

Innocent until Proven Guilty: U.S. EPA's Petroleum Vapor Intrusion Technical Guide

Lenny Siegel
August, 2015

On June 11, 2015, the U.S. Environmental Protection Agency released its 3.0 MB PDF *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites*, along with its companion 3.2 MB PDF *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*. Go to <http://www.epa.gov/oswer/vaporintrusion/guidance.html#EO12866OSWERVI> to download both document. In addition, the Petroleum Guide may be found, along with supporting technical documents, at <http://www.epa.gov/oust/cat/pvi/>.

The Petroleum Guide, as its full title suggests, addresses a narrow but common type of vapor intrusion problem, where there is suspicion that petroleum hydrocarbons (PHCs) and non-petroleum fuel additives that have been released from leaking regulated underground storage tanks will form vapors that migrate into overlying buildings. A large fraction of the nation's 571,000 underground storage tanks, primarily at gasoline stations, have experienced leaks or spills. The Petroleum Guide is designed for the regulated underground storage tank universe. It is **not** designed for sites where the principal contaminants are chlorinated volatile organic compounds such as trichloroethylene (TCE) or tetrachloroethylene (PCE). Nor does it apply to large petroleum release sites such as refineries and pipelines. For those, consult the other, more general Technical Guide. On the other hand, Petroleum Guide is expected to provide useful guidance in the remediation and reuse of petroleum-contaminated brownfields.

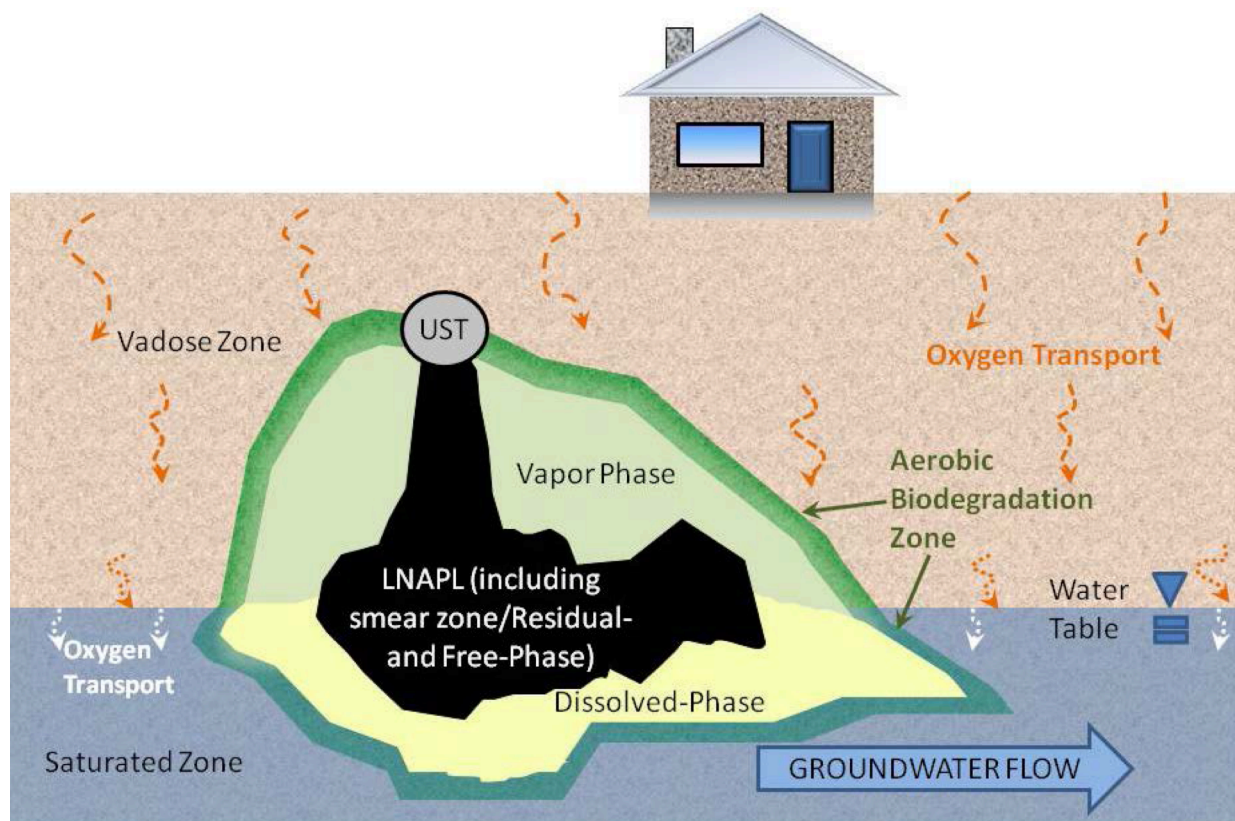
Like the general Technical Guide, the Petroleum Guide does not impose any new requirements. Rather, it is designed to provide technical information to local, tribal, and state environmental regulators, as well as EPA staff and consultants, responding to the potential for petroleum vapor intrusion. It also does a good job of explaining, for the lay reader, the various forms of petroleum hydrocarbons found at contamination sites. See page 17 of the PDF for a description of the composition of petroleum fuels.

