

How to Collect Reliable Soil-Gas Data for Risk-Based Applications—Specifically Vapor Intrusion

Part 3 – Answers to Frequently Asked Questions

by Blayne Hartman

Since I wrote Parts 1 and 2 in July 2002 and October 2003 (LUSTLines #42 and #44), vapor intrusion has continued to be a “box-office blockbuster” throughout the environmental remediation community. I have provided vapor-intrusion training to no fewer than 12 states, several U.S. EPA regions, and the Department of Defense. Others, including U.S. EPA staff and the American Petroleum Institute (API), are providing training at conferences and to interested parties. Groups such as EPA’s Office of Solid Waste and Emergency Response and the Office of Underground Storage Tanks, ITRC, and API have formed vapor-intrusion technical workgroups. Many states have written soil-gas policy/guidance, promulgated regulations (e.g., CT, LA), prepared draft documents (i.e., NJ, MI), or are presently contemplating preparing guidance (i.e., WA, AZ). Everyday, I receive phone and e-mail inquiries on a variety of topics, including soil-gas protocols, analytical methods, and sampling strategies. With all this interest, I figure it’s time for Part 3 in this series: *Answers to Frequently Asked Questions*. The following questions are accompanied by answers, as I see them, that I hope will be helpful.

■ What is the primary reason that soil-gas sampling for vapor intrusion differs from soil-gas sampling for typical site assessment?

The difference is in how low a concentration you have to measure. For site-assessment applications, we typically worry about contaminant concentrations above 1 µg/L. For vapor-intrusion applications, we measure down to levels as low as 1 µg/m³, fully 1,000 to 10,000 times lower. This means that we need to be much more careful in how we collect and analyze samples. Field and analytical techniques that are suitable for higher concentrations are often not suitable for these ultra-low concentrations. Small contaminant blanks from equipment, fingers, clothing, the working surface (e.g., the tailgate of your pick-up), even the ambient air can be enough to fail acceptable risk levels.

■ Why do you say that vapor units are the most common (and very significant) error in vapor-intrusion assessments?

In the vapor-intrusion world, labs and regulations employ a vast array of units, including most commonly ppmv, ppbv, µg/L, µg/m³, mg/m³, and %. It’s enough to drive a geologist and risk assessor mad. Even the engineers are having trouble (although they will never admit it).

For water samples, a ppb is equivalent to an µg/L. For vapor, a ppbv is not equivalent to a µg/L.

Because the vast majority of us in this field (e.g., regulators, consultants, project managers) are used to dealing with groundwater, it is very easy to carry over this equivalency to vapor samples. Undoubtedly, this is the most common error that I see being made by practitioners in the vapor-intrusion field. And it’s huge! The reason? For benzene, one µg/L is equal to ~300 ppbv; for TCE, ~180 ppbv. So, we’re talking greater than two orders of magnitude error if the units are inadvertently thought to be equivalent.

This confusion about units occurs most commonly in the following situations:

- When vapor-risk models, such as EPA’s Johnson-Ettinger model spreadsheets, are used. If you inadvertently flip the units, you’ll start off two orders of magnitude too high or too low. Compare the magnitude of this error to the sensitivity of some of the other common J-E model parameters from default values. Porosity: factor of 5; Q_{soil}: factor of 3; Ventilation rate: factor of 10. The point is this error is much greater than all of the others combined.
- Calculating soil-gas concentrations from groundwater data using Henry’s constant. For benzene, the equilibrium soil-gas concentration with 10 µg/L in the groundwater is ~2 µg/L. If

you inadvertently write it as 2 ppbv, then you have erred by 300 times.

- Comparing on-site results in units of µg/L to off-site results reported in ppbv. If the off-site confirmation samples show hits at 100 ppbv and the on-site data were all below detection at a DL (detection level) of 1 µg/L, don’t panic. The results agree.

■ What’s an easy way out of unit-conversion madness?

- Instruct your lab on what units and detection levels you want the data reported in.
- Go to www.HandPmg.com for a handy-dandy, easy-to-use unit conversion spreadsheet.

■ What are “vapor clouds” and why should we care about them?

