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Vapor Intrusion Basics

By Larry Schnapf

Until recently, federal and state remedial programs have focused on identifying and addressing contaminant concentrations in soil and groundwater. The upward migration of contaminated vapors from soil or groundwater into indoor air was generally not considered to be a significant potential exposure pathway. As a result, cleanup remedies usually focused on reducing soil or groundwater contamination or at least eliminating the pathways of exposure to the contaminated media. The exception to this rule was radon gas in certain parts of the country, gasoline vapors associated with large fuel leaks, or migration and accumulation of explosive levels of methane gas from former landfills.

The past decade has witnessed a huge transformation in the way that contaminated properties have been cleaned up. The EPA and most state brownfield programs adopted risk-based cleanup approaches that permitted residual contamination to remain at a site depending on the nature of the land use and allowed the use of institutional controls to prevent exposure to the residual contamination.

These developments stimulated the reuse of contaminated properties by expediting remediation and reducing cleanup costs. However, owners of these sites may now find themselves subject to additional cleanup because the potential for vapor intrusion may not have been evaluated when the cleanup was completed. For example, the New York State Department of Environmental Conservation ("NYSDEC") recently announced that it would re-examine approximately 430 sites contaminated with chlorinated solvents that had been remediated before 2004.

Like the NYSDEC, the EPA and many state environmental agencies have been increasingly focusing on vapor intrusion in the investigation and remediation of contaminated sites. Because the science behind vapor intrusion is rapidly evolving and the preferred technical approaches for addressing the issue vary considerably from state to state, owners and operators of contaminated sites are finding themselves subject to costly delays and much uncertainty as they try to satisfy the ever-changing regulatory requirements. In addition, responsible parties who thought they had completed remediation at sites and received "no further action" letters are now finding themselves subject to additional investigation and remedial obligations. Moreover, the potential for vapor intrusion is creating potential exposure for third-party claims for personal injury and property damage.

Vapor intrusion may present new terms and technical concepts that may be unfamiliar even to experienced environmental lawyers. For example, contamination is usually expressed in terms of mass (e.g., parts per million, parts per billion). For vapor intrusion, the key measurement will be contamination per volume of air, which is expressed in terms of micrograms per cubic meter (mcg/m3).

Some of the key issues that lawyers and consultants must be prepared when addressing vapor intrusion are as follows:

- How to determine if there is a potential for vapor intrusion;
- How to investigate the extent of a potential vapor intrusion issue;
- How to determine the appropriate action level (for example, OSHA vs. state health-based standard);
- When to proceed with further investigation or when to simply implement mitigation;
- How to determine if mitigation is sufficient or if more extensive remediation is necessary;
- When and how to communicate with occupants and adjacent property owners or operators about potential vapor intrusion issues;
- How to evaluate if the current or proposed mitigation system is adequately designed to protect the health of building occupants; and
- What kind of long-term operation and maintenance systems should be established?

Concern over the potential migration of gases buildings is not new. For decades, developers have had to address potential health and safety dangers posed acute or short-term build-up of explosive or flammable vapors in buildings in certain locations as well as less dangerous levels that resulted in odor or aesthetic complaints. For example, if a structure was to be located in an area methane gas was prevalent or to be constructed near on or near a former municipal solid waste landfill where methane from which methane might be able to migrate, the developer would normally determine if there was a potential for the methane gas concentrations to infiltrate a building and reach its lower explosive limit (LEL) of 5%. If there was a potential for methane gas concentrations to enter a building and approach the LEL of 5%, the builder would incorporate design features into the building to prevent accumulation of methane gas. Similarly, if floating petroleum fuel identified near a building posed a risk that flammable vapors or began entering a building from a rising water table, the developer would implement emergency response measures to mitigate the risk of flammable vapors accumulating in the building.

What is different and challenging about the VI pathway is that it involves risks not from acute exposure but from chronic or long-term exposure to extremely low levels of contaminants that are usually below detectable odor thresholds.[1] The low levels of contaminants are difficult to sample because the action thresholds approach laboratory detection limits. Even when the presence of vapors can be accurately samples, it may he hard to distinguish vapors attributable to sub-surface contamination from background levels resulting from naturally sources or from chemicals commonly used in buildings and workplaces, combustion of fossil fuels for heating purposes, and even air pollutants in the ambient or outside air[2].

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[1] It is commonly believed that humans should be able to smell odors at sites with petroleum-contaminated sites before dangerous levels of benzene vapors can accumulate in a building. In contrast, vapors of chlorinated solvents can generally exceed health-based action levels for indoor without being detected by human olfactory senses.

[2] For example, in many urban areas, ambient levels of a compound (e.g., benzene) may exceed allowable risk based levels established for the VI pathway.

1. What is Vapor Intrusion?

Vapor intrusion (VI) refers to the transport of vapors from subsurface soils or groundwater into buildings through the natural exchange of air or mechanical ventilation systems. To develop a vapor intrusion problem, there must be a source of contamination and a pathway for entry of the contaminants into a building.

The VI pathway is one of the exposure pathways that are considered when performing risk assessments or selecting a remedial action for a site. Until recently, state and federal remedial managers did not focus on the vapor intrusion VI pathway when selecting remedial actions or cleanup standards. However, the VI pathway is now fast becoming one of the critical factors in the remedy selection process for sites that are contaminated with chlorinated solvents or petroleum fuels.

The source of the vapors can be from contamination in the soil, dissolved in groundwater or that exists as a separate phase with the groundwater known as a non-aqueous phase liquid (NAPL) such as gasoline floating on the top of the water table (LNAPL) or chlorinated solvents that sink and exist as a dense non-aqueous phase liquid (DNAPL) at the bottom of an aquifer. Once these contaminants are introduced into the subsurface, they may move as a vapor through the soil and into building structures.

The VI pathway is complex and not well understood by regulators or environmental consultants. The potential for vapor intrusion is dependent on highly variable, site-specific factors. To accurately assess the VI pathway, it is often necessary to employ a multi-disciplinary team that should include an indoor air specialist or certified health technician, a toxicologist or risk assessor and a professional with expertise in collecting indoor air measurements. Because of the uncertainty surrounding the VI pathway, it is important that environmental lawyers be actively involved in examining the critical assumptions and judgments that are used to support decisions involving the VI pathway. This will, of course, require lawyers to become familiar with the variables involved the vapor pathway as well as new terminology.

In general, contaminated vapors want to move from areas of high concentration (e.g., groundwater) to areas of low concentration (building interiors). Buildings where there is porous fill material or soil beneath the building, high concentrations of contamination, and either shallow contaminated groundwater or contaminated soil just below the building foundation or slab will generally be more prone to vapor intrusion. As a result, the potential for vapor intrusion is highly site specific and will depend on such variables as:

- Type of contaminant;
- Concentration of the contaminant;
- Depth and location of the contamination;
- Nature of the soil;
- The pathway of exposure; and
- Building design.

In general, contamination levels will significantly reduce as they move from one media to another (e.g., from groundwater to soil). Thus, contamination that is dissolved in groundwater must be present at higher concentrations to present a potential for vapor intrusion than contamination in soil. The potential for vapor intrusion may also vary by season. For example, contaminants will be more volatile when temperatures are warmer.

2. Regulatory Background

Since state and federal remedial programs were established in the late 1970s and early 1980s, the remediation goals have traditionally been established based on minimizing direct exposure to impacted soil or groundwater or restoration of the impacted resources (e.g., attaining drinking water standards known as Maximum Containment Levels or MCLs, eliminating or reducing sources of soil contamination). In most cases, the potential for inhalation of vapors migrating from shallow soil or groundwater contamination was not considered in cleanup decisions. As a result, cleanup remedies usually focused on reducing soil or groundwater contamination or at least eliminating the pathways of exposure to the contaminated media. The exception to this rule was if regulators became of information indicating that indoor air contaminants posed an acute risk to occupants of a building, if there were odor complaints such as with petroleum-contaminated sites, or where there was a risk of explosion such as buildings constructed over former landfills or petroleum-producing areas that generated significant quantities of methane gas.

