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Vapor Intrusion—An Evolving Concern at Sites with Buildings Over Contaminated Soils or Shallow Groundwater

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Why Is Vapor Intrusion Becoming Such an Important Issue?

There are tens of thousands of sites in the United States with gasoline, solvents, or mixtures of other volatile chemicals in shallow soil and/or groundwater. Almost all of these sites are being managed under federal or state regulatory programs, and many have undergone some form of remediation. Historically, cleanup decisions were based on concerns associated with potential direct exposure to affected soil and/or groundwater, without consideration of the potential inhalation exposure if vapors migrated from shallow soil or groundwater into buildings. Within the last 5 years, however, regulatory agencies have placed an increased emphasis on vapor intrusion as a pathway contributing to the exposure of workers or residents occupying affected buildings.

In 2002, the U.S. Environmental Protection Agency (EPA) published guidance on evaluating vapor intrusion that describes a three-tiered evaluation process: primary screening, secondary screening, and site-specific pathway assessment. Consequently, there is growing interest within the broader regulatory community to more fully evaluate or, perhaps more importantly, to reevaluate vapor intrusion at sites that in many cases have had an extensive history of investigation and substantial remediation efforts.

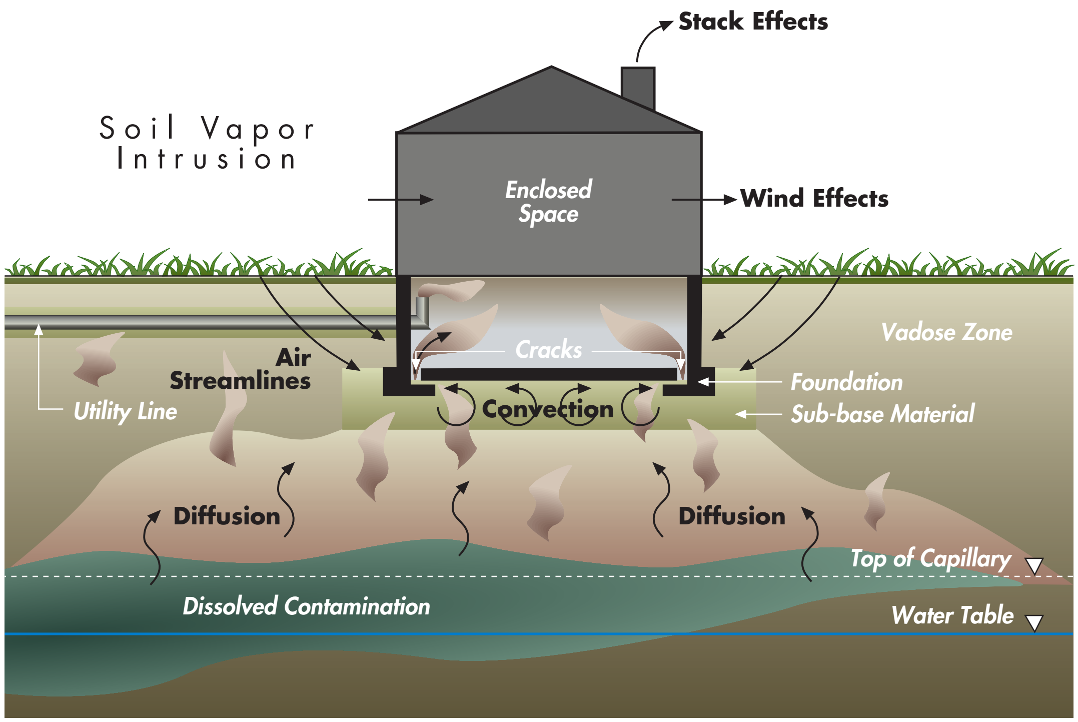
Regulatory interest in vapor intrusion coincidentally arose at the same time that EPA was reevaluating the toxicity of several volatile chemicals including trichloroethene (TCE), which has been detected at more than 1,000 National Priority List sites. EPA has recently requested vapor intrusion evaluations as part of the five-year review of some Superfund sites and has used this issue to reopen some previously issued records of decision at sites where TCE is the primary chemical of interest. In turn, media reports of vapor intrusion investigations, particularly stories of chemical vapors potentially entering homes and commercial buildings, have heightened public concern. In some cases, the level of concern has been sufficient to precipitate lawsuits against potentially responsible parties. This series of events has for many companies propelled vapor intrusion evaluations to the top of their priority lists.

Provided below are some of the vapor intrusion issues that we at Exponent have been asked to address for our clients and the approaches that we have found useful in addressing these issues.

How Exponent Has Contributed

Exponent has played several roles in facilitating vapor intrusion evaluations, including the following:

- Conducting modeling evaluations
- Designing and implementing air sampling programs
- Meeting with EPA regional staff and EPA's TCE risk assessment team on the issue of the inhalation cancer potency of TCE
- Conducting an independent risk assessment and developing an inhalation cancer potency factor for TCE
- Providing health-based criteria for other volatile chemicals of interest
- Evaluating the health significance of indoor air concentrations from a sampling program
- Assisting in communicating the risks associated with the concentration of TCE found in indoor air
- Assisting in identifying remedial measures to reduce vapor intrusion
- Conducting environmental fate and forensics (source, allocation) studies of TCE and aromatic hydrocarbons.