Vapor clouds refer to situations where there is subsurface contamination of the soil vapor with little or no coincident soil or groundwater contamination, hence the term “cloud.” They arise from leaking vapors, not from contaminated soil or groundwater. Common sources for vapor clouds are sites that contain surface sources of chlorinated solvents (e.g., vapor degreasers, dry cleaners, clarifiers), where the dense chlorinated vapors enter the vadose zone from above, or where vapors are leaking out of USTs.

You should care about vapor clouds for a number of reasons. First, unlike groundwater, vapors can move in all directions, regardless of the groundwater gradient, and move quickly—approximately 25 feet/year by molecular diffusion alone. So, a vapor cloud from a dry-cleaning washer unit can move laterally underneath adjoining businesses in a strip mall within one year and represent an upward migration threat to nearby residences within a few years.

Vapors leaking from an UST can move downward through the vadose zone to the groundwater and represent a groundwater contamination threat. (See “The Downward Migration of Vapors,” *LUSTLine* #29 and “The Great Escape from the UST,” *LUSTLine* #30 for discussions of this pathway.)

When the J-E model underpredicts the measured risk, or indoor air results don’t match with groundwater patterns, or when vertical profiles of the soil gas don’t show increasing concentrations with depth, vapor clouds should be suspected and soil-gas data, not soil or groundwater data, must be collected to adequately assess the upward vapor risk pathway.

Finally, as pointed out by a reviewer of this article from the rainy south, while vapor sources can exist anywhere, vapor clouds are more likely to exist in areas with deeper groundwater and less rain. In areas with shallow groundwater and abundant rain, any leaking vapors are more likely to get scrubbed (partition) into the groundwater (similar to a “Mister Coffee”).

■ **Is it true that an equation written to allow passive soil-gas data to be converted to concentration units is now applicable for vapor-intrusion assessment?**

Yes and no. It is true that an equation has been written by a firm providing passive soil-gas services. The analysis of passive soil-gas samplers gives the mass on the passive collector (e.g., micrograms [μg] or some other form of relative units), not concentration. Concentration is mass/volume. So, to convert mass to concentration we must know the volume of vapor that comes into contact with the adsorbent during burial. There is no way to know this and no accurate way to

measure this volume on a true passive sampler. Therefore passive soil-vapor data cannot be used for quantitative upward vapor-migration assessment, despite what you might be hearing. One could pump a known volume of air through a passive collector, similar to the NIOSH methods or TO-17, but this is far different than simply burying a collector into the ground and is actually a form of active soil-gas surveys.

■ **Why weren’t you more bullish on flux chambers in your last article?**

The primary purpose of the article was to describe the two common chamber methods (i.e., static and dynamic), how to use them, and the pros and cons of each. The article was written in response to numerous questions I was receiving from both the consulting and regulatory communities about the technique. But the overriding problem with the approach is whether chambers can be located properly. In many structures, the primary entry of soil gas into the structure is through discontinuities in the floor slab (e.g., cracks, holes, sumps), and these locations might be concealed by barriers such as floor coverings, walls, and stairs.

However, as I wrote in the article, I think flux chambers have their place when the right conditions exist. Examples of “right conditions” include slabs in good condition with limited pipes/utilities poking through, larger slabs (i.e., larger than a typical residence), and undeveloped lots in warmer climates or where estimates of a future stack effect due to the building can be made.

If you elect to use flux chambers, be sure that enough chamber measurements are collected to get a representative value over the footprint of the building (analogous to placing enough borings on a typical site) and that they are located near edges where the slab meets the footing, over any zones with more cracks, and over the center of the contamination, if known.

Assuming uniform subsurface contamination, five chambers might be appropriate (one on each side of the structure and one in the center). If the contamination is not directly below, then fewer chambers on the

side of the contamination might be appropriate. In all cases, chambers should be deployed for long enough periods to enable temporal variations to be assessed, similar to indoor air measurements (8 to 24 hours depending on the conditions; 24 hours if large temperature differences exist between day and night).

■ **Why do you recommend small purge-and-sample volumes for soil-gas samples?**

Multiple reasons. I too often see soil-gas data from large Summa canisters (3L to 6L) with tracer/leak compound detections. (By tracer/leak compound, I am referring to a compound such as butane or isopropanol, deliberately applied during sample collection, that acts as a tracer of leaks from the surface or leaks in the sampling system.) Also, successive duplicate samples (i.e., one collected after the other) show larger variations than duplicates collected with smaller volumes. Remember, the larger the volume collected, the greater the uncertainty as to the source of the sample. (See Figure 1.) That’s a plain fact.