However, the 1990s witnessed a paradigm shift in the remediation of contaminated properties. EPA and most state brownfield programs have adopted risk-based cleanups where cleanup levels are based on the actual as opposed to theoretical risks posed by contaminants. Risk-based decision-making may permit residual contamination to remain at a site depending on the nature of the land use and allow the use of institutional or engineering controls to prevent exposure to the residual contamination. While this approach has stimulated the re-use of contaminated properties by expediting remediation and reducing cleanup costs, regulatory agencies are now increasingly focusing on vapor intrusion as a concern that must be addressed during investigation and remediation of contaminated sites. Regulators are not only focusing on vapor intrusion at sites that are being actively remediated but are also beginning to re-examine completed cleanups at sites where the VI pathway was not explored or fully delineated. [3] As a result, owners of these sites may now find themselves subject to additional cleanup because the potential for vapor intrusion may not have been evaluated when the cleanup was completed.

In 1992, EPA issued its first guidance document to assess indoor air impacts in buildings located near superfund sites.[4] This guidance recognized that sampling indoor air in all structures impacted or potentially impacted by contaminants from superfund sites would be an enormous undertaking and be of limited value because the sampling would represent a snapshot of conditions existing at the time of the sampling and might not be representative of conditions at other times of the year. The guidance discussed a variety of models that could be used to estimate exposures to contaminants migrating from soils, groundwater or ambient air including the Johnson & Ettinger model (the "J&E Model")[5]. The guidance also discussed various

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[3] For example, the New York State Department of Environmental Conservation (NYSDEC) recently announced that it would re-examine approximately 430 sites contaminated with chlorinated solvents that had been remediated prior to 2004. In addition, EPA announced it institutional control tracking system (ICTS) for its Superfund program where it will begin reviewing nearly 900 Construction Complete (CC) sites to evaluate the effectiveness of institutional controls (ICs) at those sites. This review will include evaluating adequacy of engineering controls intended to address the VI pathway.

[4] EPA 451/R-92-002 “Air/Superfund National Technical Guidance Study Series: Assessing Potential Indoor Air Impacts for Superfund Sites.” (September 1992).

[5]

sampling and monitoring methods as well as reviewed case studies illustrating the challenges and lessons learned for various vapor intrusion scenarios.

In 1994, EPA's Office of Underground Storage Tanks (OUST) worked with the American Society for Testing and Materials (ASTM) and the American Petroleum Institute (API) to develop risk-based corrective action (RBCA).[6] The RBCA practice did provide for estimating indoor air concentrations of volatile compounds found in soil or groundwater using a form of the J&E Model. However, because petroleum compounds bio-grade fairly rapidly, the common belief was that impacts from sub-surface petroleum contamination would attenuate before reaching buildings within proximity of the contamination.

Many states and EPA adopted this approach and allowed responsible parties to simply model the VI pathway instead of collecting indoor air samples even for contamination involving chlorinated solvents. For example, EPA's 1996 guidance establishing generic soil screening levels for volatile organic compounds ("VOCs") set forth specific equations for evaluating the groundwater to indoor air pathway. [7]

EPA also referred to vapor intrusion in supplement guidance for its Human Exposure Environmental Indicators ("EI") determination[8] for measuring progress under the Resource Conservation and Recovery Act (RCRA)[9] corrective action program. The states that did evaluate vapor intrusion usually predicted potential indoor air concentrations based on groundwater concentrations. If groundwater was below 15 feet in depth, evaluation of the vapor pathway was generally not required.

In September 1998, EPA developed a series of models for estimating indoor air concentrations and associated health risks from subsurface vapor intrusion into buildings. These models were based on the analytical solutions of Johnson and Ettinger (2001) for contaminant partitioning and subsurface vapor transport into buildings. These models were subsequently revised a series of new models have been added.[10]

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[6] E 1739 – 95, *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*. EPA subsequently issued its own RBCA guidance "Use Of Risk-Based Decision-Making In UST Corrective Action Programs" OSWER Directive 9610.17 March 1, 1995.

[7] *Soil Screening Guidance: User's Guide (* EPA540/R-96/018 July 1996).

[8] *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 (CA 725)" Current Human Exposures Under Control"*. Under the Government Performance and Results Act (GPRA), EPA had established a goal of controlling human exposure at 1741 RCRA corrective action sites by 2005.

[9] 42 U.S.C. 6901 et seq.

[10] EPA modified its guidance in 2000 and in February 2004. The revised "User's Guide for Evaluating Subsurface Intrusion into Buildings" includes new values of intermediate variables for estimating the soil vapor permeability and the degree of water saturation in the capillary zone above the water table. In addition, new human health benchmarks have been added for some chemicals and revised for others. Finally, a series of automatic checks have been added to the models to prevent the use of inappropriate initial soil or ground water contaminant concentrations (i.e., soil concentrations greater than the soil saturation concentration or ground water concentrations greater than the solubility limit). The 3-phase soil contamination models evaluate three discrete phases: 1) in solution with water, 2) adsorbed (attached) to the soil organic carbon, and 3) in vapor phase within the soil air-filled pores. The 3-phase models replace the old models previously available on this website. These models are applicable when NAPL is not present in subsurface soils or in ground water. Two new soil gas models have been added allowing the user to estimate vapor intrusion into buildings from measured soil gas data.

When NAPL is present in soils, the contamination includes a fourth or residual phase. In such cases, the new NAPL models can be used to estimate the rate of vapor intrusion into buildings and the associated health risks.

The regulatory landscape changed after significant levels of chlorinated solvents in the form of trichloroethylene ("TCE") and dichloroethylene ("DCE") were found in homes near the Colorado Department of Transportation Materials Testing Laboratory site (also known as the Redfield Rifle field Scopes Site) in Denver, Colorado in 2000.[11] The elevated levels were detected even though the J&E model EPA had predicted little or no contamination. This discovery led EPA and state agencies to re-examine their policies toward vapor intrusion. In December 2001, EPA issued its Supplemental EI Guidance[12]

Since then, state and federal regulators have begun to move away from modelling as the preferred method of assessing the VI pathway to the use of look-up tables and collection of air measurements. EPA issued draft technical guidance in November 2002 that was designed to provide regulators and responsible parties with procedures for screening sites to determine if the VI pathway was complete and assessing if the pathway presented an unacceptable risk to human health.[13] The guidance was not intended as a tool for evaluating the extent of the risk or for eliminating the risk. EPA also recommended that the guidance be used not just for the RCRA corrective action program but also for Superfund and brownfield sites. For UST sites, EPA recommended that regulators and responsible parties continue to use the agency's RBCA guidance.[14]

This draft 2002 guidance superseded the draft RCRA EI Supplemental Guidance but does not supersede State guidance. However, EPA believes that states will find this guidance useful and anticipates that states will consider this draft guidance when evaluating the VI pathway. Additionally, the lead regulatory authority for a site may determine that criteria other than those recommended in this draft guidance are more appropriate for the specific site or area. For example, site-specific indoor air criteria may differ from the generic indoor air criteria generally recommended in this guidance and, consequently, the corresponding soil gas or groundwater screening levels may differ. Also, the site-specific relationship between indoor air concentrations and subsurface soil gas or groundwater concentrations may differ from that assumed in developing this guidance. Therefore, EPA suggested that the parties performing remediation should first consult with the lead regulatory authority to identify the most appropriate approach for evaluation of any potential vapor intrusion to indoor air pathway. In addition to revising its technical guidance, EPA also tightened the acceptable exposure limits for TCE. [15]

Dozens of states have revised or are in the process of revamping their remedial programs to address vapor intrusion. In the fall of 2004, the Interstate Technology and Regulatory Council's (ITRC) Vapor Intrusion Team developed and conducted an on-line survey of state, federal, and tribal agencies regarding vapor intrusion regulations, policy, and guidance. 88% of

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The new NAPL models use a numerical approach for simultaneously solving the time-averaged soil and building vapor concentration for each of up to ten soil contaminants. This involves a series of iterative calculations for each contaminant.

