A Stakeholder's Guide to Vapor Intrusion

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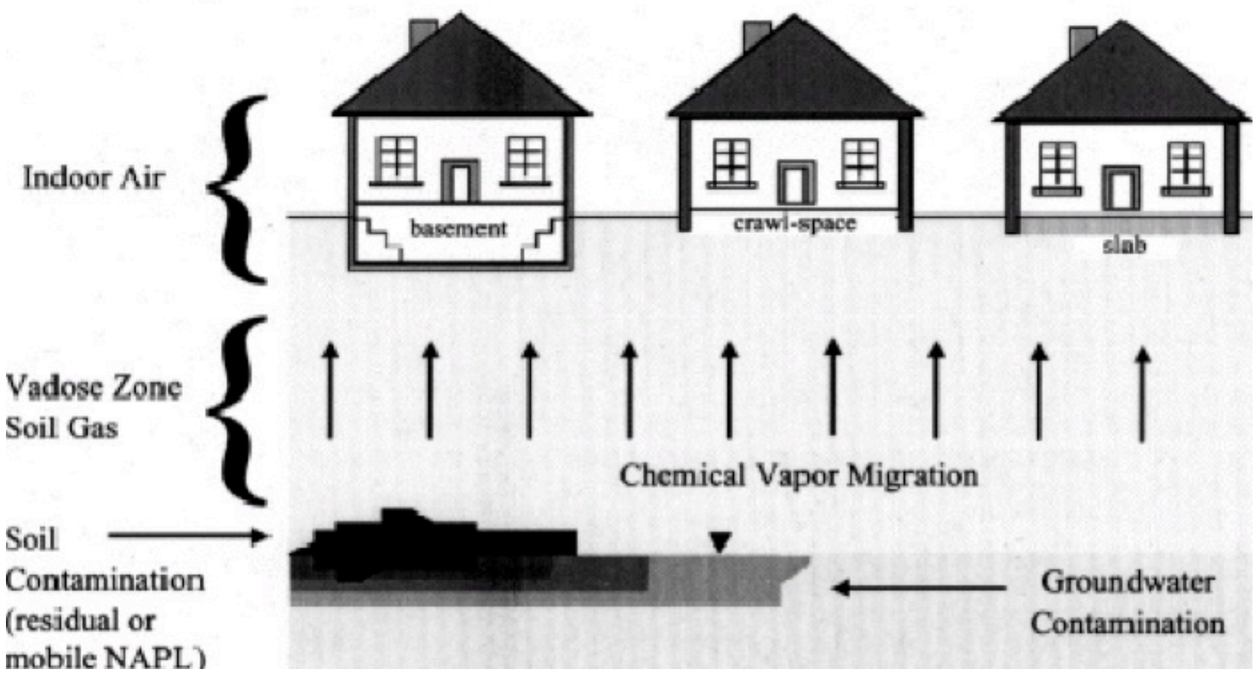
Vapor intrusion refers to the migration of toxic vapors from the subsurface—that is, soil or groundwater—into homes, schools, and other overlying buildings. Though many substances, such as petroleum hydrocarbons and even elemental mercury, can intrude into buildings, sites that require a response usually contain chlorinated solvents—that is, volatile organic compounds (VOCs) such as trichloroethylene (TCE) and tetracholoroethylene (also known as perchloroethylene or PCE). TCE was widely used as a solvent in industries such as aerospace and electronics, but in recent years a relatively small number of businesses, primarily in metals processing, continue to use it. It is still found in consumer products such as gun cleaner and plastic cement. PCE is still widely used in dry-cleaning and automotive servicing. Toxic compounds found in petroleum products, such as benzene, toluene, ethylbenzene, and xylene (BTEX), may also pose a vapor intrusion risk, but they tend to pose less of a risk because they normally degrade near the ground surface as they come into contact with atmospheric oxygen.

While individual scientists and some states, such as Massachusetts and Colorado, have been addressing vapor intrusion since the since the 1990s, vapor intrusion started to become a standard part of contaminated-site response in 2001, when U.S. EPA's Resource Conservation and Recovery Act program stipulated such an assessment for all Environmental Indicator human health decisions. In early 2002, the *Denver Post* brought national attention to the problem with a landmark series on vapor intrusion. Since then environmental regulatory agencies across the country—U.S. EPA and most states—have developed technical and policy guidance for investigating and mitigating toxic gas vapors. Thousands of officials and consultants attend frequent conferences and workshops on the subject. Vapor intrusion responses are often major local news stories. But many Americans who are potentially exposed via the vapor intrusion pathway do not know about it, and many who know about it do not understand the many complexities involved in assessing and responding to vapor intrusion.

