APPENDIX B.3

Alternate Approach for Investigating Vapors for Petroleum Hydrocarbons Considering Biodegradation
ALTERNATE APPROACH
FOR
INVESTIGATING VAPORS FOR PETROLEUM HYDROCARBONS
CONSIDERING BIODEGRADATION

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A policy guidance document cannot establish regulatory requirements for parties outside of the Michigan Department of Environmental Quality (MDEQ). It is explanatory and provides direction to staff, guidance to the regulated community, and consistency in enforcing the NREPA, but does not have the force and effect of law and is not legally binding on the public or the regulated community.
PLEASE NOTE:

This approach was developed based on a compilation of available information, knowledge, field experience, and general industry practices to provide an alternate approach to parties implementing a response action in Michigan. It was created to promote an alternate approach that is consistent with Part 201, Environmental Remediation, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended (NREPA). This document is not a statutory requirement, but could be implemented as an alternate approach under R 299.5714 and R 299.5724.

In general, this document should be used as a reference. Differences may exist between the procedures referenced in this document and what is appropriate under site-specific conditions. This document also does not represent an endorsement of practitioners or products mentioned in the document nor does it ensure that this approach is appropriate for all sites. It is imperative that the environmental professional implementing this approach provide adequate justification of this approach.

This approach is made available as a technical reference that may be informative when conducting work at sites where vapor intrusion issues are of concern. The MDEQ is not responsible for the misuse or misinterpretation of the information presented herein. Please note that because the approach was written for the MDEQ staff, it may contain references to specific equipment for field investigations that the MDEQ currently uses. Such references do not represent endorsements of particular vendors.
1.0 INTRODUCTION

It has been well documented (USEPA, 2011 and others) that there are differences between petroleum hydrocarbons (PHCs) and chlorinated hydrocarbons (CHCs) with respect to the processes that influence whether and how vapors associated with these compounds migrate into buildings. One of the most significant differences is the relative biodegradability of these compounds. The PHC vapors in the subsurface are known to readily biodegrade in the presence of oxygen (O\textsubscript{2}), which is referred to as aerobic conditions, thus impacting both their concentration and subsurface migration. Conversely, biodegradation of CHC vapors is an anaerobic process that occurs at a much slower rate (Howard, 1991) and typically does not have a significant impact on contaminant levels or migration in the subsurface.

Because of the relatively rapid rate at which PHCs biodegrade when O\textsubscript{2} is present, biodegradation can play a significant role in determining if vapor intrusion (VI) is a relevant pathway for PHC impacted sites. Biodegradation occurs when microorganisms in the soil have an easily consumable food source (e.g., PHCs), as well as sufficient O\textsubscript{2} for the organisms to metabolize the food. Depending on the depth and concentration of the contaminants, the soil column can act as a natural “biofilter” within which microorganisms consume volatile contaminants and limit the potential for petroleum hydrocarbon-VI (PHC-VI).

Subsurface transport behavior under commonly observed subsurface conditions for CHC and PHC chemicals has been illustrated in Figures 1 and 2. The conceptual scenarios in these figures are overly simplified and do not represent the complexity of actual subsurface environments, such as variations in contaminant distribution due to subsurface heterogeneities. Rather, they are intended to illustrate and contrast several essential behaviors characteristic of petroleum and chlorinated solvent contaminants that are often observed under common site conditions.

As shown in Figures 1 and 2, both the dissolved and vapor plumes associated with CHCs tend to migrate further than the PHC plumes. This is the result of the much slower anaerobic biodegradation process associated with CHCs. In contrast, an aerobic biodegradation zone is typically present along the perimeter of the PHC plumes in both the groundwater and in the soil gas (Figure 2). Within this bioactive zone, natural microbial activity can degrade many PHCs into nontoxic end products like carbon dioxide (CO\textsubscript{2}) and water (although some biodegradation pathways can produce methane (CH\textsubscript{4})). Because soil microbes consume O\textsubscript{2} to degrade PHCs, O\textsubscript{2} may become depleted where contaminant concentrations are elevated such as in the interior of a groundwater or vapor plume. The
aerobic biodegradation zone generally develops around the perimeter of the contaminant plume, where \( O_2 \) transport from the atmosphere or oxygenated groundwater (depicted as dashed arrows in Figure 2) can replenish the \( O_2 \) consumed from degradation in this bioactive zone. Atmospheric \( O_2 \) migrates into the subsurface through diffusion and advection (e.g., flow of soil gas into and out of the subsurface in response to changes in barometric pressure), as well as through infiltrating rainwater that contains dissolved \( O_2 \).