[11] In December 2003, a jury awarded homeowners near the site approximately $1 million in damages after a 12-week trial.

[12] Draft RCRA EI Supplemental Guidance for Evaluating the Vapor Intrusion To Indoor Air Pathway (December 2001).

[13] Draft Guidance For Evaluating the Vapor Intrusion To Indoor Air Pathway From Groundwater And Soils (Subsurface Vapor Intrusion Guidance), 67 FR 71169 (November 29, 2002)

[14] OSWER Directive 9610.17: Use of Risk-Based Decision Making in UST Corrective Action Program"

[15] At the time of this writing, EPA is in the process of revising its 2002 vapor guidance.

the respondents indicated that VI was being addressed by their remedial programs and 87% indicated the VI programs were being implemented through guidance and not through formal regulations. Of the 88% of the respondents that indicated that VI was being addressed by their remedial programs, 25% reported indicated that their agency had 50 sites or more where vapor intrusion was being investigated and another 25% indicated they had between 25 and 50 VI sites. One-third of the respondents reported that their agency had a vapor intrusion policy or guidance in place and 40% indicated that they relied on EPA vapor intrusion guidance.

3. Key VI Terms

Like any field of science, vapor intrusion comes with its own terminology and laws. Following are some of the key terms that parties should be familiar with to understand the VI Pathway.

- **Advection-** This term refers to horizontal movement of air.

- **Attenuation or Alpha Factor-** This is the amount of dilution that will occur as a contamination moves from one environmental media to another. The alpha factor (α) is the ratio of the indoor air concentration to either a subsurface soil gas concentration (αsg) or to a groundwater concentration (αgw). Alpha factors can be used to calculate risk-based screening levels (RBSLs) for soil gas and groundwater. Lower alpha factors mean higher allowable contamination levels and can make the difference between passing or failing the vapor intrusion risk assessment.

- **Capillary Fringe-** This is the portion of the soil column above the water table (saturated zone) where water has risen by due to molecular attraction between water and soil particles so that the water occupies some or all of pore spaces or voids between soil particles. The capillary fringe will be higher in finer grained soils but lower in soil consisting of gravel or coarse sands.

- **Convection-** This term refers to the vertical movement of air due to unequal heating or cooling of air.

- **Diffusion-** This is the principal mechanism that causes contaminants to move from one media to another. In general, contaminants will move by molecular diffusion from an area of high concentration to low concentration. Diffusion occurs in three dimensions so contaminants move away from a contaminant source in all directions, similar to an expanding balloon.

- **Flux-** This term refers to the directional movement of contaminants in environmental media. The flux will always be from a high to low concentration.

- **Milligrams per cubic meter (mg/m3)** - This refers to the quantity of contaminants in a particular volume of air. May also be expressed in PPBv (parts per billion, volume) or PPMv (parts per million, volume).

- **Permeability**- This refers to the relative ease that water may flow through rock or soil. The property will determine the rate of groundwater movement.

- **Porosity-** This term refers to the total volume of pore space within bedrock or soil and is an indication of the ability of the rock or soil to hold water. Soil gas can travel more easily in soil with more pore spaces.

- **Saturated Zone-** This is the portion of the soil column where all of the pore space or voids between soil particles are filled with water.

- **Vadose Zone or Unsaturated Zone-** This is the portion of the soil column between the land surface and the water table where the pore space between the soil particles is primarily occupied by air. The vadose zone can include the capillary fringe and perched water.

- ***Note: C****ontaminants move through the vadose zone by molecular diffusion at a rate of 800 cm/yr (approximately 25 ft/yr or 1 inch a day). This calculation suggests that contaminant vapors can move long distances through the vadose zone in a short period of time. Within a few years, vapor contamination can move laterally underneath a neighboring room or building, or downward to the groundwater surface. In contrast, contaminants move through liquid 100 times slower because the diffusion coefficient for liquids is 10,000 times lower. Thus, volatilization of contaminants out of an undisturbed water interface (e.g., groundwater) is glacially slow and typically orders of magnitude below equilibrium conditions. This is a crucial concept to remember when using groundwater data to calculate soil gas concentrations. Calculated soil gas values will nearly always be over estimated.*

- **Partitioning-** This refers to the ability of contaminants to move from one environmental media to another. Contaminants will partition or volatilize out of groundwater much more slowly than from soil to estimates of contaminants in soil gas from groundwater data are likely to be over-estimated.

- **Soil Gas**- This refers to the air between soil particles.

4. Factors that Influence Vapor Intrusion

The factors that influence the movement of vapors from the subsurface soil or groundwater into buildings can be very complex. Buildings where there is porous fill material or soil beneath the building, high concentrations of contamination and either shallow contaminated groundwater or contaminated soil just below the building foundation or slab will generally are more prone to vapor intrusion.

Contaminants can vaporize from soil and groundwater directly beneath a building or migrate from a preferential pathway such as sewer or utility conduit. Vapors can move from the pore spaces in the soil and infiltrate buildings through cracks in walls or foundations and through open windows or doors. Buildings with dirt floors or crawl spaces, stone foundations and basements will have a higher potential for vapor intrusion since the below-grade spaces create greater surface area for vapors to infiltrate and may be closer to the subsurface source of the contamination. Foundations and subsurface walls constructed from cement blocks may be more prone to vapor intrusion because of cracks around mortar that can allow subsurface vapors to enter the building. A single-pour cement foundation may be more resistant to vapor intrusion than foundations with footers and floors are that are poured separately because of the potential for cracks along stress lines. Buildings with sumps or with gaps around piping or utility lines may also have a higher potential for vapor intrusion.

The deeper the contamination is located, the less likely it is to present a potential for vapor intrusion. Until recently, the conventional thinking was that contamination deeper than 15 feet would not likely present a significant risk of vapor intrusion. However, the new EPA guidance suggests that regulators and responsible parties evaluate the VI pathway when the contamination is within 100 feet of a structure.

The nature of the geology beneath a building can also influence the potential for vapor intrusion. Vapors can migrate through porous soil such as sand much easier than through clayey soils. Likewise, there is a greater potential vapor intrusion when the bedrock below a building is fractured.

A building's mechanical ventilation system can also create a negative air pressure that can draw contaminated vapors from the subsurface into the building. The use of fireplaces, heaters, open windows, air conditioners or wind can also result in building depressurization Newer buildings that have "tight" building design for energy efficiency have a greater potential for accumulation of vapors than older buildings that may have greater exchange rates with the outside air. Moreover, during winter months when fresh air exchange is reduced, the temperature differential between the indoor air of building and the air in the soil can cause a "stack effect" that can draw vapors into a building much like a fireplace draws air from a room. Fortunately, building air-handling system can also be used to mitigate these effects by increasing the air exchange or creating a positive air pressure gradient on the ground floor.

Once inside a building, the principal concern is exposure to occupants through inhalation. In some extreme cases, vapors may accumulate to levels that can pose short-term safety hazards (e.g., risk of explosion), acute health effects or aesthetic problems such as odors (e.g., methane, gasoline). Often though, vapors associated with TCE or PCE may accumulate at low levels that are not below odor thresholds. In such situations, the principal concern is the potential for chronic health effects from long-term exposure to the low concentrations.

Although vapor intrusion may not be an issue at every brownfield site, it can pose significant concerns at sites where volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs) and petroleum fuels may be present. The VI pathway is not limited to existing industrial or commercial structures sites but may have to be addressed at redevelopment projects that located on abandoned landfills or other sites where hazardous substances may have been spilled or disposed.