What Are the Key Questions?

There are several key questions that need to be addressed when considering whether vapor intrusion is an issue.

1. Is vapor intrusion occurring?
2. If so, what is the source?
3. What is the baseline? That is, what are the concentrations of that chemical that would have existed without the particular source?
4. Are the concentrations of chemicals accumulating in buildings sufficient to warrant either short-term or long-term measures to mitigate potential exposures?
5. If actions are warranted, what are the most cost-effective approaches to address the problem?
6. What is the best way to communicate the results of a vapor intrusion evaluation to affected parties?

These six questions cover the environmental evaluation, risk assessment, remedial action, and risk communication parts of the process.

How Is Vapor Intrusion Best Evaluated?

Vapor intrusion may be evaluated using chemical transport and fate modeling, air monitoring (sampling), or both approaches. There are inherent benefits and limitations to each approach.

Modeling

EPA has published a building infiltration model based on the Johnson and Ettinger model for chemical partitioning and subsurface vapor transport. This model directly predicts concentrations and thus can be used to assess vapor intrusion. The model is applicable to most site conditions, is relatively easy to use, and has frequently been employed in screening evaluations of risk to building occupants.

The model estimates risks of potential exposures to chemicals in indoor air based on actual groundwater or soil gas data, or it can be used to calculate target concentrations for specific chemicals in indoor air for various levels of risk. Because the model uses actual soil gas data to account for the contributions from both soil and groundwater, it negates the need to

Relevant Skills for Assessing Soil Vapor Intrusion

- Groundwater, soil gas, and indoor air sampling
- Soil gas transport modeling
- Biodegradation analysis
- Groundwater modeling
- Epidemiological and toxicological analysis
- Remedial engineering design
- Soil vapor ventilation systems in buildings
- Soil and groundwater removal systems.

make assumptions about chemical partitioning among media. The model can also incorporate specific hydro-geologic data for a site, or it can be run using default parameters.

The indoor air chemical concentrations estimated by the model have generally been considered conservative; that is, concentrations are overestimated in most cases. However, some recent evaluations indicate that under certain conditions, such as when preferential pathways that could increase vapor transport are not adequately considered, the model will underestimate the levels of chemicals that may accumulate in a building that is situated over contaminated media. Like all models of environmental processes, this model has some limitations. It is dependent on site-specific data to provide representative results and is particularly sensitive to certain input parameters such as water-filled soil porosity that are often not collected at sites during typical environmental investigations. And, as with all models, its outputs and predictions require verification in the field with actual air sampling, whenever possible.

Buildings Susceptible to Soil Vapor Intrusion and Factors Affecting the Problem

Which sites can pose soil vapor intrusion?

- Sites with chemicals present of sufficient volatility and toxicity. Volatility is one factor that affects a chemical's ability to enter into and move with soil gas. Toxicity determines what indoor air concentrations of a chemical are considered to pose significant risk. EPA has identified more than 100 chemicals that have a combination of volatility and toxicity making it necessary to consider soil vapor intrusion if they are found at a site. Most sites to date that require remediation are contaminated with chlorinated solvents, such as the dry-cleaning fluid PCE or the degreasing solvents TCE and TCA, or with petroleum hydrocarbon compounds, such as benzene that may originate from underground tank leaks of gasoline or diesel fuel.
- Sites with buildings, either present or planned, in proximity to a contaminated groundwater plume or soil region. As a general matter, EPA considers sites with a horizontal or vertical separation distance less than 100 ft as candidates for soil vapor intrusion.

Previous site remediation does not automatically preclude the possibility of a soil vapor intrusion problem, nor does the absence of a basement.

What factors increase the magnitude of any problem?

- High chemical concentrations in soil or groundwater.
- Contaminated soils or groundwater a short vertical distance from a basement foundation or building slab.
- Permeable (sandy) soils permitting rapid soil gas diffusion.
- Limited biodegradation during transport. For petroleum hydrocarbons, biodegradation can be an ameliorating factor.
- Significant building openings to the subsurface such as sumps, dirt floors, unlined crawl spaces, or cracked slabs.
- Low building air exchange rates characteristic of weatherized buildings.

Additional factors such as building design and HVAC status can affect the actual concentrations measured indoors.

Air Sampling

The sampling of indoor air in the breathing zone in potentially affected buildings offers a more direct approach to characterizing potential exposure concentrations. Sampling eliminates the need for transport and fate modeling, is relatively easy to implement, and has gained favor within the regulatory community because actual measurements of concentrations are provided rather than model estimates.

However, interpreting concentration data from air samples can be complicated and may require additional information. The samples represent the conditions at the time of sampling and are not necessarily representative of all the environmental and meteorological conditions to which the site is subjected. Therefore, sampling is often conducted under a range of conditions (e.g., summer and winter weather) to better characterize exposure concentrations.