Gasoline station pollution sites are indeed a special case. Vapor intrusion from these types of sites rarely poses a serious health risk, because petroleum products tend to degrade into non-hazardous substances as they come into contact with oxygen, which itself migrates downward from the soil surface, as well as microbes present in the subsurface. Thus, the Guide takes what I call an "innocent until proven guilty" approach. At leaking petroleum tank sites, vapor intrusion can be ruled out unless subsurface contamination is within a site-specific lateral distance, and vertically either 6 feet for dissolved contamination or 15 feet for light non-aqueous phase liquids (LNAPL). "Dissolved" means that the petroleum hydrocarbons found spread out in solution within the groundwater. LNAPL refers to the petroleum product that has not dissolved, but instead, because it is lighter than water, sits at the top of the underground water table.

At sites where the contamination consists of chlorinated volatile organic compounds, I argue that in most cases that it's premature to rule out vapor intrusion above or near

contaminated groundwater without sampling for the toxic chemicals in indoor air, the best measure of potential exposures. Though there may be indoor or even outdoor sources (together called “background”) of the contaminants, there are a number of ways to distinguish background sources from vapors emanating from the soil and groundwater below. I find it more difficult to make that case for petroleum products, because they tend not to survive the trip to the surface. That is, they are degraded by microorganisms in the soil as they come into contact with oxygen moving downward from the surface. In my work with communities, I rarely find sites where petroleum vapor intrusion is a serious concern.

However, there are many situations in which the general findings do not apply. Therefore, much of the Petroleum Guide is devoted to ways to ensure that none of those exceptions apply. The following paragraphs highlight those exceptions as well as other elements of the Petroleum Guide. Note that the page numbers that I cite apply to the PDF, not the printed version, to make it easier to search for specific sections in the Guide. For ease of reading, I have also removed most of the references from the text. As with the general Technical Guide, I urge everyone who wants to gain a full understanding of how EPA recommends addressing vapor intrusion to familiarize himself/herself with the entire Guide.



Conceptual Site Model

The Petroleum Guide, like the general Technical Guide, recommends starting with the formulation of a Conceptual Site Model. For petroleum, it’s not only important to identify sources, pathways, and receptors, but also to consider the phase of the contamination. For example, dissolved hydrocarbons pose less risk of exposure than LNAPL. The Guide explains:

When petroleum fuels are released into the subsurface from a leaking UST, PHCs may partition into several phases:

- Globules of light non-aqueous phase liquid (LNAPL) trapped within soil pore spaces (i.e., residual LNAPL)
- Dissolved in soil moisture
- Adhered onto the surface of, or absorbed into, soil solids
- Vapors in soil gas
- Accumulations of mobile LNAPL on and in the capillary fringe
- Dissolved in groundwater (*page 18 of the PDF*)