This guide is intended only as an introduction to the topic. For those who wish more detailed information, the Reference section at the end contains links to several important sources.



Source: U.S. EPA 2002 Draft Vapor Intrusion Guidance

What Is Vapor Intrusion?

Vapor intrusion can occur when *volatile* (vapor-forming) contaminants are found in either the uppermost *aquifer* (groundwater reservoir) or in the *vadose zone* (the soil above the groundwater). Substances such as TCE and PCE mix with water in the subsurface, even sinking toward the bottom of the aquifer, but like the carbon dioxide in soda drinks a portion of the substance rises as a gas, or *volatilizes* into the vadose zone, where it can be measured in *soil gas* (the gas between grains of soil). The portion of the liquid contamination that volatilizes into the gas phase varies by chemical

Contaminants in soil gas tend to *diffuse,* or spread out to equalize the gaseous concentration, but the principal reason that soil gas enters buildings is that buildings tend to have a lower pressure (i.e., negative pressure) than the subsurface. That is, like a weak vacuum cleaner a building sucks up gaseous contaminants, not just from the soil directly beneath, but also from the area around the building. This occurs whether the building has a poured (concrete) slab foundation at-grade, a crawlspace, or a basement with or without a slab floor. Where fireplaces or furnaces are used to heat homes, this pressure differential is even more pronounced during winter months, as indoor air is consumed for combustion and exhausts up the chimney.

Like air escaping through a tiny puncture in a tire, the soil gas "finds" holes or cracks in the slab or floor above. As the vapor contaminant enters the overlying building, it spreads out, so contaminant gas concentrations inside are generally much lower than those found in soil gas. If the building or crawlspace is well ventilated, indoor concentrations tend to be reduced further.

While measurements of the concentrations of contaminants in indoor air are the most direct way to know the *exposure point concentrations* (what people breathe), to estimate the amount of vapor that might enter a building, scientists and engineers generally use what they call *attenuation factors*. The most common attenuation factor is the ratio of the concentration of the gas in indoor air to the concentration of the gas in the subsurface source (soil gas, at some depth). It is usually labeled with the Greek letter *alpha* (α) and sometimes a subscript to show if it applies to an exterior soil-gas (sg) or a subslab (ss) sample. While one can calculate an attenuation factor using the theoretical relationship between measured groundwater contamination and indoor air concentrations, it is generally more reliable to use a soil-gas-to-indoor-air attenuation factor. Often those conducting investigations measure soil gas contamination concentrations and use α—either an observed α based upon historical data collected by U.S. EPA, or a calculated α using the theoretical formulas in the Johnson-Ettinger model—to predict indoor air concentrations. Typically, for chlorinated compounds the attenuation factors for sub-slab to indoor air (α_{ss}) range from 1/50 (.02) to 1/10,000 (.0001), although much higher and lower values have been found.

Indoor air concentrations of compounds such as TCE and PCE from vapor intrusion are usually very low, but most toxicologists believe that *chronic* exposure—that is, over many years—even at low concentrations increases the chance of contracting cancer or other serious diseases. It's unusual but possible for vapor intrusion to cause exposures at levels high enough to cause *acute*—that is, more immediate—health concerns. Actual risk, of course, is a function of all exposures, including contaminated drinking water and vapors from showers. The goal of vapor intrusion response is either to eliminate these exposures or at least to reduce them below thresholds that regulatory agency scientists associate with acceptable risk.

Access

Since investigations in residential settings usually entail sampling indoor air and/or soil gas directly beneath homes, one of the biggest challenges facing vapor intrusion investigations in residential neighborhoods is enlisting the cooperation of homeowners and, in some cases, renters to gain access for sampling. Investigators usually must collect samples in homes or yards. They may need to drill holes in floors, and they may restrict the opening of doors and windows. If samples are taken from indoor air, they may require the removal of VOC-containing commercial products from cupboards and garages, since these may contain chemicals that generate vapors that falsely appear to be present because of vapor intrusion.

While some residents welcome the opportunity to be tested, others are mistrustful of government agencies and/or corporate polluters. In some cases the mistrust results from denials of the existence of, or responsibility for, contamination or the slow pace of response, but in others people are mistrustful because of experiences which may have occurred decades before or in far away locations. Regulatory agencies often must devote extensive time and resources to winning public confidence, but there are models of public involvement—such as the establishment of community advisory groups or partnering with existing community organizations—that usually help increase cooperation.