So, if you are sampling near the surface, large extraction volumes will increase the potential that atmospheric air might be drawn down the outside of the probe body. If you are sampling under a slab, large extraction volumes will increase the potential that samples might be from a deeper depth or outside the slab. In addition, large purge-and-sample volumes can create vacuum conditions that cause contaminant partitioning from the soil into the soil gas.

All of these issues increase the potential that the collected soil-gas sample is not representative of in-situ soil vapor at the target depth. Finally, the larger the volume required, the larger and more complex the sample collection system required (e.g., vacuum pumps, larger sample containers).

■ **What about when air labs tell me I need to collect 6L volumes to reach my required DL?**

You shouldn’t need to. Soil-gas DLs for VOCs of 0.2 to 0.5 ppbv (~ 1 $\mu\text{g}/\text{m}^3$ for most compounds) can be reached with only 300 cc of sample (as reported to me by a nationwide air lab) using method TO-15, and

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with volumes as small as 50 cc using methods 8260 SIM or 8021. Yes, larger canisters are useful in case repeated runs are required. But, for the TO-methods, one to three liters should be more than sufficient to enable re-runs, if necessary. For methods 8260 or 8021, 500 cc should be more than sufficient.

■ Is it true that the toxic organic (TO) methods are the only appropriate method for analyzing soil-gas samples?

No, but you may be hearing this from some of the labs that specialize in these analyses. The argument is that EPA methods such as 8260 and 8021 are soil and water methods that use liquid standards and hence are not appropriate for air samples. Further, according to the argument, soil-gas samples are air samples and, thus, should be analyzed by air methods that use gaseous standards. The key difference in the methods is not the type of standard but how the standard and sample are introduced into the analytical instrument. TO-methods use air concentrators. Methods 8260 and 8021 use direct injection or purge-and-trap injection systems.

For the majority of compounds of concern at vapor-intrusion sites (e.g., BTEX, chlorinated solvents), there is no significant difference caused by the injection methods. For some compounds (typically the more polar ones such as ketones and alcohols), methods 8021 and 8260 can give different values from the TO-methods by up to a factor of two to three if the



FIGURE 1. A basketball or a baseball? The 6L Summa canister has a volume about the size of a basketball, whereas the mini-can has an approximate volume of a baseball.

purge-and-trap injection method with liquid standards is used. In the cases where this might be an issue, either use the TO-methods or ask the laboratory to use vapor standards for 8260 or 8021.

The decision on what analytical method to use should be based primarily on the required detection level, project scope, and cost—in this order. See Table 1 to help you decide.

For example, if the compounds of concern at a site are only TCE, PCE, TCA, and DCE, then the GC-ECD is more than likely to reach the DLs required and it costs one-third what a TO-15 SIM would cost. And yes, the data will be legally defensible if the

lab follows the method QA/QC.

■ Why do you promote on-site analysis so heavily?

Mostly because on-site analysis allows you to use your brains in real-time. This is especially powerful for vapor-intrusion assessments because additional locations can be added, either spatially or vertically, based on the real-time data. It also allows mistakes (e.g., leaked gas breakthroughs, inconsistent numbers, hardware blanks) to be recognized on-site and verification or replicate samples to be collected as needed. Laboratory-grade instruments, including mass spectrometers, can be transported into the field, and they fulfill necessary analytical protocols.

■ Isn't your opinion biased, since you provide on-site services?

Yes, but not for this reason. The real reason for any bias is the power that real-time data and decision making bring to assessing this risk pathway—and I'm not the only one who feels this way. A growing number of federal and state regulatory agencies and consultants are hopping on this bandwagon. In fact, EPA has a real-time, instantaneous analyzer called the Trace Atmospheric Gas Analyzer (TAGA) that staff actively promote and use on vapor-intrusion sites. Also, EPA is a strong supporter and promoter of the Triad approach that includes on-site analyses (<http://www.clu-in.org/triad/#usin>).