With the Conceptual Site Model in place, investigators should establish **the lateral inclusion zone**. The Guide recommends using *An Approach for Developing Site-Specific Lateral and Vertical Inclusion Zones within which Structures Should be Evaluated for Petroleum Vapor Intrusion due to Releases of Motor Fuel from Underground Storage Tanks* (see <http://www.epa.gov/oust/cat/pvi/epa600r13047.pdf>). This process is complex, with no one number (or even a few) standing as a default. On the positive side, less dense sampling networks lead to larger lateral distance. The Guide explains:

The lateral inclusion zone is the area surrounding a contaminant source through which vapor-phase contamination may travel and intrude into buildings. Determination of the lateral distance within which buildings and other structures may be threatened by PVI is site-specific. In general, with increasing confidence in the site characterization and the CSM, there can be a corresponding decrease in the distance the lateral inclusion zone extends from clean monitoring points. All buildings within the lateral inclusion zone should be further assessed to determine if they are separated from vapor sources by an adequate vertical separation distance.... Further assessment may be unnecessary for those buildings outside the lateral inclusion zone unless preferential transport pathways are present. If contaminated groundwater is the source of vapors, migration of the contaminant plume (in the longitudinal, transverse, and vertical directions) should be assessed when evaluating the potential for future risks. (50)

The Guide adds:

Though in theory the length of the lateral separation distance may be on the same scale as the vertical separation distance, a greater lateral distance is generally warranted in the down gradient direction. This is because the lateral boundaries of a migrating plume are more difficult to accurately delineate, as they are not stationary. (50)

Then investigators should determine the **vertical separation distance**, “the thickness of clean, biologically active soil between the highest vertical extent of a contaminant source and the lowest point of an overlying building.” If buildings within the lateral inclusion zone are within six vertical feet of dissolved PHC contamination or 15 feet of the more problematic LNAPL, then vapor sampling should occur. If sampling demonstrates that exposure levels are above, or are predicted to be above, health-based standards, then mitigation is necessary.

Dissolved PHC contamination does not seem to be much of a vapor intrusion threat:

PHC vapor concentrations generally decrease with increasing distance from a subsurface vapor source. At a relatively short distance from the source, concentrations of PHCs in

soil gas will typically fall below potentially significant levels of concern provided that oxygen replenishment is adequate to ensure complete aerobic biodegradation. Lahvis, Baehr, and Baker observed that PHC vapors from a dissolved plume were almost completely degraded within 1 meter (3.3 feet) above the water table and that significant transport of PHC vapors may only be significant if the vapor source is LNAPL. (74)

It's not always easy to know whether petroleum hydrocarbons are present in LNAPL form:

The presence of LNAPL may be determined from direct or indirect evidence. Direct evidence includes measureable accumulations of free product in monitoring wells, an oily sheen or floating globules on the water table, and petroleum hydrocarbon-saturated bulk soil samples. Lahvis et al. caution that the presence or absence of free-phase LNAPL in monitoring wells may not be a reliable indicator of the presence of residual-phase LNAPL. The absence of LNAPL can only be determined through analysis of core samples. This is important to recognize because free-phase and residual LNAPL have a greater vapor-generating capability than dissolved sources. Indirect evidence includes high concentrations of benzene and other PHCs, often measured as TPH. There is considerable variation and uncertainty in LNAPL thresholds determined from indirect evidence and Lahvis et al. suggest that multiple indicators of the presence of LNAPL be evaluated. (54-55)

The prevalence of aerobic (that is, enable by the presence oxygen) degradation is the reason EPA is confident that in most cases contamination that is outside the inclusion zones will not cause unacceptable vapor intrusion. That's why the soil must be biologically active:

For a PVI investigation, clean soil does not necessarily mean that it is contaminant-free, but rather that the level of any contamination present is low enough so that the biological activity of the soil is not diminished and the subsurface environment will support sufficient populations of microorganisms to aerobically biodegrade PHC vapors....