Initially, many property owners don't even want to hear about the possibility of vapor intrusion because they are worried, with good reason, that it may have a negative effect on property values. While the health effects of low-level exposure to volatile contaminants in one's home are uncertain and long-term, the impact on property values is often immediate and undeniable. Some people believe that if vapors are not documented, they won't experience economic losses.

However, once an area is known to be contaminated, the evidence—thus far—is that a systematic response, either demonstrating that a home is clean or installing mitigation system to make the air acceptable, is the best way to protect or restore property values. In some cases, property tax assessments can be reduced, and in some communities residents, either through proposed local legislation or legal action, are seeking to recover economic damages from the polluters. Many environmental officials choose not to discuss property value, because it is beyond their jurisdiction, but confronting the problem as seen by property owners may be the best way to increase cooperation with the investigation.

Assessing the Potential for Vapor Intrusion with Multiple Lines of Evidence

While occasionally a vapor intrusion site is discovered through direct measurements of indoor air, most are identified from areas of known groundwater contamination. In some cases groundwater contamination is mapped after a hazardous substance release is reported from a factory or other source; in others elevated levels of contamination are first found in drinking water supplies—particularly shallow private wells.

In areas where groundwater is not used as a drinking water supply, such as New York City, there may be unknown or unreported plumes of groundwater contaminated with volatiles such as TCE and PCE. In such cases, it is important to evaluate the potential for vapor intrusion in the environmental site assessments that are normally conducted for a change of land ownership or use. Properties containing, or near, present or former dry-cleaners, metals manufacturers, or automobile service centers should be carefully examined for possible volatile contamination.

Because vapor intrusion can involve liquid, solid (soil), and gaseous materials, unlike most other exposure pathways vapor intrusion investigations typically require sampling in multiple media, particularly the groundwater, soil gas, indoor air, and outdoor air. Because the physical phenomenon of vapor intrusion is very complex and remains incompletely understood, single lines of evidence (e.g., similar samples from a single medium) are often insufficient to identify the source of indoor contamination. That is, an approach involving *multiple lines of* (independent) *evidence* often must be evaluated to determine whether the lines converge on a defensible conclusion on whether vapor intrusion is occurring or likely to occur.

Groundwater. Since known shallow groundwater contamination is often the trigger that starts a vapor intrusion investigation, some groundwater data is usually already available. However, sampling points may not be broad enough or dense enough to support a vapor intrusion investigation. While variations in groundwater concentrations may have little bearing on strategies to protect public drinking water supplies (because they are designed to protect large areas), small variations in groundwater concentrations may influence decisions on where to sample soil gas and indoor air to investigate vapor intrusion at individual buildings. So in many cases additional groundwater sampling is conducted to support the vapor investigation.

There are formulas for predicting soil gas levels from shallow groundwater concentrations. Some state regulatory agencies adjust those formulas based upon climate, since cold weather tends to reduce volatilization. (On the other hand, lower outdoor temperatures also increase the pressure differentials and increase the flow of soil-gas into indoor air.) However, groundwater concentrations are only a rough indicator of soil gas levels due to soil types at the water table, fluctuating water table levels, rainfall, etc. For these reasons, groundwater data is generally used only to establish general boundaries for vapor intrusion studies.

Regulatory agencies generally use the Maximum Contaminant Level (MCL), or drinking water standard, to delineate the boundary of vapor intrusion investigations—with an additional 100 feet added laterally to account for uncertainty and/or gas migration. At most locations this is currently 5 parts per billion (ppb) for TCE and PCE, but at some sites 1 ppb is used as the investigative boundary.

The likelihood of significant vapor intrusion decreases with increased depth to groundwater, but vapor intrusion problems have been reported at locations where the top of the contaminated aquifer is more than 100 feet below the surface. More important, concentrations in the shallowest (uppermost) aquifer are all that matters in the near term. Contamination from deeper aquifers cannot release gases to the surface without impacting shallower groundwater. Of course, this condition needs to be confirmed periodically, especially if deep concentrations are particularly high.

Soil Gas. Soil gas measurements are generally regarded as the best external predictors of vapor intrusion, particularly if the measurements are made immediately under the building of concern (i.e., subslab samples). These measurements are generally made with a Summa™ canister, which is a stainless steel sphere with a valve on top, brought to the site with a set vacuum pressure. Tubing from the canister is inserted into the ground, and the vacuum pulls in soil vapors. The valve is then closed, and the entire canister is sent to a lab for analysis. Passive sensors may also be used, primarily for qualitative measurements. And EPA's Trace Atmospheric Gas Analyzer (TAGA) van may also outfitted with soil gas probes.