This document will help to categorize biodegradation at PHC impacted sites into one of three categories:
1. Those in which biodegradation clearly occurs and there is therefore a low potential for VI
2. Those in which biodegradation clearly does not occur and the potential for VI must be evaluated
3. Those in which a conclusion regarding biodegradation cannot be drawn without further evaluation

Though this guidance has tried to make this process applicable for sites that meet the pre-described conditions, when evaluating the potential impact of biodegradation, it is not sufficient to merely reference this guidance and state that biodegradation is occurring or that VI is not occurring. If it is concluded that VI does not pose a risk to the structure identified, it is the responsibility of the party proposing the response action to document the conditions by providing supporting documentation presented in a clear and concise format. It is the intent of this document to help provide the support necessary to document those conditions. If during this evaluation, information is obtained showing that biodegradation is not occurring and vapors are found to be entering into the structure being evaluated, it is expected that the appropriate response actions will be taken.

The MDEQ has established the approach outlined in this document as an alternate way to demonstrate compliance with the volatilization to indoor air pathway for PHCs, in accordance with the alternative approaches identified for groundwater (R 299.5714(5)) and soil (R 299.5724(5)). Modifications to this approach can be proposed with supporting information. This approach is not applicable to sites with the potential for CHC vapors or for sites that may have areas of commingled PHC and CHC vapors.

Note: When determining the possible presence and location of vapor sources, it should be noted that both impacted soil and impacted groundwater can serve as sources of vapors.

2.0 CONCEPTUAL SITE MODEL, SCREENING LEVEL ASSESSMENT, AND RECEPTOR SURVEY

An accurate conceptual site model (CSM) is necessary to adequately interpret site investigation results, to determine whether additional investigation is required, to provide support in selecting appropriate remedial actions, and to document that site closure criteria have been achieved. In addition, a screening-level assessment is also needed to determine if the VI pathway is complete, and in some circumstances, to identify the need for an emergency assessment and/or interim response actions (R 299.5526).

When considering sites impacted with petroleum hydrocarbons, it should be noted that the risk for VI is influenced by the strength and mass distribution of the source and is fundamentally different for LNAPL (residual or free-phase) and dissolved-phase sources. Source concentrations will typically be much higher for LNAPL sources than for dissolved-phase sources. In addition, LNAPL sources will tend to be distributed above the capillary zone as a result of smearing from water-table fluctuations. This will tend to enhance mass flux to the unsaturated zone because of direct partitioning between LNAPL (residual) and vapor phases. Conversely, the mass flux will be more limited for
dissolved-phase sources because the source is distributed below the capillary zone which serves as a barrier to vapor transport. For dissolved phase sources, the depth to groundwater may be the critical control parameter rather than source concentration. It is important that the CSM discussion provided bears this out.

The CSM is a combination of report narrative, cross-sections, plan-view site figures, and data tables. Cross-sections should identify vapor sources, the interpreted site geology, depth to groundwater, and receptor locations as appropriate. Site maps should identify the spatial relationships between vapor sources, receptors, sample locations, and known or suspected locations of soil gas and groundwater plumes.

A detailed description of how to develop a CSM and perform a VI screening-level assessment are provided in MDEQ’s document titled Guidance Document for the Vapor Intrusion Pathway (MDEQ VI Guidance Document). In addition to developing a CSM and documenting the extent of the potential sources of vapors, a VI receptor survey should be performed to document possible receptors within the preliminary screening area. More detailed information regarding the VI receptor survey and how to establish the preliminary screening area can be found in the MDEQ VI Guidance Document.

Note: In circumstances where it is likely that bioattenuation is occurring, the preliminary screening area radius for the VI receptor survey (as identified in Section 3.2.2 of the MDEQ’s VI Guidance Document) can be reduced from 100 feet to 30 feet from the vapor source.