Effective aerobic biodegradation of PHCs depends on the soil having sufficient oxygen and enough moisture to provide a habitat for adequate populations of active microorganisms. Although most soils contain indigenous microorganisms capable of degrading PHC vapors, typically there is an acclimation period between the time they are exposed to the PHC vapors and the time they begin to biodegrade the vapors. (81)

But one still needs to consider conditions that might prevent that degradation from taking place:

Several factors may preclude the effectiveness of aerobic biodegradation to mitigate the threat of vapor intrusion. They include:

- Source volume and composition (including PHCs and non-PHC fuel additives)
- Soil properties (moisture content, permeability, high organic carbon content, especially peat)
- Large building size
- Extensive impermeable surface covering (e.g., asphalt, concrete)
- Preferential transport pathways (including both natural and man-made) (22)

Investigators need to watch for such conditions and adjust their site characterization

strategies to account for them. For example:

Although biodegradation is known to occur for many individual non-PHC fuel additives and classes of additives, the rate of biodegradation in soil gas has not necessarily been rigorously quantified; this is especially true for the lead scavengers EDB [ethyl dibromide] and 1,2-DCA. Therefore, for these two chemicals in particular, vertical separation distances recommended in this guide may not be sufficient for petroleum fuel releases that contain EDB and 1,2-DCA and additional investigation may be necessary to assess their potential for vapor intrusion. (57)

The discussion of lead scavengers, particularly EDB, should be useful for those addressing plumes at larger petroleum sites not directly addressed in this Guide. EDB has been found in large spills at Air Force bases. Table 7 (94) provides example screening concentrations for EDB and 1,2-DCA in groundwater and indoor air.

Petroleum hydrocarbon vapors are different than CVOCs in another critical way. In high enough concentrations both methane and gasoline fumes are flammable, posing an explosive as well as a toxic risk:

In confined spaces, the presence of flammable PHC vapors and non-PHC fuel additive vapors or methane may pose a threat of fire or explosion and endanger building occupants. Federal regulations (40 CFR 280.61) require that immediate action be taken to prevent any further release of the regulated substance into the environment and that fire, explosion, and vapor hazards be identified and mitigated. Section 280.64 requires that free product (mobile LNAPL) be recovered to the maximum extent practicable and that records be kept of the volumes recovered. First responders, typically fire department personnel, should be notified if there are reports of either odor from petroleum or the presence of an oily sheen on basement floors or in sumps, drains, or elevator pits. It may be necessary to evacuate building occupants until the threat from fire or explosion has been mitigated. Since methane is odorless and colorless, monitoring devices are required if methane is suspected. (24)

Gasoline containing a significant fraction of ethanol is of particular concern: “[T]he biodegradation of ethanol may result in the advective transport of methane and a potential risk of explosion.” (23)

The Guide offers two sampling strategies for buildings within the inclusion zones but not in direct contact with the contamination:

If contamination (either dissolved, or LNAPL whether mobile or residual) is in direct contact with a building EPA recommends indoor air sampling. In the case of direct contact, sub-slab samples cannot be collected because there is no subsurface soil between the contamination and the building. Where contamination is not in direct contact with an overlying building, then choose one of two options: (1) collect near-slab (exterior) shallow soil gas samples paired with deep (source) soil gas samples, or (2) collect indoor air samples paired with sub-slab soil gas samples. (11)

EPA recommends the first option when:

- A building, with the shortest side no longer than 66 feet, overlies LNAPL and the vertical separation distance is less than 15 feet, but not in direct contact with the building basement floor, foundation, or crawl space surface.
- A building, of any dimension, overlies dissolved PHC contamination and the vertical separation distance is less than 6 feet, but not in direct contact with the building basement floor, foundation, or crawl space surface. (26)

On the other hand, it suggests:

Use option 2 for buildings larger than 66 feet on a side or if near-slab soil gas samples from around smaller buildings do not clearly demonstrate that biodegradation is sufficient to mitigate the threat of PVI by reducing PHC concentrations to below applicable human health thresholds. (27)

Note that for option 2 if the measured concentration of vapor in indoor air is below the applicable allowable indoor concentration there is no need to measure sub-slab vapor concentration. (209)

While investigators may use calculated or generic attenuation factors to predict the concentration of CVOCs in indoor air based on soil gas data, EPA recommends the derivation of site-specific attenuation factors for PHCs:

The purpose of collecting paired samples is to enable determination of a **building-specific vapor intrusion attenuation factor**. Generic attenuation factors that do not account for biodegradation of soil PHCs are conservative and, likely overestimate the transfer of contaminants from gas to indoor air in most buildings. Attenuation factors (see **Section 12**, p.100) that account for biodegradation can be derived from models such as *BioVapor* or *PVIScren*. (27)

