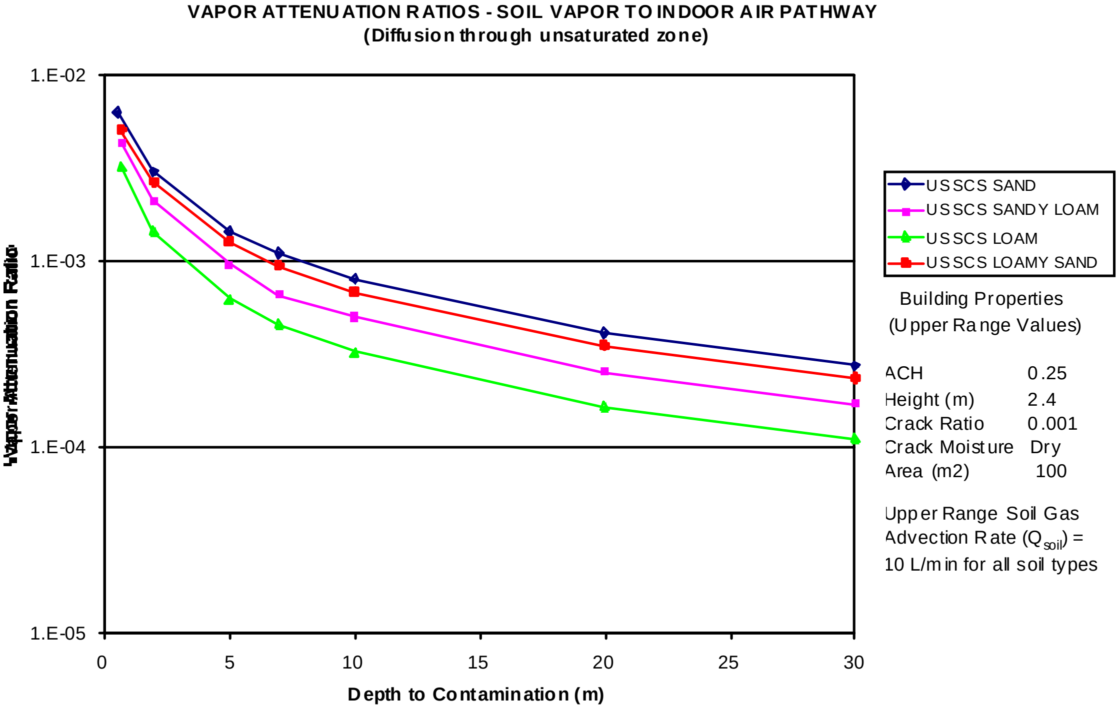
VAPOR ATTENUATION RATIOS - SOIL VAPOR TO INDOOR AIR PATHWAY
(Diffusion through unsaturated zone)

FIGURE 1

Figure B1. For use with soil gas monitoring data.

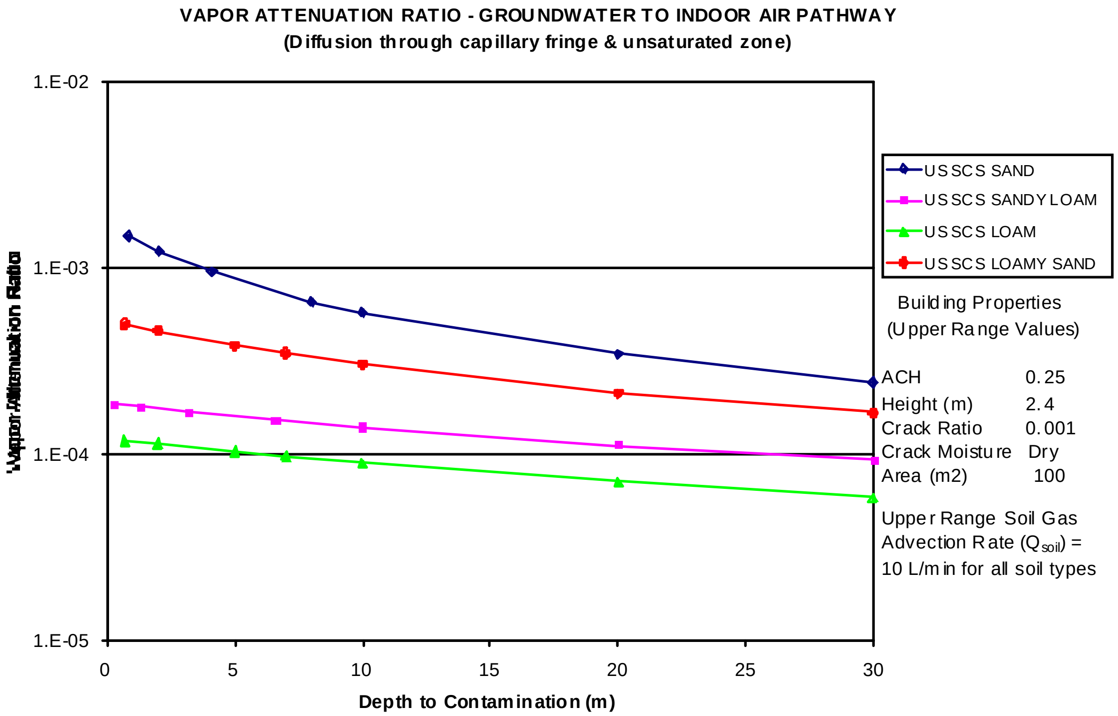

FIGURE 2

Figure B2. For use with groundwater monitoring data.

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Additional References from a recent survey of State programs with:

“Migration Concentrations for the Migration of Chemicals From Groundwater, Soil, or Soil Gas to Indoor Air”

including web sites and concentration values from Connecticut, Massachusetts, Michigan, New Hampshire, Oregon, and Virginia. **To be added to next version.**