TABLE 1 Summary of Analytical Methods for VOCs in Soil-Gas Samples

METHOD	DETECTION LEVEL (µG/M3)	PRICE*	COMMENTS
8021 for MTBE/BTEX	10 to 20	\$ 75	False positives if high TPH
8260	100	\$ 100	Complete VOC list & naphthalene
8260 SIM	5 to 10	\$ 150	Subset of 5-10 compounds#
TO14 or 15	1 to 5	\$ 250	Complete VOC list, no naph.
TO15-SIM	0.01 to 0.05	\$ 325	Subset of 5-10 compounds#
GC-ECD	0.5 to 5	\$ 90	Chlorinated compounds only

* Listed price are estimated and will vary around the country.

You select the subset from the full VOC list.

(See "LUST Innovations, TRIAD, and Computer Imaging Move LUST Site Investigation into the 21st Century," LUSTLine #45.)

■ Why are you so worried about the hardware required by the TO-methods for soil-gas samples?

For a number of reasons, primarily:

- There are many connections and fittings, all with dead-volume and possibilities of leaks. (See Figure 2.)
- More hardware means more can break, have blanks, or not work properly.
- Few field technicians or field-sampling companies have the experience of testing and using the hardware properly or fixing or repairing it if problems are recognized.
- Often, the connecting fitting/tubing or flow chokes are reused between samples without being cleaned. Very recently, a lab provided me 30 canisters for a program with only two flow chokes (one to use plus a spare). What's wrong with this picture? If you're reusing flow chokes between samples, how do you know that they are not contaminated from the previous sample? At a minimum, a cleaning kit and instructions on how to clean the flow choke between samples should have been included.

Throw into this mix the bulkiness of the hardware (ever tried to put sixteen 6L canisters in your car?), and hopefully you can understand my concern.

■ I keep getting tracer/leak gas detections in my samples, and the regulators are not accepting the data. What am I doing wrong?

The problem probably stems from any one or all of the following scenarios:

- Collecting too large a volume of soil-gas sample (>1 liter) too close to the surface
- Not adequately sealing at the surface of the ground where the probe rod enters
- Leakage at the coupling inside the probe rod, if the post-run tubing method is being used



FIGURE 2. Comparison of a sampling train provided by a lab to fill canisters for off-site analysis vs. a syringe used for on-site analysis. The larger dead-volume and numerous connections of the sampling train increase the chances of equipment blanks and leaks.

- Using a permeable tubing to collect soil-gas samples
- Loose fittings on your sampling system train

■ What tubing do you recommend?

Rigid-wall, nylon tubing, 1/8" or 1/4" outer diameter. Believe it or not, Teflon, while inert, has a relatively high sorption for many compounds. The 1/8" nylon tubing is easier to work with than the 1/4" tubing if soil-gas sampling is your only need. If permeability testing is desired, the 1/4" tubing is better. Stainless-steel tubing is fine for shallow sampling but is logistically more difficult to install as the sampling depth increases (>5'). Flexible tubing (e.g., rubber, plastic), such as the type available on rolls at the hardware stores, or tygon tubing should be avoided at all costs (too permeable).

■ What is an "alpha factor," and how do I use it when trying to scope a vapor-intrusion project?

An alpha factor is a unitless empirical attenuation factor relating the indoor air concentration to either a subsurface soil-gas concentration (α_{sg}) or to

a groundwater concentration (α_{gw}) as follows:

$$(\alpha_{sg}) = C_{\text{indoor}} / C_{\text{soil gas}}$$

$$(\alpha_{gw}) = C_{\text{indoor}} / (C_{\text{water}} * H)$$

H is the compound's unitless Henry's law constant.

U.S. EPA and most oversight agencies have tabulated acceptable levels for compounds in breathing air for various risk levels (C_{indoor}). So, if you know the alpha factor that the oversight agency allows for soil gas or groundwater, you can calculate the required "fail level" and hence, detection level for the compound in either the soil gas or groundwater. Let's try one to see how it works:

From Table 2 of the EPA draft vapor-intrusion guidance, the allowable air concentration for benzene at a 1 in a million risk level is 0.31 $\mu\text{g}/\text{m}^3$. For soil-gas samples collected at 5 feet below the structure, the default alpha factor from Figure 3a of the guidance for sandy soils is 0.002. What is the

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soil-gas "fail level" and what analytical method(s) could be used?