Photo courtesy of Blayne Hartman, H&P Geochemistry

Summa™ canister and mini-can

Soil gas samples may vary significantly over space and to a lesser degree over time. Thus, a large number of sample locations and sampling events may be needed to accurately characterize the contaminant distribution in soil gas.

Exterior soil gas measurements are collected above the water table but more than five feet from the ground surface, while subslab samples are taken just below the foundation slab. There are three principal scenarios:

1) Exterior samples near structures are rough indicators of the potential for vapor intrusion, but they often do not provide accurate predictions of indoor air levels. Even near-slab soil gas measurements are often much lower than results from samples taken directly beneath the slab.

2) Subslab or crawlspace samples, from directly beneath structures, better represent the conditions influencing the buildings above. However, subslab results have been found to vary significantly under the same structure, even beneath small individual residences. At large buildings (apartments, townhomes, schools, offices, etc.) soil gas variations are more likely. Where a building sits almost directly on fractured bedrock, variability in subslab soil gas can be even more pronounced.

3) On vacant property planned for development, soil gas and groundwater measurements are the best ways to roughly predict future indoor air levels, but construction—when it occurs—should be expected to alter the flow of soil gas and actual indoor air concentrations that result. U.S. EPA's *Brownfields Technology Primer* on Vapor Intrusion recommends that new buildings in areas with a potential for vapor intrusion be built with a low-cost passive venting system to which a suction fan can be added later, if needed.

Some regulatory agencies start an assessment of potential vapor intrusion with exterior soil gas sampling. If levels suggest a potential for vapor intrusion, they conduct indoor air and possibly subslab tests. This approach avoids intense interaction with residents. Other agencies eschew exterior sampling as too uncertain, since there is evidence that it often underestimates soil gas levels under buildings. In buildings above known plumes, they require simultaneous indoor *and* subslab or sub-crawlspace samples. Subslab sampling—the drilling of holes through floors (to be plugged airtight once the sample is taken)—requires coordination with building occupants.

Many community members—residents, school parents, etc.—prefer the latter approach. That is, they don't trust an "all clear" finding based only upon a mathematical calculation estimating indoor air concentrations. But there are others who simply don't want government officials and environmental consultants in their homes.

While residents are often uncomfortable about holes being drilled in their floors, the physical intrusion can be minimized by placing the holes in closets or under carpets.

Indoor Air. Direct indoor air sampling, usually conducted with a Summa canister over eight or twenty-four hours, is the best way to measure what is in the indoor air (i.e., the concentration the building occupants would be exposed to). Most agencies specify that canisters be placed at "breathing height," but some also place canisters near potential vapor entry points. It may also be sampled with near- real-time instruments such as a gas chromatograph with an electron capture detector or EPA's real-time TAGA.

With the TAGA, a long-plastic tube is run from the TAGA instrument into the building. The instrument registers continuous concentrations of two target compounds as the end of the tube is moved through the building. Thus, it can be used to identify pathways, such as cracks in flooring, or false positives, such as emissions from consumer products. The TAGA is expensive to mobilize, but it can provide a large number of samples quickly for essentially one price.

Because indoor air concentrations can vary due to weather and other conditions, most agencies call for two or more samples, during different seasons, to determine whether vapor intrusion is occurring. At least one of those samples should be during worst case conditions, which is often the winter in colder states but may be during dry hot months in warm states, if buildings have central air conditioning. Buildings should be tested with windows and doors closed—or the samples will simply reflect concentrations in outdoor air. In commercial buildings and schools, it may be helpful to conduct two sets of samples: one with centralized heating, ventilation, and air conditioning (HVAC) systems running, another with the HVAC turned off.

Even if elevated levels of the target contaminants are found, sources other than vapor intrusion need to be considered. If simultaneous sub-structure sampling shows correspondingly elevated levels in the soil gas or crawlspace, that suggests that vapor intrusion is a source. But potential indoor sources, which may range from gun cleaner to recently dry-cleaned clothes, should be removed before sampling.

