Guidance for Professionals

State of Wisconsin
Department of Health and Family Services
Division of Public Health

Chemical Vapor Intrusion and Residential Indoor Air

Guidance for Environmental Consultants and Contractors

CONTENTS

Sites with volatile organic compound (VOC) contamination are potential public health hazards. Contact with contaminated soil and the contamination of drinking water are widely recognized pathways of exposure. One commonly overlooked pathway involves VOC movement from groundwater or soil into nearby building foundations, and then into the indoor air that people breathe. This pathway is commonly known as chemical vapor intrusion. This is the most complicated pathway to evaluate in terms of assessing a public health threat, since changing atmospheric conditions such as wind, pressure, and precipitation rapidly affect indoor VOC concentrations. Although measurable effects to indoor air are not seen at every VOC-contaminated site, the efficiency of inhalation exposure makes it important to investigate vapor intrusion as a potential exposure pathway. The health risks from breathing VOCs in air are much greater than from drinking comparably contaminated water. The Wisconsin Division of Public Health (DPH), Department of Health and Family Services (DHFS) has developed this document as guidance for environmental consultants and contractors addressing chemical vapor intrusion questions. Basic vapor intrusion concepts are reviewed in an effort to develop a simplified, pragmatic approach to addressing this exposure pathway.

1. Document Purpose

This document is intended to assist consultants and contractors in understanding the basic concepts of chemical vapor intrusion and the importance of addressing this potential public health issue. The guidance in this document should not be interpreted to contradict existing guidance and regulations related to the investigation and remediation of environmental contamination.

This document does not represent new policy. It was developed to describe existing DHFS policy and practice for evaluating indoor air quality impacts from chemical vapor intrusion. Every project site will present unique circumstances. DHFS staff work with Department of Natural Resources (DNR) or Department of Commerce (Commerce) staff to address special circumstances on a site-specific basis. The Indoor Air Program in DHFS has provided health advice on related topics since the late 1970s. DHFS staff provide technical assistance on human health risk assessment issues to other agencies and the public.

2. How Vapor Intrusion Occurs

Vapor intrusion occurs when volatile contaminants migrate from contaminated groundwater or soil to the indoor air of a building. The most common vapor intrusion cases involve **petroleum** contaminants from leaking underground storage tanks and spills. Projects involving **chlorinated solvents** from commercial sites, industrial sites, and landfills make up the remaining cases. Although less common than petroleum vapor intrusion, projects involving vapor intrusion of chlorinated solvents are much more complicated to evaluate because of their greater mobility and the lack of accompanying odor.

Several factors must be present for vapor intrusion to impact indoor air and cause exposures of public health concern. Some conditions that make this exposure pathway either more or less likely are:

Building Features

- Susceptibility to Radon Impacts – The building features that influence chemical vapor intrusion are the same as those that influence the movement of radon gas from soils into a home. Because many homeowners are testing their homes for radon (particularly when the home is purchased), information may already be available about the susceptibility of some homes in the area of concern. The absence of radon in indoor air does not mean chemical vapor intrusion cannot occur.
- Construction style – Vapor intrusion can occur in homes without basements. Investigation of sites in other states has found that even slab-on-grade construction can be affected by vapor intrusion. Prior to learning about these sites, DHFS had de-emphasized the potential for vapor intrusion in homes without basements or crawl spaces. However, the condition of the foundation and presence/absence of an adequate vapor barrier appear to be more important indicators of susceptibility.
- Age of home – Older homes are less likely to have adequate vapor barriers incorporated into the foundation construction, and the foundation itself is more likely to have developed cracks with age. However, newer homes have become more airtight and will have less fresh air exchange, which can increase the buildup of contaminants from soil vapor intrusion.
- Dirt floors and stone foundations - Earthen floors and limestone or field stone foundations are more porous and provide increased opportunity for vapor intrusion from that of poured concrete foundations found in newer homes.
- Drain tile/sumps - If the building has a foundation drain tile connected to a sump there is a direct conduit to the indoor air. If the sump is active, even low VOC concentrations in the water can contribute to significant indoor air problems. As the water flows over the ridged drain tile and then into the sump, much of the VOC mass is efficiently stripped from the water (particularly for VOCs with high Henry's Law Constants), and then into the head space of the tile, sump and indoor air.
- Wet basement - If the building has chronic water problems, VOCs dissolved in water infiltrating into the basement will off-gas to indoor air. Periodic water problems can be related to improper landscaping and drainage, but also may indicate a shallow water table.
- Utility lines - Gaps or cracks around piping or other utility lines that enter through the foundation can be important preferential migration paths for vapor intrusion. Permeable soil in a utility trench can also provide a conduit through which contaminants may migrate greater distances from the source area. The DNR has a useful guidance document on this topic on their website at:
  http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR649.pdf

Environmental Conditions

- Proximity of source to buildings - Vapor intrusion should be an obvious concern to rule out when buildings are very close to the source of VOC contamination. If free product or extremely high concentrations of source VOCs are migrating from the site, this should be considered an extension of the source area.