Furthermore:

If contamination (either dissolved, or LNAPL whether mobile or residual) is in direct contact with a building basement floor, foundation, or crawlspace surface, EPA recommends indoor air sampling (these samples cannot be paired with subsurface soil gas samples because there is no clean, biologically active soil between the contamination and the building.) (27)

Normally, ambient (nearby outdoor) air measurements should be taken, at the same time as indoor samples. I emphasize this because I have seen sites where investigators instead have relied upon generic values for outdoor air concentrations:

While these studies provide expected ranges of indoor air contaminants, EPA recommends building-specific sampling (rather than using literature values) to characterize actual contaminant levels. (28)

EPA's Petroleum Vapor Intrusion Guide makes a number of other important points that may show up at any point in an investigation:

- The Guide reminds us to be careful in the vertical screening of groundwater monitoring wells:

Conventional monitoring wells may provide an incomplete picture of the true distribution of contaminants in groundwater. If the length of the screen in a monitoring well is long compared to the thickness of the plume of contamination, the sample obtained will be diluted by the inflow of clean(er) groundwater from above or below the plume. Also, plumes may dive below the screened interval of the wells leading to the false impression that the plume is shorter than it actually is. (68)

- The Guide discusses where oxygen shadows—where insufficient oxygen is present beneath a building to support degradation of PHCs—are likely:

For LNAPL sources, an oxygen shadow was not observed to form beneath buildings up to 66 feet on the shortest side. This length represents the threshold below which oxygen replenishment is sufficient to support aerobic biodegradation; above this length oxygen replenishment may be impeded and there may be insufficient oxygen present to support aerobic biodegradation. (74, footnote 35)

However, a recent study by EPA indicates that for an oxygen shadow to form beneath a building, the PHC vapor source must be shallow LNAPL and the building must be greater than 66 feet in length on the shortest side. For simulations with dissolved sources, no oxygen shadow formed even under a square building with sides that were 2,073 feet in length. (75)

But there is still uncertainty about the how ice affects the vertical movement of oxygen:

There is conflicting evidence as to whether, and under what additional conditions, frozen or ice-covered soil reduces the movement of oxygen into the subsurface. (102)

- The Guide also addresses the practicality of taking very shallow soil-gas measurements:

In some cases, relatively shallow soil gas samples (less than five feet below ground surface) will be needed to characterize active biodegradation zones in the shallow soil (e.g., in the presence of shallow contamination sources). Some state regulatory programs do not allow soil gas sampling at depths less than 5 feet based on the concern that accurate sampling may not be possible at shallow depths because air from the surface may leak into the sample. However, recent research has shown that the collection of accurate shallow-soil gas samples is possible at depths as shallow as 2 feet below ground surface using appropriate field methods (e.g., leak testing), such as those documented in *Temporal Variation of VOCs in Soils from Groundwater to the Surface*.

- EPA considers when there is adequate soil moisture for biodegradation to occur:

The habitat of soil bacteria is the thin film of water held to the surface of soil particles by

capillary attraction. EPA notes that soil moisture content greater than 2 percent is adequate to support biodegradation activity, although biodegradation is limited when the moisture content is at or below the permanent wilting point. Adequate soil moisture is also indicated if the landscape supports the growth of non-irrigated vegetation. (81)

- EPA evaluates modeling:

The appropriate role for a model in a PVI investigation is as a means to explain observed behavior. EPA recommends the use of a model that considers aerobic biodegradation when assessing the potential for PVI. (115)

Estimates using the BioVapor model indicate that for moderate or weak sources (especially dissolved plumes), biodegradation effectively eliminates the potential for PVI. Conversely, where vapor sources are both high in concentration and in close proximity to the bottom of a foundation, the BioVapor model predicts significant potential for PVI. Notably, in these cases the BioVapor model predicts significantly higher potential for PVI below a foundation, where oxygen availability is more limited, than adjacent to the foundation where the soil surface is open to air and oxygen availability is greater. (114)