3.0 ESTABLISHING ZONES WHERE BIOATTENUATION IS LIKELY PRESENT

Once the site data is compiled, an evaluation of whether bioattenuation is occurring at the site can take place. In general, as part of the evaluation process, a site can fall into one of three possible bioattenuation zones. The zone a site falls within is based on a number of factors, such as the depth of groundwater relative to the structure and the presence of impacted groundwater above the screening values (SVvi) provided in the MDEQ’s VI Guidance Document. These zones are based upon site characteristics that have unique properties and may either encourage or prevent biodegradation from occurring. The zones established in this approach include:

- **Biodegradation Zone**: Conditions exist in which bioattenuation is likely to occur (Davis, 2011). When the conditions for this category are met and able to be documented, no further investigation is warranted and the VI pathway should not be considered complete.
- **Vapor Intrusion Zone**: Conditions will not support biodegradation. In these circumstances the biodegradation alternate procedure is not applicable, and therefore the modifications to attenuation factors, site-specific criteria, etc. that are tied to this procedure are excluded from consideration. It should be noted that the standard approach to VI, as detailed in the main portion of the guidance document, would apply which would allow for site specific criteria to be generated, though biodegradation would not be a component of the site specific analysis.
- **Transition Zone**: Site conditions are such that a clear determination regarding bioattenuation cannot be made without the collection of additional lines-of-evidence.

It is possible that a site may contain more than one of these zones and if that is the case, a specific CSM should be developed for each of these areas. Information and details of each zone are discussed in more detail below.
3.1 Biodegradation Zone

A number of well characterized field studies demonstrate extensive aerobic biodegradation of PHCs in unsaturated soils (Ostendorf and Kampbell, 1991; Ririe and Sweeney, 1995; Ririe et al., 1998; Ostendorf et al., 2000; Hers et al., 2000; Roggemans et al., 2002; Sanders and Hers, 2006; Davis et al., 2009; Patterson and Davis, 2009). Several of these studies documented vapor concentrations at least two to three orders of magnitude lower than would be predicted, in the absence of biodegradation.

Information provided at several sites investigated by the MDEQ has supported the idea that when certain conditions are present, there is a very low potential for VI to occur. In those situations, a party may be able to conclude that the pathway is not complete and no further investigation of PHC vapors is warranted if certain site conditions are met and are able to be documented. However, as stated above, it remains the responsibility of the party proposing the response action to draw their own conclusions on this approach, as well as to consider the potential for CH₄ as a by-product of biodegradation as discussed in Section 4.0 of this document.

A discussion of site conditions conducive for bioremediation is given below. Figure 3 provides an example of the Biodegradation Zone.

![Figure 3: Typical Biodegradation Zone Scenario](image)
Aerobic Conditions. Decades of scientific research and site investigations have demonstrated conclusively that microorganisms capable of aerobically degrading PHCs are present in nearly all subsurface soil environments (Zobell, 1946; Atlas, 1981; Wilson et al., 1986; Leahy and Colwell, 1990; Bedient et al., 1994; USEPA, 1999). If O₂ is present at concentrations of five percent or greater, aerobic conditions exist and these organisms will generally consume available PHCs. Furthermore, aerobic biodegradation of petroleum compounds can occur relatively quickly, with degradation half lives as short as hours or days under some conditions (DeVaul, 2007). Some PHCs can also biodegrade under anaerobic conditions; however, this process is less important and generally much slower than aerobic biodegradation.

Key processes for the biodegradation of PHCs in the unsaturated zone include: downward O₂ transport from the atmosphere, upward hydrocarbon migration from the contaminant source, and aerobic biodegradation along the perimeter of the contamination zone where PHCs are consumed by microbial activity, as previously shown in Figure 1. Important factors influencing aerobic biodegradation include the source concentration, the O₂ demand (the O₂ required to biodegrade the available hydrocarbons and any ambient soil organic matter that is present), the distance between the source and the building, and the soil type.

Separation Distance. The presence of NAPL must be at least five meters (15 feet) (Lahvis (2012), Hers et al. (2012), Peargin and Kohlhatkar (2011)) and all other sources of vapors (impacted soil and dissolved groundwater) are at least three meters (10 feet) from any current, proposed or planned structure.