$ Shallow groundwater - The potential for vapor intrusion decreases with increasing groundwater depth. The U.S. Environmental Protection Agency (EPA) suggests that vapor intrusion cannot be safely ruled out when the groundwater table is less than 100 feet from the surface.
$ Contaminants in shallow groundwater - VOCs off-gas to soil from the surface of the water table. If there are significant downward groundwater gradients, it is possible that most contaminants are deeper and unlikely to partition to soil vapor.
$ Soil type - Soil type greatly influences the transport of contaminants in soil vapor and groundwater. Coarse-grained soil types can direct contaminant migration long distances, but also provide easier venting to the atmosphere. Fine grained or tight soils inhibit long distance migration, but increased capillarity allows greater vertical contaminant transport. The spatial arrangement of soil type features is as important as the presence of various soil types.
$ Fractured bedrock - Shallow fractured bedrock can increase vapor intrusion potential by encouraging faster soil gas migration and movement of contaminated groundwater. This becomes a greater concern when the bedrock is near the base of the foundation.
$ Degradation - Petroleum hydrocarbons biodegrade relatively well in unsaturated soils. Therefore, petroleum-related VOCs generally have to be in “free product” state or groundwater very near, if not in contact with, the building foundation to result in vapor intrusion. In contrast, chlorinated solvents undergo limited biodegradation and can cause a vapor intrusion concern even when the source is a long distance away.

Seasonal variation can influence both the susceptibility of the building as well as the environmental conditions for vapor intrusion. During the winter months of the year fresh air exchange is reduced because homes are closed more tightly. A stack effect commonly results from the indoor to outdoor air temperature differential as well as the operation of many types of heating systems.

3. Health Implications of VOCs in Indoor Air

Risks from exposure to environmental contamination in water, soil, and air, by estimating how much of a chemical is likely to enter the body based on how the resource is used. The assumptions used for estimating air exposures are more realistic than those used for other media. Breathing rates per body weight are generally uniform, with less variability than daily rates of water intake. People spend a predictable amount of time in their homes (particularly small children, the elderly, and home bound individuals), and there are no alternatives for breathing air sources as there are for contaminated drinking water (i.e. bottled water).

Chemical vapor intrusion poses the greatest immediate threat to health when there is a potential for fire and explosion. The second concern is for a high level, acute chemical exposure that could result in immediate health symptoms. The third tier is comprised of the possible cancer and non-cancer health effects caused by long-term exposure to contaminants in indoor air. The fire and explosion hazard is by far the least likely, while concerns about chronic long-term exposures are the most common.

Fire and Explosion Hazards

Although uncommon, the potential for fire and explosion from vapor intrusion must not be ignored. This threat is greatest when the contamination is related to landfill gas migration or sewer gas co-migrating with methane. **<u>Important Note: this document is not intended to address cases involving landfill or sewer gases. Contact the local fire department or agency staff directly with these issues.</u>** This concern is commonly raised with petroleum vapors because people associate the familiar smell with flammability. The lower explosive limit for gasoline vapors is 1.4%, or roughly 50,000 times higher than its corresponding odor threshold, making this an unlikely threat. However unlikely an explosion may be, it must be ruled out, particularly if odors are strong. Fire and explosion hazards related to chlorinated solvent contaminants in indoor air are also unlikely. Very strong solvent odors would accompany flammable levels (>1000 times odor thresholds). In practice, the local fire department is usually called on to help address this concern. However, after the fire department clears the building of a fire and explosion hazard, an evaluation of the health threats from chemical exposures must still take place.

Acute Health Effects

Once a fire and explosion threat is ruled out, any noticeable odors can be a nuisance. However, vapors may also pose a health risk to residents. Health effects from acute or short-term exposures to VOCs in indoor air are more common for petroleum contaminants than for chlorinated solvents. At levels relevant to vapor intrusion, chlorinated solvent exposures are less likely to cause irritation or nuisance problems.

Exposure to vapors from petroleum contamination can cause headaches, nausea, eye and respiratory irritation. Vapors from heating oils and diesel fuels can be more irritating than vapors from gasoline. Benzene is often the most chronically toxic compound found in petroleum based fuel. Although fuel oil and diesel fuel have lower fractions of benzene than gasoline, they have higher fractions of naphthalene, which can be acutely irritating at very low levels. The most common symptoms people may notice when petroleum odors are strong are headaches, nausea, dizziness, and irritation of the eyes, nose, throat and lungs. Sensitivity to these effects can vary greatly from one person to the next. The individuals most affected by petroleum vapors are children, the elderly, and others with pre-existing respiratory problems such as asthma or bronchitis. In addition to their increased sensitivity to contaminant exposures, children and the elderly tend to spend more of their time at home, which also increases their exposure duration and risk. When residents experience health symptoms, contractors should contact DHFS or the local health department for assistance.