Outdoor Air. Since most of the air inside of a building is from outdoor air, an "ambient" outdoor air sample is routinely taken, usually with a Summa canister, near the buildings where indoor air samples are collected. This is for two reasons. First, elevated outdoor concentrations may account for elevated indoor concentrations in the same range. Second, the standard methods for reducing indoor air contamination will not work if contamination from outdoor air can simply enter the building through windows, doors, or HVAC systems.

Though they do not naturally occur, chlorinated solvents such as TCE and PCE are found at low levels in outdoor air in metropolitan areas throughout the U.S. This is caused by continuing releases, because TCE has a half-life of three to seven days in outdoor air. That is, every three to seven days, half of the TCE mixed into the atmosphere degrades. TCE is in some consumer products, and a small number of industrial operations still use the chemical, but treatment systems, vapor intrusion, and fugitive releases (through soil to the surface) are also potential sources. PCE is still widely used in dry-cleaning, so ongoing operations are a major source of PCE in outdoor air, particularly in urban areas such as New York City, where dry cleaners are mixed with other land uses.

These ambient sources represent a health risk similar to vapor intrusion, though more people are exposed at lower concentrations. In fact, where TCE and PCE are consistently found at comparable levels in outdoor air, there may be a greater overall risk, because vast numbers of people may be exposed continuously throughout the air shed. Still, the officials responsible for groundwater cleanup and vapor intrusion response do not have the authority to address TCE, PCE, and other chemicals released from current business operations. At best, they will report their findings to the agencies (or branches of the same agencies) responsible for monitoring and cleaning air toxics.

BTEX compounds are frequently found in outdoor air at levels of concern. Because these compounds are commonly emitted from motor vehicles, it is difficult to attribute them to vapor intrusion, and more important, the mitigation strategies used to control vapor intrusion will not eliminate "background" BTEX (from outdoor or indoor sources).

Action Levels

Reviewing groundwater, soil gas, indoor air, and outdoor air data, environmental regulators and the entities that they regulate determine whether they believe vapor intrusion is occurring, and *whether the contamination level in the soil gas and/or indoor air is high enough to require a response.* If it is, they will order or implement vapor intrusion mitigation. If they are uncertain, they may engage in additional monitoring and more complex analysis of the data—for example, comparing the attenuation of multiple contaminants found at the site. If the source is vapor intrusion, and the chemicals are distributed identically, the attenuation is expected to be roughly the same for each compound.

Determining whether contamination levels in the soil gas and/or indoor air are high enough to require a response is no simple question. Many regulatory agencies set an action level equal to the concentration believed to trigger an excess lifetime cancer risk of one in a million, or ten-to-the minus-six (10^{-6}). This means that if a million people are exposed to the specified concentration round-the-clock for thirty years (or longer with some agencies), then one additional person is expected to contract cancer as a result of that exposure. As of 2009, the prevailing indoor air action level used by EPA and most states with active vapor intrusion programs for TCE is 1.0 to 1.2 micrograms per cubic meter ($\mu g/m^3$)—equivalent to .2 parts per billion by volume (ppbv). In November 2009, however, U.S. EPA issued a draft Toxicological Review of TCE. If finalized, the new cancer value for TCE would lower the indoor air action level to .25 $\mu g/m^3$ or below. For PCE it is .41 $\mu g/m^3$ (.06 ppbv). Soil gas action levels, which depend upon assumptions regarding the attenuation factor, range from the tens of $\mu g/m^3$ to the thousands of $\mu g/m^3$.

Though a great deal of scientific research has gone into the development of these action levels, they are arguable and uncertain. The various studies give conflicting answers. There are disagreements over how to protect more vulnerable populations, such as children or people with diseases, such as diabetes, or who take some medications that interact with the contaminants, making them more susceptible to typical vapor intrusion releases. There are also disagreements over how to handle cumulative exposures, including exposure to multiple chemicals through multiple pathways.

New York State, one of the most active jurisdictions in addressing vapor intrusion, uses matrices (tables), where the requirement for action is based upon two numbers, the subslab soil gas level and the indoor air level. The matrix approach has two advantages: 1) If soil gas levels represent a threat of vapor intrusion that has not yet materialized in indoor air, action may be required, if the concentrations are high enough; and 2) If soil gas levels are low enough to suggest other sources of indoor air contamination, action may be put off. However, New York's default indoor air action level for PCE is 30 $\mu g/m^3$, high enough to make PCE mitigation a rarity.