Preferential Transport Pathways. Preferential pathways may be geologic features such as fractures in the bedrock, clay, or coarse-grained channels, and may also include engineered features such as utility lines. These pathways are a cause for concern when they enable the transport of contaminants which might otherwise be contained. If preferential transport pathways exist that are in contact with highly impacted source soils or groundwater the associated chemical transport may extend farther than transport through the surrounding soils.

Preferential pathways of significance are not a common occurrence and are generally restricted to sites with lines that intersect high concentration dissolved phase hydrocarbon or LNAPL and building foundations (e.g., Pennsylvania DEP, 2001; Riis et al., 2010, Lavis, 2012). Therefore in most instances the preliminary screening area will not be affected and could remain at 30 feet.
Building Size. Small and medium sized buildings (less than 30 feet wide/deep) typically do not occlude O₂ distribution or impede biodegradation (Davis et al., 2009). Depending on the construction methods utilized, large buildings can in fact result in anaerobic conditions beneath the structure (Davis, 2011). Therefore, for buildings less than 2,500 square feet (ft²), it can be assumed that the availability of O₂ is not limited by the structure. Soils directly beneath structures greater than 2,500 ft² should be evaluated for the presence of O₂ to determine if aerobic conditions exist.

Note: The 2,500 square feet utilized in this alternative approach is a simplification by the MDEQ of the research described by Davis et al. (2009) that generally identifies slabs with a dimension of less than 50 feet (15 meters), either length or width does not inhibit the flow of oxygen.

Summary. There are a number of site conditions that can result in the conclusion that bioattenuation is occurring in the subsurface. In those circumstances, the potential for VI to occur is greatly reduced and with the proper documentation, a party may be able to conclude that the VI pathway is not complete and no further investigation of PHC vapors is warranted.

Documentation of these conditions is typically achieved through the use of a CSM, soil and groundwater data, and site maps. A summary of conditions that typically indicate that biodegradation is occurring, as well as the documentation needed to support that these conditions are present, is provided in Table 1.

3.2 Vapor Intrusion Zone

While the MDEQ concurs that the biodegradation of PHCs is well documented and occurs in many circumstances, it is also true that there are certain site conditions in which biodegradation will not or cannot occur (Roggemans et al., 2001). Because PHCs can pose a VI risk under certain site conditions (DTSC, 2005), utilizing a generic approach for biodegradation to address all sites is not appropriate.

Should any of the following situations apply, it can be assumed that biodegradation is not likely to occur and that further assessment of the VI pathway is needed. In these circumstances, a party may utilize the MDEQ’s VI Guidance Document to evaluate the pathway (without any additions or modifications) or choose to develop site-specific criteria using site-specific data. Figure 5 provides an example of a VI Zone which typically does not support biodegradation. The conditions associated with this zone are discussed below.

Aerobic Conditions. For biodegradation to limit the potential for PHC-VI, a sufficiently thick layer of biologically active soil is needed between the building foundation and the contamination to allow for biodegradation of PHCs. If site conditions do not promote this biologically active soil layer, bioattenuation will not occur.

Aerobic biodegradation requires sufficient O₂ in order to be an effective contaminant-removal mechanism. The availability of O₂ or lack thereof, can be affected by natural conditions such as elevated water tables or the presence of highly organic soils (e.g., peat). Additional conditions, such as very high PHC concentrations or the presence of concrete foundations and pavement under and adjacent to the structure can also result in limiting the amount of O₂ available in the subsurface. Recent studies suggest that in the case of very large building footprints, O₂ under the structure may be limited (Patterson and Davis, 2009), though it has been
found that the O₂ levels in soils beneath average sized structures are not reduced significantly enough to inhibit biodegradation (Lundegard et al., 2008). This issue will be discussed in greater detail under the Building Size section below.

### TABLE 1
SUMMARY OF CONDITIONS INDICATIVE OF THE BIODEGRADATION ZONE

<table>
<thead>
<tr>
<th>Condition</th>
<th>Supporting Documentation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerobic Conditions</strong></td>
<td>Natural conditions are conducive to aerobic conditions</td>
</tr>
<tr>
<td><strong>Separation Distance</strong></td>
<td>All sources of vapors (soil and groundwater) are at least three meters (ten feet) from any structure</td>
</tr>
<tr>
<td></td>
<td>Building footprint is less than 2,500 ft²</td>
</tr>
<tr>
<td></td>
<td>Or</td>
</tr>
<tr>
<td></td>
<td>O₂ is documented beneath or adjacent to the structure</td>
</tr>
<tr>
<td><strong>Preferential Transport Pathways</strong></td>
<td>Preferential pathways are at least three meters (ten feet) from a source of vapors</td>
</tr>
<tr>
<td></td>
<td>Or</td>
</tr>
<tr>
<td></td>
<td>O₂ is present within the preferential pathways up to the structure</td>
</tr>
</tbody>
</table>