5. Common Chemicals of Concern

The contamination source can be natural such as radon gas or from human activity such as releases or spills of certain types of hazardous materials. For a vapor intrusion problem to occur, the contaminants must readily volatize into gas at normal atmospheric pressure and temperature, and present health risks at low concentrations.

The EPA has identified 107 compounds that potentially present unacceptable inhalation risk but the principal contaminants of concern tend to be chlorinated solvents such as:

- DCE;
- TCE;
- Tetrachloroethylene (“PCE”);
- Carbon tetrachloride; and
- Vinyl chloride;
- Petroleum contamination (the principal constituent of concern is benzene);
- Mercury;
- polychlorinated biphenyls ("PCBs"); and
- Semi-volatile organic compounds ("SVOCs") associated with diesel fuel and heating oil.

6. VI Regulatory Levels

The EPA and many states have adopted their own indoor action levels that can vary significantly from state to state and within a state depending on the regulatory agency that is supervising the cleanup. Often times, the disparity is a due to different inhalation cancer slope factors or exposure assumptions.

It should be noted that the indoor air action levels for chlorinated solvents involve very low levels that push the limits of most laboratory equipment. Thus, special laboratory tests are often necessary to achieve the very low detection limits required by many chlorinated solvent indoor air action levels. In addition, sampling protocols are laborious, intrusive, expensive, offer little control and samples can easily become contaminated.

Perhaps the principal complicating factor is that many commonly used household products contain some of the target compounds of concern. For example, household cleaners, polishes, adhesives, furniture, carpets, textiles, sealants, glues, paints, waxes, lubricants, heating systems (i.e. fuels), cooking vapors, and personal care products contain VOC that can be identical to the subsurface contaminants and be present in concentrations that exceed indoor air action levels. In addition, many household materials such as wallboard, ceiling tile, carpet, and upholstery can absorb VOCs during high-concentration periods and then release or “off-gas” the compounds when the indoor air VOC concentration decrease of because of changes in temperature or other environmental factors. In some areas, especially urban centers,

Further complicating the problem is that states may use different indoor air standards. 48% of the respondents in the 2004 ITRC Vapor Study indicated that their states had adopted numerical criteria for evaluating the VI pathway yet there was considerable divergence on how those criteria were derived with 10% stating the standards were agency-wide default criteria, 11% were based on regional or published background levels, 14% reporting that they were based on site-specific factors, 25% on land use scenarios, and 29% on human health risk levels

7. Methods for Assessing Vapor Intrusion

There is considerable controversy among regulators whether numeric models such as the J&E Model should be used to extrapolate indoor air concentrations from groundwater or soil vapor concentrations in lieu of air sampling. Some states require some indoor air sampling and will not permit the use of models. Others do not mandate indoor air samples but instead require collection of soil gas sampling from just beneath the slab, which is known as sub-slab sampling. Still others allow a combination of sampling and modelling.

One of the interest findings of the 2004 ITRC study was that a majority of states reported that they did not have written guidance on how to collect samples for vapor intrusion from various environmental media. A majority of states also indicated that they did not have specific laboratory methods for analyzing vapor samples.

The debate over the usefulness of indoor air samples was reflected in the survey results with 32% of the states indicating that they did require

a. Indoor Air Sampling

Indoor air measurement is the most direct measure of human health exposure for the VI pathway. However, this sampling is typically the last method recommended by regulators because of the problems associated with sampling.

Simply detecting VOCs in indoor air may not serve as conclusive evidence that source of the VOCs is the subsurface contamination. Background sources of contamination must be properly assessed when interpreting the data. This typically necessitates the concurrent collection of outdoor ambient air samples. Unless the background levels can be identified and distinguished from the actual impacts from subsurface contamination, regulators may require additional testing program that will go well beyond the impacted area.

For these reasons, the EPA and many states generally recommend collecting indoor air data only after other subsurface environmental samples (e.g. groundwater and soil gas) indicate the need to conduct an internal site-specific assessment, unless there is an immediate need such as odors in the residence. However, sampling may still be the best method to use from the beginning if the contaminant of concern is not one commonly found in household products (e.g., 1,1 DCE) and/or if site conditions do not enable other investigation methods to be used, such as groundwater contacting the foundation.

b. Modelling

Since collecting indoor air samples are not favored by most regulatory agencies, the VI pathway is typically assessed by collecting samples from groundwater, soil phase, or soil gas and then either applying a predictive model or comparing the results to tabulated risk-based screening levels (RBSLs) that in turn were determined from a predictive model. So, some understanding of these models is necessary.

The use of fate and transport models to calculate an indoor air concentration, and in turn a health risk, is commonplace. Existing models use groundwater, soil, or soil gas data and are relatively easy to use. In their simplest form, models are one-dimensional that consider upward diffusion from an underlying source, convective transport into the building, and mixing of contaminant vapors in the building air space. More complex versions also exist that are multi-dimensional and include other processes such as contaminant decay, and the effects of different building construction.

The Johnson and Ettinger (1991) model (J/E) is the most commonly used model for evaluating the indoor air exposure pathway nationwide. In this model, contaminants move through the vadose zone by molecular diffusion from the source until they enter the “building zone of influence”. At this point, the contaminants are swept into the building through foundation cracks by advection due to the indoor – outdoor building pressure differential. The distance of the “building zone of influence” is usually less than a few feet. The J/E model is based on the following assumptions:

- Steady state conditions exist.
- An infinite source of contamination exists.
- The subsurface is homogeneous.
- Air mixing in the building is uniform.
- Preferential pathways do not exist.
- Biodegradation of vapors does not occur.
- Contaminants are homogeneously distributed.
- Contaminant vapors enter a building primarily through cracks in the foundation and walls.
- Buildings are constructed on slabs or with basements.
- Ventilation rates and pressure differences are assumed to remain constant.

To facilitate its use and to avoid errors, EPA has programmed the J/E model into Microsoft EXCEL™ and added a health risk component that calculates the human health risk. New versions of the spreadsheet are being released by EPA in 2006 and offer significant advantages over earlier versions released in 2001 and 2003. The spreadsheets allow the use of either groundwater or soil gas data. Soil matrix data is not allowed in the newest versions. The spreadsheet contains a number of default parameters that can be changed with site-specific values. Typically, agencies will customize the spreadsheet by changing the default values and putting limitations of the parameters that can be changed with site-specific data.

For the majority of vapor intrusion assessments, modelling will be limited to use of these spreadsheets using groundwater or soil gas data to predict a risk or indoor air concentration. Models are also useful to assess the relative significance of changes in a particular input parameter (sensitivity analysis) and as predictive tools to assess future conditions. However, models/spreadsheets have limitations.

For example, if groundwater or soil spreadsheets are being used, the spreadsheet calculates the soil gas concentration assuming equilibrium partitioning. This is likely to give a soil gas concentration significantly higher than actual values.

Also, for petroleum hydrocarbons, the spreadsheet does not take into account potential for bio-attenuation. Thus, the model result will likely be too conservative (i.e., predict higher concentrations than are actually present).

For chlorinated compounds, the spreadsheet is also likely to over predict the risk for the same reason, but not as much since bio-attenuation is not as prevalent. In contrast, if vapors are the source of the site contamination, then the actual soil gas concentration might be higher than calculated from groundwater or soil data, so in turn, the risk will be underestimated (i.e., models will under-predict potential levels of chlorinated solvents).

A vast number of studies have been performed clearly demonstrating that the bio-attenuation of hydrocarbon vapors occurs in aerobic soils. In general, the studies show that when oxygen levels are 5% or greater and at least two feet of vadose zone exist between the contaminant source and overlying structure, that the hydrocarbons are not likely to pose an unacceptable risk.

While there is a current effort to try and quantify the bio-attenuation process and add a quantitative term to the existing models, it is more likely to expect that the bio-attenuation 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 studying this issue consisting of EPA and State regulators from across the country with the intention of preparing guidelines or recommendations on assessing vapor intrusion at hydrocarbons sites.