Two SSD Systems at a New Jersey School

Complicating the situation, soil gas and indoor air measurements vary significantly over time and space. In some situation, this triggers more intense or repeated sampling. In other cases, however, those conducting the investigation may decide that it is cheaper and more protective to start mitigation right away, rather than delay the decision and collect more data. In some locations, they will draw a line around the apparently impacted area and require/implement mitigation for all the buildings within the area, rather than rely on sampling for each structure. Known as the "blanket approach," this is similar to what was often done for contaminated private drinking water wells.

Activists at vapor intrusion sites tend to support the blanket approach. They don't understand why one home might have a mitigation system, but the neighbor does not. Furthermore, if the action levels for their site are not as protective as those in other communities, with similar circumstances, they want comparable thresholds. In fact, many want a response wherever and whenever indoor air contamination, documented to be from the subsurface, exceeds the level in the outdoor air. They are mistrustful that the standards are based upon calculations that "risk away" the problem.

Mitigation

Fortunately, it is relatively easy and inexpensive to prevent vapor intrusion. Subslab and sub-membrane depressurization systems, developed through decades of response to radon intrusion, can prevent the flow of contaminants from the subsurface into buildings.

Subslab depressurization systems (SSD). In existing structures, SSD systems are installed by cutting one or more holes in the slab, removing a small quantity of soil from beneath the slab to create an open hole or "suction pit" (with a 6- to 18-inch radius), and placing into the holes vertical suction pipes, which are in turn vented outdoors. One or two suction pits are adequate to depressurize typical residential homes. In new buildings perforated pipes are usually placed horizontally before laying the foundation directly above. Larger buildings may require multiple pipes, connected by manifolds. The pipe or manifold is connected to an exhaust pipe that rises through the building or alongside an exterior wall, where it ventilates above the roofline. *Active* depressurization systems, which have blower fans that suck vapors from beneath the building, have shown concentration reductions in the 90% to 99% range.

In some case, *passive* systems are installed, relying upon atmospheric conditions to create a pressure differential that draws gases from the subsurface out through a stack. Passive systems are generally not reliable, but if installed during the construction of new buildings they may be activated later, with the additions of fans, if testing shows that indoor air contamination is problem. It is much easier—cheaper, less disruptive, aesthetically acceptable—to insert pipe before, rather than after construction.

While depressurization systems may remove toxic fumes from the soil gas, that's not exactly what makes them protective for building occupants. *They are protective because they lower the pressure beneath the building so that pressure inside the building is higher than below the building.* Thus, even if there are holes, cracks, gaps (between walls and the foundation), or other pathways between the building and the subsurface, vapors flow downward, not upward. Thus, a well-designed depressurization system prevents toxic vapors from intruding above.

The installation of vapor mitigation systems must follow building codes. Exhaust pipes should extend beyond the roof and away from windows, and they must also not impact adjacent buildings. In colder climates drip-legs are often installed in vent pipes to prevent condensation from freezing and blocking the exhaust.

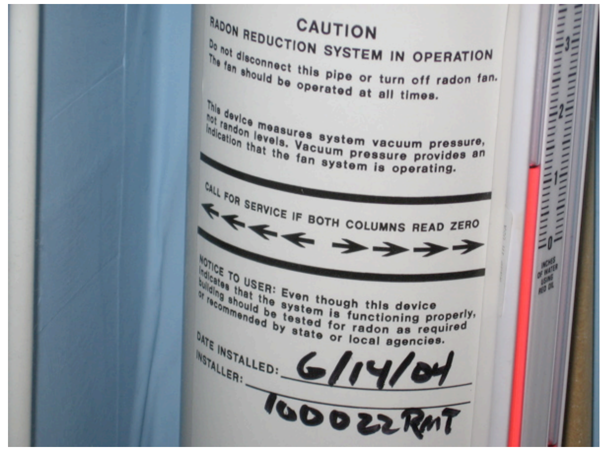
In locations that use furnaces or other types of combustion heating, "backdrafting" should be considered prior to installation of the SSD system. While rare, backdrafting is of concern if negative pressures (created by the SSD) within the building are stronger than the pressures that would drive the combustion gases up a chimney or stack. In such rare cases, potentially deadly combustion gases (e.g., carbon monoxide) could be concentrated within the building. An HVAC or vapor mitigation contractor should be able to diagnose the potential for this problem.

Sub-membrane depressurization systems. These systems are similar to subslab systems, but they are applied to buildings with crawlspaces. Plastic or rubber membranes that are impermeable to gases are placed under the floor or directly on the soil, and one or more perforated pipes are placed beneath. Like subslab systems, they create a downward air flow.