**Separation Distance.** As stated above, for biodegradation to occur, a sufficiently thick layer of biologically active soil is needed between the building foundation and the contamination. When a source (either in soil or groundwater) is in direct contact with or has entered into a structure (either directly or in a sump), that layer does not exist and contaminants are able to directly volatize to indoor air preventing any possibility for the biodegradation of vapors. In addition to highly impacted soils that are directly in contact with the structure, impacted groundwater can also be a cause for concern. This is specifically an issue when impacted groundwater enters into a structure or a sump (even seasonally) at concentrations above the GWvi-sump.

For ease of implementation, it should be assumed that if the source of vapors (either soil or groundwater) is within one meter of the structure that it is in contact with it due to the typical presence of footings and other subsurface features.

**Preferential Transport Pathways.** As discussed earlier, the MDEQ has a general rule of thumb that preferential pathways should be considered a viable pathway for up to 100 feet from a source of vapors. Although the preliminary screening area can be reduced to 30 feet within the Biodegradation Zone, if it is
determined that the preferential pathway is within the VI Zone, the 100 foot screening radius should be utilized.

Figure 5  Typical Vapor Intrusion Scenarios for PHCs.

**Building Size.** Though data provided by Patterson and Davis, 2009 suggest that O₂ may be limited if the building footprint is very large (greater than 2,500 ft²), there is also the potential that O₂ is present, depending on the construction and use of the structure. Information and data available to date does not provide a conclusion as to what the potential for O₂ concentrations should be in these situations and therefore it should undergo further evaluation. If this is the only limiting factor that may prevent biodegradation from occurring, it is highly recommended that the site undergo further evaluation (as discussed in Section 3.3), as there still remains a potential for biodegradation to occur.

**Summary.** There are a number of site conditions that can result in the conclusion that biodegradation will not reduce or eliminate the potential for VI to occur. When these conditions exist, this alternate approach is not appropriate and the VI pathway should be assessed as outlined in the MDEQ VI Guidance Document.

A summary of conditions that typically indicate that biodegradation is not occurring, as well as the documentation that could be used to make this determination, is provided in Table 2. As discussed earlier, documentation of these conditions is typically achieved through the use of a CSM, soil and groundwater data, and site maps.
TABLE 2
SUMMARY OF CONDITIONS INDICATIVE OF THE VAPOR INTRUSION ZONE

<table>
<thead>
<tr>
<th>Condition</th>
<th>Supporting Documentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic Conditions Site conditions inhibit subsurface O₂</td>
<td>-CSM</td>
</tr>
<tr>
<td>Separation Distance Sources of vapors (soil and groundwater) are one meter (three feet) or less from any structure</td>
<td>-CSM, Soil and groundwater data</td>
</tr>
<tr>
<td>Building Size Building footprint is greater than 2,500 ft²</td>
<td>-CSM, Site map to scale with structures identified</td>
</tr>
<tr>
<td>Preferential Transport Pathways Preferential pathways exist connecting the structure with a source of vapors</td>
<td>-CSM</td>
</tr>
</tbody>
</table>

3.3 Transition Zone

In many circumstances, it cannot be easily determined if site conditions will either promote or prohibit the bioattenuation of PHCs. When the site does not clearly fall into the Biodegradation Zone or the VI Zone, a further evaluation is needed to determine if biodegradation is occurring. In these situations, the site is considered to be in the Transition Zone. Conditions associated with the Transition Zone are summarized in Table 3.

The MDEQ has established two methods for evaluating site conditions to determine and document whether bioattenuation is likely present within the Transition Zone. Both methods require the completion of a CSM and identification of any potential source of vapors.

- **Method 1.** The first method relies on the collection of vertical concentration profiles in the unsaturated zone, where O₂ concentrations decrease with depth and PHCs and carbon dioxide concentrations increase with depth.