To document bio-attenuation is occurring, soil gas data should be collected at a minimum of three locations vertically in the upper vadose zone to ensure that vertical variations are characterized adequately. The soil gas samples should be analyzed for the compounds of concern within the petroleum hydrocarbon mixture, such as alkanes, aromatics (BTEX), naphthalene, fuel oxygenates, and possibly PAHs depending upon the type of hydrocarbon contamination (e.g., gasoline vs. diesel vs. oil). In addition, soil gas samples should also be analyzed for oxygen and carbon dioxide and any biodegradation by-products that may pose a health risk.

There are also other scenarios such as where buildings are constructed over bedrock where there is less confidence in the model results. Another area of concern is the use of samples collected from outside a building footprint. There is some evidence that suggests the moisture and oxygen levels may be different below building structures and therefore not accurately predict the potential for vapor intrusion. As a result of the questions about modelling, some states do not allow any modelling at all and require actual indoor air sampling.

c. Groundwater Sampling

Because models tend to over-predict the risk, especially from groundwater and soil data, consultants and responsible parties should always verify the model results with actual field data if they show an unacceptable risk.

At many sites, groundwater monitoring wells and previous groundwater data already exists. These data can then be compared to any applicable groundwater screening levels or used in a predictive model as described previously. If measured values exceed allowable levels or give an unacceptable risk, additional field investigation or mitigation is generally required. If measured values do not exceed allowable levels or give an acceptable risk, additional field investigation may not be required if sufficient coverage exists. Most often, the number of groundwater wells is limited and additional delineation of the ground water contamination is required by the regulatory agency.

If additional groundwater data are to be collected, there are special considerations for vapor intrusion applications that differ from typical groundwater monitoring wells. The primary issue is that concentrations near or at the top of the water table are more relevant to the vapor risk pathway and sampling protocols need to be adjusted to measure this interval. Federal & State agencies have issued guidance and procedures for collecting the installation of groundwater monitoring wells and the acquisition of high-quality groundwater VOC sample data suitable for vapor intrusion assessment. Some of the recommendations are:

- **Proper Screen Intervals**- Contaminants at the top of the water table, rather than deeper contamination, are responsible for causing potential vapor intrusion problems. Hence, monitoring wells used to make vapor intrusion evaluations should be screened across the air-water interface, meaning the well screens should not be submerged below the top of the water table.

- **Proper Screen Lengths**- Monitoring wells with excessively long well screens, regardless of screen placement, should not be used to make vapor intrusion evaluations. When sampling long well screens, clean water entering the well screen at depth may dilute the contaminated groundwater near the top of the screen, biasing the sampling results and the associated risk determination. Hence, short screen lengths are preferred for monitoring wells that will be used to make vapor intrusion evaluations. Ideally, the thickness of the water column in the well should be 10 feet or less. For new water table wells installed as part of a VI investigation, a 5 to 10 foot screen is generally recommended unless this conflicts with other site investigation objectives. Additional construction recommendations are discussed by NJDEP in its vapor intrusion guidance.

- **Proper Well Installation**- Monitoring wells should be designed and installed to yield representative samples of groundwater conditions. Monitoring wells should have proper filter packs, slot sizes, and annular seals. Direct push sampling methods and alternate/temporary ground water sampling techniques are often well suited for VI investigations especially if attempting to determine the depth of the interface between a shallow clean water lens and an underlying plume or for determining vertical gradients. Repeated sampling over time at the same locations may be necessary for some sites to determine if shallow ground water quality has changed due to water table elevation fluctuations or other factors.

- **Proper Well Development-** Monitoring wells should be developed to create an effective filter pack around the well screen, rectify damage to the formation caused by drilling, optimize hydraulic communication between the formation and well screen, and assist in the restoration of natural water quality of the aquifer near the well.

- **Proper Well Purging**- Prior to sampling, monitoring wells should be purged to remove stagnant casing water from the well that is not representative of aquifer conditions. Wells can be purged by removing the traditional three casing volumes prior to sampling or the well can be purged with low-flow techniques as described further below.

- **Proper Well Sampling**- Sampling methods that minimize the loss of VOCs during sample collection and handling are preferred, such as bladder pumps or submersible pumps. Other methods, such as peristaltic pumps and bailers, may cause unacceptable volatilization of chemicals.

d. **Soil Sampling**

Soil matrix data are generally not considered a suitable type of data for evaluating vapor intrusion risk because of the uncertainty associated with calculating soil gas concentrations from soil data, and the potential loss of VOCs during sample collection. There is generally not a good correlation between soil and soil gas data on a consistent basis. Consequently, soil data is typically allowed as a screening or secondary line of evidence in vapor intrusion assessments. This is unfortunate because soil phase data exist at the vast majority of sites.

If soil data already available from previous investigations has delineated the contamination zone, this information can be used to determine what nearby receptors are potentially at risk by the vapor pathway. Soil samples may also be useful to characterize the human health risk associated with other exposure pathways, such as dermal contact and direct ingestion of soil.

When geologic materials have a very low permeability, it may not be possible to collect a representative soil gas sample, in which case soil matrix data may be allowed as an alternate line of evidence in situations where the contamination source is not groundwater, or groundwater samples cannot be obtained. When analyzing soil for VOCs, the soil samples should be collected using procedures specifically designed to minimize volatilization losses as described in EPA Method 5035A.

e. **Soil Gas Sampling**

Measurement of soil gas is the most preferred approach around the country. Actual soil gas data are reflective of subsurface properties, are less expensive than indoor air measurements, and allow real-time results. There are some drawbacks, including the lack of knowledge of the actual transport rate into an overlying structure and debate over how and where to collect samples.

Soil gas samples typically have contaminant concentrations exceeding 100 ug/L (100,000 ug/m3) for hydrocarbons with USTs and chlorinated hydrocarbons near dry cleaners or vapor degreasers. The EPA 8021 and 8260 methods offer higher calibration ranges than the TO methods and are better suited for higher concentrations (>10 ug/L). The TO methods, owing to their higher sensitivity are better suited for lower concentrations (<10 ug/L).

Regardless of the actual analytical method used, the method QA/QC should include second source standards, surrogates, and laboratory control samples (LCS) even if not stated in the written method. The TO-14 and TO-15 methods as written do not include these QA/QC criteria and it should be specified that the laboratory runs this extra QA/QC if these methods are used.

On-site analysis is extremely beneficial for vapor intrusion investigations. It provides real-time detection of VOCs from any preferential vapor migration sources or pathways, allows additional sampling locations to be added (spatially or vertically), allows recognition of spurious data, and enables measurement of the leak-test compound to ensure valid soil gas samples are collected.

Simple portable instruments can provide both qualitative & quantitative data depending upon the compound and the required detection levels. Field screening with hand-held PIDs or FIDs enable rapid screening for preferential pathways around and into structures down to the ppmv range. Quantitative oxygen, carbon dioxide, and methane data are possible from hand-held portable meters for concentrations in the per-cent range.

For lower detection limits, mobile laboratories equipped with laboratory grade instruments, including gas chromatographs and mass spectrometers, are capable of fully quantitative results meeting method required QA/QC and detection limits as low as 10 to 100 ug/m3.

There are three methods commonly employed to measure soil vapor contamination: active, passive, and surface flux chambers.

(1) Passive Soil Gas Sampling

Passive soil vapor methods consist of the burial of an adsorbent in the ground with subsequent retrieval and measurement of the adsorbent. These methods give a time-integrated measurement, and therefore reduce the uncertainty due to temporal variations.

Passive soil vapor methods only yield soil vapor data in terms of mass (e.g., micrograms), not concentration because the amount of vapor that comes into contact with the adsorbent is unknown. While published methods exist that describe the procedures to generate vapor concentration data from a passive sampler in air in the absence of soil, no published data or documents have demonstrated the applicability of the method to soil gas. This is because the gas-phase diffusion constant in the vadose zone is not known. Field studies to calibrate the passive method to actual soil gas concentrations are still too limited to validate the use of this method for quantitative soil gas concentrations. For this reason, passive soil gas is presently considered to be a qualitative tool and not applicable for stand-alone assessment of the VI pathway.