Subslab or sub-membrane depressurization has additional benefits. In fact, these technologies were originally developed to reduce the risk from exposure to naturally occurring radon gas. Radon, which occurs at some level in soil gas throughout the U.S., enters overlying buildings via mechanisms almost identical to those of chemical vapor intrusion. Studies of human health and residential indoor air radon levels from across the U.S. and Europe have shown significantly elevated rates of lung cancer for residents in homes with higher radon levels. Furthermore, depressurization systems also reduce the risks from moisture-induced problems such as mold.

Simple in theory, installing these systems properly takes some expertise. It may be necessary to conduct pilot studies beforehand to determine the zone of influence from each pipe or suction field. That zone depends upon soil conditions. In new construction, it is common practice to place a high permeability gravel bed beneath the slab to allow the free movement of vapor.

The primary performance standard used to confirm effective depressurization system operation is the demonstration of a negative pressure field extending under the entire building, using pressure testing at "worst case" test holes after system startup. In addition, smoke tests or equivalent methods should be used to test connections, holes, and membranes for leaks. Many officials consider pressure monitoring an adequate indicator of satisfactory system operation. Others, however, including many from the impacted public, also insist upon at least initial post-mitigation or periodic indoor air sampling to confirm that contaminant concentrations in indoor air are reduced to acceptable levels. Even those officials eschewing periodic indoor air testing may agree to at least one additional indoor air sampling event during the worst-case months.



"Radon" SSD Pressure Gauge for TCE Mitigation

Beyond their performance, depressurization systems should be designed to be non-obtrusive. Noise and power consumption should be minimized, and residents should not be stuck with the operating cots. Installation disruption should be minimized, and disturbed flooring should be restored. These may seem like small concerns, but they may be key to maintaining cooperative relationships with building owners and occupants.

Other approaches may also help prevent vapor intrusion. **Vapor membranes** may also be installed under new slabs. As long as membranes remain intact, they can prevent vapors from intruding, but they may be damaged during installation, perforated during building modification or maintenance, or fail due to earth movement and age. Thus most agencies consider membranes helpful, but not reliable in the long run as stand-alone mitigation. Similarly, cracks, holes, gaps (at the edges of the barrier where it should attached to the foundation), and other openings through which vapors might enter the building should be sealed with impermeable, but flexible material.

In commercial structures and schools, centralized **heating, ventilation, and air conditioning** systems may also discourage vapor intrusion. HVAC systems may remove toxic vapors due to high ventilation rates or prevent intrusion by creating a positive air pressure (compared to the subsurface) inside. Because operating HVAC systems for long enough periods to prevent intrusion may add significantly to energy bills, they are generally considered helpful but not generally accepted as stand-alone remedies.

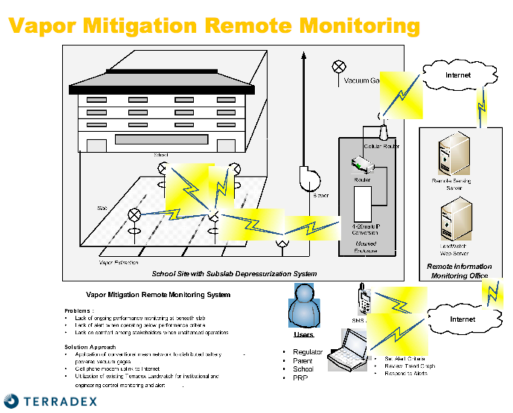
Others technologies, such as **air filtration** or **subslab pressurization/venting**, may be introduced in unusual situations, but depressurization systems are the proven, reliable, inexpensive choice in the vast majority of situations. In dirt basements, which are particularly susceptible to intrusion, **intake and**

exhaust fans may be used—without piping—to reduce toxic vapors, although the effectiveness of these needs to be demonstrated at each location.

Long-Term Management

Depressurization systems are an effective form of vapor intrusion mitigation, and other technologies may be applicable as well. *However, they only work as long as they work.* To ensure that building occupants are protected, mitigation should be anchored in long-term management, which includes operation and maintenance, monitoring and inspection, contingency planning, notification, institutional controls, and periodic review.

Operation and Maintenance. While all elements of mitigation systems should function continuously as long as intrusion remains a threat, the element requiring the most attention is usually the fan. Either a maintenance person or building occupant should check frequently to ensure that fans are operating properly, for example, by performing a visual check of the system's pressure gauge showing proper operational status, or there should be an alarm system that notifies responsible persons of breakdown. This can be an audio alarm, an autodial phone line, or ideally, a continuous Internet signal that stops when the fan fails. Broken fans should be fixed or replaced as soon as possible. Millions of radon removal systems are in place across the country, and U.S. EPA's Office of Air and Radiation has found that the average fan remains operable approximately ten years. Furthermore, it should be clear up front how much of the time active systems—depressurization, HVAC, basements fans—need to remain on.