- **Method 2.** The second method utilizes the numerical model, BioVapor, which is verified with site-specific field data.

Although the use of these two methods has been found to successfully provide documentation that biodegradation is likely occurring in the subsurface, and the potential for VI is therefore minimal, the use of these specific methods is not required and another method may be proposed.

Both methods will require the collection of soil gas or sub-slab soil gas data. If the results are identified below the SGvi-SS (or other site-specific criteria), the methods presented below will assist in gathering the necessary information to draw the conclusion that the potential for VI is minimal.

Note that if concentrations are detected in the sub-slab soil gas above the SGvi-SS (or other site-specific criteria), it is inappropriate to run a model. Further evaluation of the structure should occur.
3.3.1 Method 1: Collection of Vertical Concentration Profiles

Aerobic biodegradation consumes \( \text{O}_2 \) and generates carbon dioxide (\( \text{CO}_2 \)) and water. As shown in Figure 6 (Roggemans et al., 2001), as aerobic biodegradation in unsaturated soil occurs, PHCs will degrade, \( \text{CO}_2 \) will be produced, and \( \text{O}_2 \) will be consumed. The aerobic Biodegradation Zone extends over the area of active biodegradation. The source zone, which is anaerobic, is characterized by the maximum volatile organic compound concentrations and little biodegradation.

Creating these concentration profiles (PHC, \( \text{O}_2 \), \( \text{CO}_2 \), and \( \text{CH}_4 \)) at a number of locations on the site, by collecting data as a function of depth, will provide the information necessary to determine if and where aerobic biodegradation zones are present. Although this method will require the collection of at least four quarters of \( \text{O}_2 \), \( \text{CO}_2 \), and \( \text{CH}_4 \), once the biodegradation profiles have been determined confirmation may be accomplished in as little as one additional PHC sampling event.

<table>
<thead>
<tr>
<th>TABLE 3</th>
<th>SUMMARY OF CONDITIONS INDICATIVE OF THE TRANSITION ZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Condition</strong></td>
<td><strong>Supporting Documentation</strong></td>
</tr>
<tr>
<td>Aerobic Conditions</td>
<td>Natural conditions are conducive to aerobic conditions</td>
</tr>
<tr>
<td>Separation Distance</td>
<td>Sources of vapors (soil and groundwater) are greater than one meter (three feet) and less than three meters (ten feet) from any structure</td>
</tr>
<tr>
<td>Building Size</td>
<td>Building footprint is greater than 2,500 ft(^2)</td>
</tr>
<tr>
<td></td>
<td>( \text{O}_2 ) is documented beneath or adjacent to the structure</td>
</tr>
<tr>
<td>Preferential Transport Pathways</td>
<td>Preferential pathways are within 30 feet (ten meters) from a source of vapors</td>
</tr>
<tr>
<td></td>
<td>( \text{O}_2 ) is present within the preferential pathways up to the structure</td>
</tr>
</tbody>
</table>
When utilizing this method, the following guidelines should be used to develop vertical profiles and correlations:

- At least 25 percent of the number of sub-slab points recommended in the MDEQ VI Guidance Document should be installed and sampled.
- Each sub-slab point should result in a minimum of four vertical sampling locations of equal distance between the groundwater and the lowest surface of the structure being evaluated (not to exceed eight feet in total profile depth).
- Monitoring points should be installed using the appropriate methodologies.
- Correlating PHC, O₂, CO₂, and CH₄ samples are collected during the sampling event at each sub-slab point and at each depth within each sub-slab sampling location.
- Proper sampling methodologies should be utilized with full quality assurance/quality control procedures.
- At least three other quarters monitoring the O₂, CO₂, and CH₄ levels should be collected with all profiles showing similar trends.
- Assuming proper correlations have been established from the initial round of sampling, a direct read meter can be utilized to evaluate PHC concentrations in lieu of running a Method TO-15 analysis.
- It should be noted that for small structures, typically with a building footprint of less than 2,500 ft², it may be challenging to collect vertical concentration profiles from within the structure. In these circumstances, it may be appropriate to collect the data needed to create the vertical profiles from outside of the structure. The location(s) selected to collect this information should be between the source and the structure, and be directly adjacent to the structure.