Rearranging the first equation above:

$$C_{\text{soil gas}} = C_{\text{indoor}} / (\alpha_{\text{sg}}) = 0.31 / .002 = 155 \mu\text{g}/\text{m}^3$$

From Table 1 in this article, we see that all the methods can reach this detection level.

But, for sub-slab sampling, the EPA draft vapor-intrusion guidance uses a default alpha factor of 0.1. Now what is the soil-gas "fail level" and what methods suffice?

Answers:

Soil-gas "fail level" = 3.1 $\mu\text{g}/\text{m}^3$

Analytical methods = 8260 SIM, TO14, or TO15

■ What is the EPA vapor-intrusion "dead zone"?

Well, to be honest, it's my own term to describe the lack of direction in EPA's draft vapor-intrusion guidance on what sampling to do between 5 feet and the sub-slab (in review of this article an EPA representative called it the "No Predictive Modeling Zone"). This amounts to a 4 1/2' gap in the vadose zone where there is no instruction. And yet, this is an important zone.

A number of key processes influencing the soil-gas concentrations are active in this zone, including bioattenuation, surface reaeration, barometric pumping, and infiltration of surface precipitation. Vertical profiles of soil gas adjacent to or under structures can be very informative and demonstrate that attenuation of the contaminant is occurring. Agencies should allow and encourage these data. The San Diego County Department of Environmental Health (DEH) is currently writing regulatory guidance and protocols for the "dead zone."

■ What is your opinion on sub-slab vs. near-slab sampling?

The default approach right now by some agencies is to collect sub-slab soil-gas samples and apply an alpha factor of 0.1 to 0.01. But sub-slab sampling has its share of problems.

Operationally, sub-slab sampling is easy to do. But for the responsible

party (RP), sub-slab sampling can definitely be a "Prozac moment." First, sub-slab sampling is much more intrusive than outside sampling and, more likely than not, will require access agreements and attorneys, especially if you are an RP with deep pockets. Second, the proper alpha factor to apply is not known, so the significance of detected values is not clear, and you may over exaggerate the risk. Third, sub-slab data alone give you no information on what is going on below in the vadose zone towards the source.

For these reasons, I typically recommend that clients refrain from sub-slab sampling at the start. Instead, I prefer to collect soil-gas data around the structure for an underlying source (e.g., groundwater contamination), or on the side of the structure towards the source for a lateral source (e.g., adjoining groundwater or soil contamination or a vapor cloud), in an attempt to demonstrate there is no potential risk. If oxygen levels are high, groundwater levels are not within two feet of the structure (e.g., basement, slab, crawlspace), and areas for air penetration exist around the slab (e.g., lawns and gardens), then chances are high that reaeration is occurring under the slab, and near-slab data will be representative of sub-slab, especially for residences with small slabs.

Remember also that contaminants in the vapor phase, like balls and groundwater, cannot run uphill and accumulate under a slab at higher concentrations than the source concentration. In other words, the very highest the sub-slab soil-gas concentration can be is the same as the soil-gas concentration at the source. So, assuming a groundwater source, if you measure the soil-gas concentration just above the groundwater, the sub-slab concentration can be no higher, even with preferential pathways. If the risk calculation passes using this measured value, you need not collect sub-slab samples.

Likewise, if you measure the soil gas midway between the source and structure, the soil-gas concentration will be approximately one-half the source concentration assuming a homogeneous vadose zone with no advection. So if measured values all

around the structure at the mid-depth agree, and the risk calculation passes by more than a factor of two, sub-slab sampling is likely not necessary unless you have reason to suspect a preferential conduit.

If you must go sub-slab, try to stay in garages (if technically sound) to do so. And remember, collect enough samples to get a representative value under the slab. EPA recommends three sub-slab samples per domestic residence to characterize spatial variability, although I personally think one per side and one in the middle is better (total of five).

■ What's this I'm hearing about using radon gas as a natural tracer?

As mentioned previously, the difficulty with sub-slab soil-gas data is that the alpha factor is not really known and regulatory default values tend to be conservative, so use of them may overestimate the risk. Measurement of naturally occurring radon inside the structure and sub-slab can allow a site-specific alpha factor to be calculated that may be considerably less than the value allowed by the regulatory agency. That same alpha factor can then be used to estimate the indoor air concentration of the contaminant of concern, assuming that all vapors are entering the building at equal rates.