Passive soil gas sampling can be an effective tool in vapor intrusion assessments. Passive methods offer a quick and relatively inexpensive method to find preferential pathways into a structure or around a structure, such as utility corridors. The composition of subsurface soil gases can be determined from passive soil samples and the location of subsurface plumes can be mapped, particularly edges of plumes to determine if contamination is near current or future buildings. Passive soil gas sampling methods can also be useful in situations where active methods may not be applicable, e.g., areas of low-permeability and high-moisture settings. Further, they are capable of detecting and reporting compounds present in very low concentrations.

(2) Flux Chamber

Flux chambers are enclosures that are placed directly on the surface (ground, floor, etc.) for a period of time and the resulting contaminant concentration in the enclosure is measured. An effective room concentration is easily calculated from the measured flux, which can be compared directly to allowable room concentrations for the VOC of interest.

This method offers advantages in some cases because it yields the actual flux of the contaminant out of the ground, which eliminates some of the uncertainty when using other types of subsurface data. The method has long been used by regulatory agencies at hazardous waste sites and it is widely used for measuring trace emissions from natural soils, but its application to vapor intrusion assessments is relatively limited.

The testing is typically conducted in one of two modes: static or dynamic. In dynamic systems, a sweep gas is introduced into the chamber to maintain a large concentration gradient across the emitting surface. The effluent air from the chamber is collected using canisters and analyzed for chemicals of concern. The method is best suited for situations where large fluxes are anticipated. In static systems, a chamber is emplaced and the contaminant concentration build-up is measured over time. This method is best suited for situations where lower fluxes are anticipated.

Flux chambers are best suited for situations where measurement from bare soils is desired, such as:

- Homes with dirt basements or crawl spaces.
- Mobile homes above unfinished slabs or soil.
- Evaluation of future use scenarios at sites without existing buildings.
- To demonstrate the occurrence of bio-attenuation from areas with shallow soil gas contamination (<5' bgs)

Flux chambers are less applicable to existing structures because the preferred vapor entry points are unknown. In many structures, the primary entry of soil gas into the structure is through discontinuities in the floor slab (cracks, holes, sumps, etc.) and floor coverings, walls, stairs, etc often conceal these locations. Thus, there is uncertainty whether they can be placed in the proper locations in an existing structure, especially residences. The method has more application to larger industrial and commercial buildings with slab-on-grade construction where the slab is mostly uncovered. Flux chambers can also be used as a qualitative tool to locate surface fluxes of VOC contamination and entry points into structures.

Regardless of the method used, enough chamber measurements should be collected to get a representative value under 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 cracks or conduits, and over the center of the contamination if known. 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 upon the conditions; 24 hours if large temperature differences exist between day and night).

(3) Active Soil Gas Sampling

Active soil gas method is generally most commonly used approach for vapor intrusion and consists of the drawing soil vapor from the subsurface. The analysis is provided by volume (e.g., ug/m3) that can be directly compared to risk based screening levels or used in predictive models.

Regulators generally prefer soil gas data over soil or groundwater data because soil gas data represent a direct measurement of the contaminant that will migrate into indoor air. Soil and groundwater data is reported in mass per unit ("ppb", mg/km) and must then be converted to volumetric readings. In addition, the results must be extrapolated using assumptions about the partitioning of the contaminant into the gas phase. While partitioning equations are readily available, using them increases the uncertainty in evaluating vapor intrusion. Actual soil gas data are reflective of subsurface properties, are less expensive than indoor air measurements, and allow real-time results.

Since soil gas sampling is relatively new for most regulators and consultants, and little regulatory guidance exists, this section will summarize some of the primary topics and issues that should be considered when collecting and analyzing soil gas samples for vapor intrusion assessments. Soil gas methods for vapor intrusion applications require much greater care than techniques historically used for typical site assessment applications because risk based concentration levels are so low (1,000 to 10,000 times lower than concentration levels previously of concern).

There are two types of soil gas samples that are generally collected:

- Soil gas samples collected underneath structures (sub-slab samples).
- Soil gas samples not collected underneath structures (beyond the building footprint or alongside the building foundation).

The EPA vapor intrusion guidance recommends that VI be evaluated when soil or groundwater contamination is found within 100 feet horizontally or vertically of a building's foundation. According to the 2004 ITRC VI study, 65% of the respondents indicated that their agencies have not established guidance for how for away to collect VI sampling. As a result, sampling protocols may be based on the professional judgment of a regulator or an environmental consultant.

The following criteria may influence where soil gas samples may be collected:

- The location of the contamination source relative to the receptor;
- The depth of the contamination source;
- The type and construction of the receptor;.

If the contamination source is not directly below the receptor, samples should generally be collected between the structure and the source at a depth that is deep enough to give repeatable results (3' to 5' bgs). Samples should also be collected from any known preferential pathways connecting the source to the receptor, such as sewer lines.

If the source is both below and to the side of the receptor (e.g., a groundwater plume from an adjacent source flowing under the receptor), samples should be taken from the upgradient side of the structure before going inside the structure. Consultants may use spatial averaging (collecting samples from all sides of a structure) to get a better representation of what exists below the structure and then average the results to obtain a value of vapors below the structure footprint. If the source is only directly below the receptor, sub-slab samples are likely to be required by the agency in most cases.

The closer samples are collected to the surface, the greater the chance that surface processes such as atmospheric pumping, precipitation, and influence from structures will affect the soil gas concentrations. Thus, it is generally advisable to collect samples at 3' to 5' below ground surface (bgs) to get below this zone of influence. If the contamination source is at deeper depths, there may be no need to collect deeper soil gas samples if the initial results at 3' to 5' do not indicate a problem.

With petroleum hydrocarbons, bio-attenuation can often occur within the upper 5 feet or vadose zone when there is adequate oxygen exchange. Vertical profiles of the soil gas in the upper 5 feet can document this process.

Vertical profiles also will aid in determining the direction of a contaminant source if it is unknown and in establishing an attenuation factor due to the vadose zone. This can be useful for chlorinated solvent sites and for sites with both surface and deep sources.

Some sites have surface or near-surface sources of contamination, such as dry-cleaners or product lines at service stations. At these locations, it is often best to sample right below the slab or the outside asphalt parking lot, rather than from deeper depths.

Collecting Soil Gas Samples

The draft EPA vapor intrusion guidance and many states strongly suggest collection of sub-slab samples instead of samples collected directly beneath a foundation because of a concern that contaminants could accumulate directly below a building which is referred to as the "ponding effect" due to some of the factors previously discussed (stack effect, under-pressurization, warmer temperature beneath the building, etc)..

However, contaminants in the vapor phase cannot accumulate under a slab at higher concentrations than the source concentration. If the soil gas concentrations at the source are below regulatory levels for sub-slab samples, then sub-slab samples should not be necessary. In areas of shallow groundwater (<25'), soil gas samples at the interface around the structure should be readily obtainable.

If oxygen levels around the foundation are high, groundwater levels are below the foundation, adequate soil porosity exists, and areas for air penetration exist around the structure (e.g., lawns & gardens), then the chances are high that re-aeration is occurring under the slab and near-slab data will often be representative of sub-foundation, especially for structures with small slabs such as single family homes and if the contamination is petroleum hydrocarbons.

While sub-slab sampling is fairly easily to accomplish, the process can be much more intrusive from the perspective of a building occupant or homeowner. In addition, sub-slab sampling generally requires access agreements and could raise concerns that the building owners or occupants may be more likely to bring claims for personal injury or property damage.

Allowable sub-slab concentrations are typically determined from a target indoor value and an attenuation factor If the proper attenuation factor is not known, the significance of the detected values may not be clear and this can prompt regulatory agencies have set very conservative allowable levels.