![Diagram of vertical concentration profile](image)

**Figure 6** Typical vertical concentration profile in the unsaturated zone for PHCs, O₂, CO₂. (modified from Roggemans et al, 2001).
3.3.2 Method 2: Modeling of Site Conditions using BioVapor

The method described in this section is based on the collection of site-specific data that is entered into a modeling program called BioVapor. BioVapor was developed by the American Petroleum Institute (API) as a spreadsheet-based model that allows for implementation of an algebraic solution (DeVaull, 2007). This model incorporates steady-state vapor source, diffusion-dominated, soil vapor transport in a homogeneous subsurface soil layer and mixing within a building enclosure. It assumes the soil is divided into a shallow aerobic layer, including first-order biodegradation, and a deeper anaerobic layer in which biodegradation is negligible.

The BioVapor Model does not directly account for spatial or temporal variations in parameter values. As a result, the model is not expected to provide highly accurate predictions when a single set of input parameter values are used to represent a single site (API, 2010). Therefore, the model must be run at multiple locations across a project site. More information on the limitations and inputs required for BioVapor can be found in the user guide made available by API on its website at www.api.org. For some scenarios, the model will predict unacceptable PHC concentrations in indoor air when high concentrations of PHC are present in the subsurface. The identification of these concentrations does not necessarily indicate that VI is occurring, but does mean that further investigation is warranted.

When interpreting a site using BioVapor, the user must also consider the uncertainty associated with the model inputs, along with the potential effects of spatial and temporal variability. When free-phase hydrocarbons are present in the subsurface in close proximity to the target building, the user is cautioned against relying on BioVapor model results as the primary line-of-evidence that VI is not a concern. In this case, BioVapor model results are more appropriately considered as a secondary or supporting line of evidence when other investigation results also indicate that there is no VI concern (API, 2010). In addition, the user is reminded that BioVapor does not evaluate other potential exposure routes (besides VI), migration pathways, or potential risks (such as fire and explosion) other than health toxicity. The user is responsible for evaluation of these other considerations.

The following sections provide information on the data necessary to complete the model and submit it as a line-of-evidence that supports biodegradation of PHC is occurring.

A. Data Collection

The location and frequency of the data necessary to collect for this zone (Transition Zone) is similar to that outlined in the MDEQ’s VI Guidance Document. However, with the collection of the site-specific data and appropriate results from BioVapor, as well as a sensitivity analysis of the data inputs, the sampling frequency for PHCs may be reduced to just two events. There are additional data collection requirements to support running the BioVapor Model, which include the collection of additional quarters of O2, CO2, and CH4. However, these parameters can typically be collected through the use of a properly calibrated field meter.

Additional information on the inputs or selections to be made to support bioattenuation is provided below.

B. Oxygen Boundary Condition

Earthen Floor Foundation. This option can be selected for crawlspaces and in areas where the resistance to O2 flow by a solid foundation is negligible. When this option is utilized it should be supported by the collection of O2 samples within the crawlspace. The amount of O2 and its variability should be evaluated throughout the
entire year, including the winter. The O₂ data should be collected at a frequency that allows for a statistical evaluation of the data and whether multiple populations of data are present. If multiple populations of data are present, the minimum O₂ concentration should be utilized, otherwise an upper 90 percent confidence level can be utilized.

**Slab or Basement Foundation (e.g., specify airflow).** If this option is utilized, the maximum O₂ availability is limited by atmospheric O₂ concentration and resistance to O₂ flow by both a building foundation and diffusion of O₂ from below the building foundation towards the PHC source. The O₂ levels are based on a generic assumption. Unless data is collected from the site at a frequency that allows for a statistical evaluation of the data, it should not be modified. The other parameter that should not be modified without supporting measurements and documentation is the airflow under the foundation which can be found in Section 5.0 of the data inputs in *BioVapor*.

**Specify Aerobic Depth Below Foundation.** The MDEQ prefers this methodology as it provides a strong line-of-evidence as to the amount of lateral space that exists between the structure and the potential source of vapors. There are also benefits in being able to evaluate single compounds using this method, as discussed in the *BioVapor* User’s Guide and Section C below. The use of this method requires the ability to document the depth of the aerobic zone based on site-specific O₂ profiles collected up to the potential source of vapors (typically not to exceed eight feet in total depth).