Monitoring and Inspection. In addition to checking on the blower and vent pipes, those responsible for mitigation should periodically inspect slabs, seals, and other visible barriers. While in many case this may be done infrequently, in some buildings—such as schools—it can be integrated into the daily routine of maintenance personnel—if they are properly trained. After initial tests show that depressurization systems are working, some agencies assume that installed systems continue to operate as designed. Others require periodic performance measures, such as subslab pressure tests. However, building occupants usually prefer indoor air testing, the best measure that the air is safe. The details may vary, but each site should be governed by a monitoring plan developed in consultation with building owners and occupants.

Contingency Planning. At the time mitigation systems are installed, there should be clear plans with clear triggers for doing something more should they fail, whether that failure is due to equipment failure, changes in the extent and concentration of the contamination, natural disasters, or other catastrophes. For example, one might specify that additional depressurization pipes will be installed if indoor air testing indicates unacceptable contaminant levels after system installation.

Notification. Regular building occupants, present and future, should be made aware of the potential for vapor intrusion and the need for continuing mitigation. Owners should notify renters and workers. School buildings should contain entrance plaques or signs notifying people that the structure is subject to a vapor intrusion site management plan. States have varying requirements for notifying potential buyers, but at a minimum they should be informed about the vapor intrusion problem before the paper-signing session that closes the home-purchase deal.

Institutional Controls. Most simply, there should be proprietary controls (deed restrictions) or zoning overlays to prevent a change in use or access without considering the potential for additional vapor intrusion exposures. But more important, the responsible party, property owner, or other entity must be given legally binding responsibility for all of the other aspects of long-term management. This party should demonstrate up front that it has the capacity to take responsibility for protecting building occupants for the life of the contamination.

Periodic Review. The entire vapor intrusion response should be reviewed for protectiveness every five years or less. If, in that review, mitigation is found not to be sufficiently effective, more should be done. On the other hand, if the contaminant source no longer poses a vapor intrusion threat, then mitigation may be suspended. (However, there is a benefit to continuing the operation of depressurization systems, because these systems provide significant health benefits by reducing radon concentrations in indoor air as well as by reducing indoor moisture and molds.) All aspects of the long-term management plan should be checked, and the affected public should be given the opportunity to comment.

Remediation

In the long run, the best way to prevent vapor intrusion is to remove the contaminant source. Unfortunately, contaminants such as PCE and TCE are denser than water. In liquid form, they tend to descend to the bottom of aquifers. It is difficult and time-consuming—taking decades—to achieve groundwater cleanup objectives using conventional cleanup technologies such as pump-and-treat and soil vapor extraction. Furthermore, while some states, such as arid California, require the cleanup of all *potential* drinking water supplies, others lack such a requirement. That's why the state of New York doesn't even track solvent plumes in most of New York City. The City gets its water from upstate. Yet those plumes may be releasing toxic fumes into a large number of buildings.

The first imperative, therefore, is to make sure contaminant plumes are identified and regulated anywhere they pose a threat of vapor intrusion. Once that is done, they should be folded into official cleanup programs. Even if mitigation is successful in the short run, that should not exempt them from remedial action. Not only may mitigation efforts break down or even be forgotten, but there is also evidence that persistent shallow plumes release contaminants to the outdoor air, contributing to the omnipresent background levels of these chemicals in the atmosphere.

Thus, decreasing the time to reach current groundwater concentration remedial objectives—usually five parts per billion for TCE and PCE—should itself become a remedial objective. That is, decision-makers should select remedial alternatives that speed up the cleanup process, because vapor intrusion represents a continuing risk. In fact, at sites where pump-and-treat remedies were chosen years ago, newer, alternative remedial technologies should be considered. Though it may seem difficult to re-open operating cleanup projects, responsible parties and regulators may actually go along because the financial, energy, and carbon footprint costs of extraction systems just continue and grow.

Few people were aware of the threat of vapor intrusion when many cleanup projects were initiated in the 1980s or 1990s. Now the vapor intrusion pathway is known to be widespread enough that it should cause us to re-think our entire groundwater protection strategy.

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For Further Information

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