It is important to note that detecting sub-slab soil gas concentrations does not necessarily indicate if the vapor intrusion pathway is complete (occupants are being exposed to vapors). The presence of elevated contaminant vapors in the sub-slab soil gas is generally considered a screening indicator of vapor intrusion. For these reasons, it is often beneficial to refrain from sub-slab sampling at the start and collect near-foundation samples. In many situations, soil gas samples near the foundation will give adequate information and preclude having to go inside the structure.

Special considerations for sub-slab soil gas samples include:

- Sub-slab samples should be avoided in areas where groundwater might intersect the slab.
- Underground utilities (e.g., electric, gas, water or sewer lines) might be located within or below the slab.

- If a vapor barrier already exists under the slab, sub-slab sampling might puncture the barrier so precautions need to be taken.
- For basements, primary entry points for vapors might be through the sidewalls rather then from below the floor slab.
- Sample collection and analysis is analogous to other types of soil-gas sampling as described below, however risk based screening levels for sub-slab samples are lower than deeper soil gas samples, requiring an analytical method with lower detection limits.

There is no promulgated method for sub-slab sampling. A draft standard operating procedure (SOP) was released by EPA-ORD in February 2004 and several states including New York, New Jersey, and California have adopted sub-slab sampling procedures. The procedures generally involve drilling through the concrete slab and collecting a soil gas sample for field or laboratory analysis. Sometimes, sub-slab soil gas samples must be collected concurrently with indoor air samples so that the sub-slab concentrations can be directly compared to indoor air concentrations collected at the same time.

According to the 2004 IRTC Vapor Intrusion Study, 73% of the respondents reported that their agency recommends the use of sub-slab samples. Moreover, 49% of the respondents preferred sub-slab soil gas as opposed to groundwater (21%), indoor air (20%), deep soil gas (17%), soil samples (12%) and flux chambers (6%). Another 30% indicated that soil sampling was the least preferred approach for evaluating vapor intrusion.

If sub-slab sampling appears to be warranted, it is advisable to stay in garages if technically sound to do so and to collect enough samples to get a representative value under the slab. EPA recommends three sub-slab samples per domestic residence to characterize spatial variability. This may not be practical for most single-family residences with floor coverings.

Most agencies require that soil gas samples be taken until the soil gas contaminant plume is fully delineated and concentrations of VOCs in the subsurface fall below allowable risk-based levels, both laterally and vertically towards any receptors. When subsurface contamination is encountered near buildings, soil gas samples will likely be required near or under the foundation of the receptor as described above, and from any suspected preferential pathways.

Ideally, there should be a soil gas sample for every existing or future building that lies over the contamination zone or within a certain lateral distance to the zone. Different agencies have different distance criteria ranging from 15 feet to 100 feet. The EPA draft vapor intrusion guidance suggests that a soil gas sample should be collected for every 1000 square feet. This may be cost prohibitive for larger plumes with many receptors. For sites where current and future land use will be restricted by a land use covenant, the soil gas sampling density can be modified as a function of the size of the current and future buildings pursuant to the covenant.

8. Investigation vs. Mitigation of the VI Pathway

The costs to evaluate vapor intrusion potential can be significant. Unless the regulatory agency allows the use of groundwater or soil vapor data to evaluate the potential for indoor air impacts, indoor air tests are likely to be required. This will not only increase the costs of the remediation and delay work but could also unduly alarm occupants and nearby property owners when the responsible party comes knocking at their door to request permission to install a carbon canister in their home or office building.

In some cases, it may be more cost-effective to simply retrofit an existing structure with a vapor mitigation system than to conduct comprehensive indoor air sampling. Building owners or developers who suspect that vapor intrusion may be a problem should consider implementing a mitigation system into the design of a new buildings or an older building undergoing renovation since it can be substantially cheaper than retrofitting a completed building.

Depending on the results of the site investigation, mitigation may be required to eliminate the potential to exposure to contamination by vapor intrusion. Mitigation techniques can vary from relatively inexpensive passive systems such as selective placement of buildings, installing piping without fans, and filters. Active mitigation systems can range from the radon-type sub-slab depressurization systems with installation of vapor barriers or sealing of floors and foundations to soil vapor extraction systems and adjustments to the mechanical ventilation systems. In many cases, carefully installed standard radon venting systems will reduce indoor air concentrations below action levels. These systems can cost of approximately $1200 to $1500 for typical residential homes and approximately $2 per square foot of area requiring remediation for larger commercial buildings.

The 2004 ITRC VI Survey found that sub-slab depressurization systems (SSDS) were the most common form VI mitigation with 39% of the respondents reporting that their agencies generally required SSDS to mitigate VI. However, only 15% said their states had written guidance for VI mitigation systems and only 9% had licensing programs for system installers. 67% of the respondents require post-mitigation confirmation sampling and 40% required the use of institutional controls or deed notices. Only 19% of the respondents specify how long the remediation systems should operate. A few respondents require off-gas testing of the mitigation systems, with very few requiring permits to operate the systems.

The survey also had some interesting findings for contaminated properties where redevelopment has not yet started. 75% of the respondents reported that their VI programs will require VI evaluation for buildings that are planned or under construction and 47% will said that their agencies will require a VI evaluation of a hypothetical building to fully close out a site.

However, the real impact of addressing potential vapor intrusion may be more stringent remediation standards for soil or groundwater. Ordinarily, soil and groundwater cleanup standards are based on the impact to those media. If an engineering cap can prevent exposure to contaminated soil or if groundwater is not being used for drinking water purposes, a property owner may be allowed to leave residual contamination in place at a site. However, because the indoor action levels may be so low, a property owner may be required to perform a more extensive cleanup to prevent the migration of vapors that would result in concentrations above the indoor air action levels. Indeed, in some instances, owners may find themselves forced to remediate groundwater below the maximum contaminant levels (MCLs) established for drinking water. For example, the MCL for TCE is 5 ppb. However, depending on site conditions, in some states concentrations of TCE at the MCL could result in vapor levels above the state action level. In addition to cleanup costs, vapor intrusion can also result in significant indirect costs such as labor and electrical costs for maintaining operation and maintenance systems. Building owners may also be required to adjust the operation of mechanical air systems to minimize vapor intrusion but that could result in these systems operating less efficiently.

9. EPA Vapor Intrusion Guidance

The 2002 EPA draft Vapor Intrusion Guidance uses a tiered approach to evaluating vapor intrusion. The document is organized in the form of "questions" that lead the user through up to three tiers of evaluation.

The first tier establishes whether compounds of sufficient volatility and toxicity are present in soil or groundwater within 100 feet of inhabited buildings using modelling. If the tier 1 analysis indicates that chemicals of concern are not present, then the VI pathway is considered to be not "complete" and no further exposure assessment is required. If the chemicals are present, the user must proceed to the second tier.

The second tier compares groundwater and soil vapor concentrations at the site to generic screening levels that are based on 10-4, 10-5, and 10-6 risk levels.[16] The regulatory agency has the discretion to choose which risk level to use should be appropriate for determining if further action is required. For example, the 10-4 risk factor may be appropriate for commercial settings while the 10-6 may be used when the impacted property is used for residential purposes. The generic screening levels employ assumed "attenuation factors" or decreases in vapor concentration as the vapor moves from the groundwater to soils immediately below the building and then into the indoor air.

Finally, if the screening levels are exceeded, the third tier of evaluation requires more site-specific investigation If Tier 3 models indicate a potential for exposure at levels above the applicable criteria, additional data gathering (e.g., sub-slab sampling or indoor air monitoring) or remediation may be needed to meet the human health environmental indicator.