C. **Sampling the Source of Vapors**

It is important for the user to identify all biodegradable vapor-phase hydrocarbons present in the source area. This will require samples that are collected and analyzed for soil gas and/or groundwater. Estimated concentrations are typically not recommended. It should be noted that ethanol must be included for new releases.

The “Earthen Floor Foundation” and the “Slab or Basement Foundation” boundary conditions discussed above, both utilize an O₂ mass balance (demand versus availability) to determine the depth of the aerobic zone. If the user does not identify all volatile chemicals that exert an O₂ demand, then the model will over estimate the depth of the aerobic zone and over-predict the effect of biodegradation.

If the O₂ boundary condition is “Specify Aerobic Depth Below Foundation,” no O₂ mass balance is performed and the model results for individual chemicals will not be affected by the total hydrocarbon concentration. More information can be found in the *BioVapor* User’s Guide.

D. **Exposure and Risk Factors**

The user must enter exposure and risk factor values to be used for indoor risk calculations. Though default parameters are provided through the “Paste” command available in the model, the MDEQ’s exposure and risk factors should be utilized and are provided in Table 4.
Biodegradation Of PHCs

### Table 4

**MDEQ Exposure and Risk Factors**

<table>
<thead>
<tr>
<th>Exposure and Risk Factors</th>
<th>Residential</th>
<th>Nonresidential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Hazard Quotient For Individual Chemicals (THQ)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Target Excess Individual Lifetime Cancer Risk (TR)</td>
<td>1E-05</td>
<td>1E-05</td>
</tr>
<tr>
<td>Averaging Time, Carcinogen (ATC)</td>
<td>25,550 days/yr</td>
<td>25,550 days/yr</td>
</tr>
<tr>
<td>Averaging Time, Non-carcinogenic (ATNC)</td>
<td>10,950 days/yr</td>
<td>7,665 days/yr</td>
</tr>
<tr>
<td>Exposure Duration, Carcinogen &amp; Non-carcinogenic (ED)</td>
<td>30 yrs</td>
<td>21 yrs</td>
</tr>
<tr>
<td>Exposure Frequency, Carcinogen &amp; Non-carcinogenic (EF)</td>
<td>350 days/yr</td>
<td>245 days/yr</td>
</tr>
<tr>
<td>Body Weight - Adult (BW)</td>
<td>70 kg</td>
<td>70 kg</td>
</tr>
<tr>
<td>Indoor Inhalation Rate Exposure Adjustment (CF)</td>
<td>0.25</td>
<td>1.0</td>
</tr>
</tbody>
</table>

#### E. Building and Vadose Zone Parameters

It is imperative that if any of the building or vadose zone parameters are modified, it is done with data based on site-specific information and measurements that have undergone a sensitivity analysis. One of the easiest ways to perform this test is to enter the parameters into the on-line-calculator available from the United States Environmental Protection Agency at:


This on-line calculator implements the J&E Model (Johnson and Ettinger, 1991) simplified to evaluate the VI pathway into buildings, and includes a simplified uncertainty/sensitivity analysis the other implementations lack. Though the outcomes are not expected to match, the uncertainty/sensitivity analysis will provide documentation that the parameters utilized are within the acceptable allowances for the J&E Model.

3.3.3 Output

Both of the methods can be used to determine if bioattenuation is occurring, but with any determination of compliance, will require detailed documentation of the procedures and information utilized. When using the *BioVapor* Model, the report should include all of the parameters utilized, any modifications from the MDEQ assumptions, and a sensitivity analysis.

#### 4.0 METHANE

Sources of CH₄ include solid or industrial waste deposits, oil and gas wells, groundwater contamination plumes (especially biodegrading PHCs), and leaking natural gas pipelines. CH₄ is not toxic; the principle health and safety concerns are its explosive, flammable, and asphyxiating properties. Since CH₄ is a simple asphyxiating, acting by displacement of O₂, no threshold limit value (TLV), permissible exposure limit (PEL), or recommended exposure limit value (REL) has been established. However, migrating CH₄ gas can pose serious public health and safety risks, principally fire and explosion. In addition, it is known that the presence of CH₄ inhibits the biodegradation of PHCs. In sites where biodegradation is known (or thought) to be occurring, a party should evaluate the potential for CH₄.
References


Biodegradation Of PHCs