Keep in mind that like all the other tools being used for vapor-intrusion assessment, radon has its limitations too. First, and perhaps foremost, you must have radon in high enough concentrations to be useful. Then there's a host of other questions: Are there any inside sources of radon (e.g., cement block, granite stone, and shower water)? How will the values vary with barometric pressure fluctuations? From season to season? And remember, indoor and sub-slab samples create access headaches. Nevertheless, if you are already collecting sub-slab samples, concurrent collection of radon data may prove useful, and it does not cost a great deal (<\$100 per sample).

■ Are hydrocarbons really bioattenuating in the shallow vadose zone, or is it propaganda by the oil companies in an attempt to minimize their vapor-intrusion problems?

A vast number of studies have been performed that clearly demonstrate

the bioattenuation of hydrocarbon vapors in aerobic soils. Many, but not all of these studies, were performed by the oil industry (go to www.API.org to read published studies). In general, the studies show that when oxygen levels are 10 percent or greater and at least two feet of vadose zone exists between the contaminant source and the overlying structure, the hydrocarbons aren't likely to pose an unacceptable risk. (A published study by the New Jersey Department of Environmental Protection suggested oxygen levels as low as 6 percent are sufficient).

While there is a current effort to try and quantify the bioattenuation process and add a quantitative term to the existing models, it is more likely to expect that the bioattenuation rate will be extremely site dependent. The more accepted alternative is to document that this process is occurring by collecting vertical profiles of the soil gas for the hydrocarbons, oxygen, and carbon dioxide.

If shown to occur, some agencies are conservatively allowing a factor of 10 to 100 reduction in the alpha factor. EPA-OUST currently has a technical workgroup consisting of EPA and state regulators studying this issue with the intention of preparing guidelines or recommendations on assessing vapor intrusion at hydrocarbons sites.

To document that bioattenuation is occurring, I recommended that data be collected at a minimum of three locations vertically in the upper vadose zone to ensure that vertical variations are characterized adequately. If repeated data are desired, install vapor-monitoring wells (implants) for easy resampling.

■ What are the best current documents, including regulatory, on soil-gas collection for vapor intrusion?

- The most comprehensive regulatory document for the collection of soil-gas samples was written by California EPA (Department of Toxic Substance Control) in conjunction with the Regional Water Quality Control Board in January 2003.

http://www.dtsc.ca.gov/PolicyAndProcedures/SiteCleanup/SMBR_ADV_activesoilgasinvst.pdf

- The San Diego County DEH Site Assessment Manual has soil-gas

collection guidelines for a variety of soil-gas applications, including upward vapor risk. These guidelines are not step-by-step protocols, but they present general issues that need to be considered and fulfilled.

http://www.sdcounty.ca.gov/deh/lwq/sam/vapor_risk_assessment_2000.html

- The API has written a soil-gas sampling document and has a number of papers on bioattenuation, J-E model, and other related topics.
<http://www.api.org/bulletins>
- EPA-ORD (Dr. Dominic DiGiulio) recently released a sub-slab soil-gas sampling standard operating procedure (SOP) that is available on the following Web site: (<http://iavi.rti.org/resources.cfm?pageID=document>).
- SOPs for vapor monitoring well/implants installation, sub-slab soil-gas sampling, deeper soil-gas sampling, and flux-chamber sampling are available on my Web site, as well as links to most of the above documents and Parts 1 and 2 of this series of LUSTLine articles.
www.HandPmg.com

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Blayne Hartman, Ph.D., is a partner of H&P Mobile Geochemistry (formerly HP Labs), a firm offering on-site sampling and analysis. He has lectured on soil vapor methods, data interpretation, and vapor intrusion to over 20 state agencies, to all of the U.S. EPA regions, and the DOD. Blayne has authored chapters in four textbooks on soil vapor methods and analysis. He has contributed more than ten articles to LUSTLine since 1997, and this is his fifth article on vapor intrusion-related issues. Blayne can be contacted at bhartman@HandPmg.com or check out his Web site at www.HandPmg.com.