10. Vapor Intrusion and RCRA Corrective Action Sites

EPA recommends that its November 2002 Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils be used to assess this pathway for the purpose of making RCRA EI determinations. Specifically, this would involve the use of the preliminary screening criteria in Tiers 1 and 2, and, if necessary, Tier 3 site-specific modelling for EI determinations. If scientific, site-specific models (such as the Johnson & Ettinger (1991) model spreadsheets found on the Superfund Program's website (www.epa.gov/superfund) or other appropriate models) do not indicate that the site has a potential to cause exposures above the applicable EI criteria (using site-appropriate input parameters), then this pathway should be considered to have been adequately screened for EI exposure assessment purposes. In such cases, we do not believe that confirmatory sampling will be necessary, for the purpose of making an EI determination.

If Tier 3 models indicate a potential for exposure at levels above the applicable criteria, additional data gathering (e.g., sub-slab sampling or indoor air monitoring) or remediation may be needed to meet the human health environmental indicator.

For the purpose of making *Current Human Exposure under Control* EI determinations with respect to vapor intrusion, EPA generally recommends the use of 10-5 levels for carcinogens (incremental individual lifetime cancer risk), and a Hazard Quotient (HQ) of 1 for non-cancer risks.). In addition, for purposes of Environmental Indicators, land use assumptions will reflect current, not future or potential, conditions.

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[16] The guidance sets the screening level at the maximum contaminant levels ("MCL") established under the Safe Drinking Water Act for compounds where the screening level would set a level below the MCL.

11. Role of OSHA Permissible Exposure Levels (PELs)

The Occupational Safety and Health Administration (OSHA) has established permissible exposure levels (PELs) in the workplace for a variety of chemicals. The PELs are less stringent by several orders of magnitude than the risk-based concentration used by EPA and the states for vapor intrusion that are generally based on a risk threshold of a incremental cancer risk of one in a million. Active facilities have argued that the OSHA PELs should be the applicable standards for determining if the VI pathway needs to be investigated and if remedial actions are required.

The question of what standards should apply initially came into focus at facilities subject to RCRA corrective action where EPA regional offices took the position that soil and groundwater remediation goals should take into account impacts to indoor air.[17] Facilities have pointed to language in RCRA requiring EPA to provide information to the Secretary of Labor and Director of the National Institute for Occupational Health and Safety about hazards where workers may be exposed to support the view that Congress did not intend EPA to use its own standards but to assist OSHA in enforcing its existing standards.[18]

In 1990, EPA and the Occupational Safety and Health Administration (OSHA) entered into a memorandum of understanding (MOU) that defined the respective roles of the agencies in identifying and addressing environmental and workplace hazards.[19] Under the MOU, EPA will have authority over significant adverse reactions to chemicals posing potential hazard to public health or environment; Accidental, unpermitted or deliberate releases beyond workplace; violations of EPA regulations. OSHA, in turn, generally will take the lead role in addressing occupational exposures. The MOU also provides that agencies will notify each other if their inspectors identify discover of violations of the other agency's requirements.

The EPA Vapor Guidance indicates EPA does not expect the November 2002 Vapor Intrusion Guidance to be used in occupational settings since such workplace exposures are subject to the permissible exposure levels (PELs) established by OSHA. EPA considers occupational settings to include workplaces where workers are handling hazardous chemicals (e.g., manufacturing facilities) similar to or different from those in the subsurface contamination, as well as other workplaces, such as administrative and other office buildings where chemicals are not routinely handled in daily activities. Nevertheless, we recommend that such facilities be notified of the potential for this exposure pathway and that they consider any potential exposure that may result.

EPA also indicated that the November 2002 Guidance may apply in occupational settings where the chemicals presenting a risk of vapor intrusion are no longer or never were used in the workplace, or where chemicals modified by degradation. In addition, the guidance indicates that a change in use may trigger pathway re-evaluation and that the PELs are not ARARs for purposes of remedy selection.

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[17] The jurisdictional question has also been raised in the context of an asbestos demolition that did not trigger the EPA asbestos standard but required compliance with OSHA asbestos rules. See OSHA Interpretation "Application of the asbestos standard to demolition of buildings with ACM in place." August 26, 2002.

[18] 42 U.S.C. 6971(f)

[19] "Memorandum of Understanding Between The Environmental Protection Agency and the Occupational Safety and Health Administration on Minimizing Workplace and Environmental Hazards History" November 23, 1990.

The November 2002 VI Guidance may also apply to non-residential settings where persons are in a non-working situation. EPA indicated that non-residential buildings may need to be evaluated where people (typically non-workers) may be exposed to hazardous constituents entering into the air space from the subsurface. This would include, for example, buildings where the general public may be present, e.g., schools, libraries, hospitals, hotels, and stores. However, EPA recommends that appropriate adjustments be made for non-residential exposure durations, the building specific air volumes and air exchange rates, as well as other relevant factors to be considered.

The EPA-OSHA MOU does not impact cleanups performed under state response programs. Since most site remediation is performed under state response programs, the question of whether OSHA jurisdictional may pre-empt state remedial goals for indoor air can be significant. Section 18 of the Occupational Safety and Health Act of 1970 (OSH Act)[20] expressly authorizes state jurisdiction in two situations. First, OSH Act § 18(a)[21] provides that states are not prevented from asserting jurisdiction under state law over occupational and health issues for which OSHA has not adopted a standard. Under OSH Act §18(b), states may assume responsibility for occupational safety and health issues thru approved-state enforcement.[22]

There has been very little case law on this issue. Perhaps the closest relevant authority was the United States Supreme Court decision in *Gade v. National Solid Waste Management Association*[23], which involved a conflict with OSHA's Hazardous Wastes Operations and Emergency Response (HAZWOPER) regulations[24]and similar regulations promulgated by the State of Illinois. The Supreme Court ruled that state law that substantially and specifically establishes an occupational health & safety standard on an issue that OSHA has already promulgated would be pre-empted unless the state has its own approved. OSH Act plan. The court said the state requirement would be pre-empted if the state articulates purpose other than workplace health and safety. However, the Court went on to say that state laws or regulations of general applicability (e.g., common law tort) will not be pre-empted if they regulate workers as part of general public.

The 2004 ITRC VI Study found that 48% of the respondents did not know what their state's position was regarding the use of OSHA standards at commercial vapor intrusion sites versus risk-based screening values. Respondents did indicate that they were more likely to evaluate for vapor intrusion when chemicals found in commercial buildings were not being used in the workplace. 43% of the respondents reported that their state would require evaluation of the VI pathway if the workplace concentrations exceeded OSHA PELs, 19% said they would not and 39% did not know if their state had a policy. If workplace concentrations of chemicals not used by the business exceeded state indoor criteria but were below OSHA PELs, 44% of the respondents said their agencies would require evaluation of the VI pathway while 41% were unsure. If the chemicals were used in the workplace, 17% of the respondents indicated that their states would still require evaluation of the VI pathway while 48% were unsure.

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[20] 29 U.S.C. 651 et seq.

[21] 20 U.S.C. 667(a)

[22] 20 U.S.C. 667(b). Thus far, 22 states and jurisdictions have approved State OSH plans. However, the Connecticut, New Jersey, New York and Virgin Island programs only cover public employees.

[23] 505 U.S. 88 (1992)

[24] 29 CFR 1910.120 et seq.

12. Summary

Because the science of vapor intrusion is still in its infancy and regulators are still being trained how to evaluate this pathway, there is significant potential for misunderstandings by regulators. When in doubt, regulators will often adopt the most conservative assumptions and procedures. To prevent unduly burdensome requirements, responsible parties and their lawyers should try to remain in control of the process. This means that attorneys must understand the VI pathway, the technology approaches for evaluating the pathway, the status of controversial issues, and how these might impact decisions at the site in question. By being proactive, responsible parties can identify risks in advance, reduce these risks through pre-emptive actions, and propose reasonable scopes of work to regulatory agencies, if required. Because of the growing attention to vapor intrusion, it is important that the potential for vapor intrusion should be evaluated during due diligence, particularly for sites with VOC-contaminated soil or groundwater