Because there are numerous sources of some of the volatile chemicals of interest such as benzene and TCE, additional information is necessary to determine whether these chemicals are from the subsurface, from background levels in outdoor air, or from consumer products within the building.

Background, or baseline, levels (concentrations not associated with a specific point source) of benzene, TCE, and other volatile chemicals are frequently found in outdoor air samples. It is generally imperative, therefore, that outdoor air samples be collected in conjunction with indoor air samples to identify chemicals coming into buildings from outdoor air and that other sources of these chemicals in the buildings be evaluated prior to sampling.

It is also useful to sample air near cracks in the floor or near conduits coming through the ground floor of a building to confirm or dismiss these areas as points of entry of vapors into the building. A final factor to be considered in designing an air sampling program is that often only the most sensitive analytical methods are sufficient to detect the volatile chemicals of interest at concentrations below risk-based criteria.

Combined Approaches

When sampling information is available for some buildings, models such as the Johnson and Ettinger model can be calibrated for extrapolation to other buildings of interest. We have found this type of calibration to be useful, for example, in assessing exposures for individuals in homes for which there are no sampling data. The more detailed the sampling information, the better the calibration. Subslab data and deep soil gas data are particularly valuable for calibration purposes. It is also useful, depending on the amount of data available, to stratify the sampling data by type of home (basement, slab on grade, etc.), location of the measurement (basement vs. first floor, etc.), and season of sampling before performing the calibration.

Evaluation Criteria

Risk-based criteria for the chemicals of interest are essential to the interpretation of the health significance of measured or

Background

- Constituents in soil vapor may also be present in background (hydrocarbons, volatile organic chemicals)
- Background sources may be outdoors and indoors (cleaners, thinners, solvents, gasoline)
- Background will be most important when health-based concentrations are low and within or near background concentrations
- Analytical interferences and meteorological factors may become important.

EPA's Guidance on Soil Vapor Intrusion

- First issued in 1997
- Revised in 2001–2002
  1. Tier I (volatile/toxic substances nearby)
  2. Tier II Johnson and Ettinger model—generic
  3. Tier III Johnson and Ettinger model—site-specific
- Next version expected in 2005
- Some states have more stringent guidance.

modeled chemical concentrations in indoor air. Not surprisingly, there are some complications in identifying appropriate criteria. First, there is no agreed upon set of concentration criteria for chemicals in indoor air that is applicable for evaluating exposures in both commercial and residential settings. Second, risk-based criteria are needed to evaluate both short-term and long-term exposures. Third, for certain chemicals that are often key in vapor intrusion evaluations, such as TCE, there is controversy over EPA's inhalation cancer risk estimates. Currently, while EPA is revising its TCE risk assessment, there are no agreed upon EPA toxicity criteria for evaluating TCE levels in indoor air (an independent risk assessment is currently required for TCE).

Taking into account the above factors, we have found a three-part evaluation scheme to be effective. Within this scheme, indoor air concentrations are compared to three levels of benchmarks:

- Level 1: Comparison to background concentrations—site outdoor air concentrations and local and regional background air concentrations
- Level 2: Comparison to noncancer criteria for short-term or long-term exposures—health-based noncancer benchmarks based on acute, intermediate, and chronic exposures such as state and federal Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs) and American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs) for commercial buildings, or Agency for Toxic Substances and Disease Registry (ATSDR) minimum risk levels (MRLs) for short to moderate periods, and EPA reference concentrations (RfCs) for residential exposures
- Level 3: Comparison to cancer criteria for long-term exposures—concentrations based on hypothetical cancer risks in an occupational or residential setting for a risk range of 1 in 10,000 to 1 in 1,000,000.

In applying this tiered evaluation scheme, we have suggested the following decision framework. If mean indoor air concentrations are found to be statistically greater than background concentrations, then data are further evaluated using Level 2 and Level 3 benchmarks. If the mean indoor air concentration of one or more of the chemicals of interest is found to exceed Level 2 criteria and vapor intrusion is identified as the source of the chemicals, then appropriate interim measures should be taken to reduce the levels of exposure. If the mean indoor air concentration of one or more of the chemicals is found to exceed Level 3 criteria, then potential long-term alternative measures should be considered.

What Have We Learned from Our Experience Evaluating Vapor Intrusion?

Our evaluations of vapor intrusion have led to four important findings: 1) the level of vapor intrusion into most buildings is insufficient to trigger immediate action to protect workers or residents, 2) not all buildings above contaminated soil or groundwater are at risk of vapor intrusion (well constructed and operated buildings are generally unaffected), 3) the buildings most vulnerable to vapor intrusion can often be identified by their general condition, particularly whether they have sumps or water intrusion, basement or ground floor slabs with cracks or major conduits, or malfunctioning or no HVAC system, and 4) allegations of soil vapor intrusion at several high-profile sites have led to health and property value diminution claims.

In the latter case, many of the measurement and modeling techniques described above are applicable in evaluating which properties are actually affected by vapor intrusion and the significance of any resulting chemical exposures.