Health and environmental agencies develop health protective values for air quality designed to prevent the most sensitive health effects. For this reason, environmental standards relate to long-term exposures; few quantitative thresholds address acute health effects. Occupational standards, though commonly available, should not be directly applied in a residential setting. They are established to protect a healthy adult worker population for work day exposures, and often incorporate some acceptance of health risk on the part of the worker. When more appropriate residential guidance is not available, DHFS uses 2.4% of the TLV (Threshold Limit Value) as the appropriate residential screening value. This method adjusts from a 40 hour work week to a full week, adds a factor of ten to account for sensitive individuals, and should be protective for most short term exposures. However, if people are showing symptoms consistent with those expected for the contaminants present, DHFS will assume they could be related to chemical exposure until a physician's diagnosis can be obtained. The National Institute for Occupational Safety and Health (NIOSH) Pocket Guide to Chemical Hazards (http://www.cdc.gov/niosh/npg/npg.html) can be a useful reference for both occupational thresholds and chemical and physical properties.

The irritating effects of acute VOC exposure usually diminish after exposure is stopped. If symptoms don't improve following exposure intervention, the health effect may be unrelated to VOC exposure. In all cases involving health effects from chemical exposures, the individuals should consult their physician.

Chronic Health Effects

DHFS health advice for preventing health risks from chronic exposure (periods greater than 3 months) is based on a health protective threshold of 1 in 1,000,000 increased cancer risk for carcinogens and a hazard index of 1.0 (level of exposure below which no non-cancer health effects are expected) for non-carcinogens. For carcinogens, this is consistent with the EPA inhalation unit risk factors found in their Integrated Risk Information System (IRIS) database and the federal Agency for Toxic Substances and Disease Registry (ATSDR) cancer risk evaluation guide for air (CREG). For non-carcinogens, these values are consistent with the EPA inhalation reference concentrations and ATSDR inhalation minimal risk levels (MRLs). When quantitative information on cancer potency or non-cancer effects are not available, protective values for residential indoor air may be derived from occupational limits as mentioned previously.

In vapor intrusion cases, DHFS assessment is almost always driven by the presence of a carcinogenic VOC such as vinyl chloride, trichloroethylene, tetrachloroethylene, 1,1-dichloroethylene, 1,2-dichloroethane, or benzene. Due to its comparatively high cancer potency, mobility in groundwater and high Henry's Law Constant, vinyl chloride is a vapor intrusion concern at lower levels of environmental contamination more often than other chemicals. Trichloroethylene and tetrachloroethylene also represent common concerns because of their widespread use in the past and the frequent proximity of dry cleaners to residential areas and other commercial businesses. Among non-carcinogens, naphthalene is the chemical that most commonly drives health concerns, largely due to its very low odor threshold and unpleasant smell.

In a long-term residential exposure situation, benzene levels at the odor threshold (roughly 5 ppm) pose a significantly increased cancer risk, more than one thousand times greater than health officials would permit in a drinking water exposure. Although benzene is rarely present above the odor threshold, its presence at harmful concentrations may still be suspected when the odors from other petroleum chemicals are noticed. When faint but perceptible gasoline odors are noticed, benzene levels can still be ten to one hundred fold higher than levels considered safe and appropriate for residential indoor air. Other components of petroleum, such as toluene, xylenes, and naphthalene can be smelled at very low concentrations. These low concentrations of odiferous compounds *signal* the presence of benzene. Long-term exposures to these and related VOCs can also pose a risk of non-cancer health effects including damage to the liver, kidneys, blood, nervous system, and others. These non-cancer health effects are addressed concurrently by working to prevent the unnecessary cancer risks.

Confounding Health Effects

Vapor intrusion is often associated with buildings situated over high water tables, leading to basement water problems. For homes with chronic moisture problems, the health issues from vapor intrusion can be complicated by the presence of mold and other bioaerosols. The irritation symptoms caused by mold exposures may be similar to those from acute VOC exposures. When potential mold issues are encountered a service can be provided to the residents by directing them to mold cleanup information on the DHFS web site. Many of the common irritation symptoms are similar and cannot be easily separated. Even in the presence of mold, the presence of unsafe levels of chemical vapor is not considered acceptable. Fact sheets on a variety of important indoor air quality topics including mold and carbon monoxide can be found at the DHFS web site at:(mold) http://www.dhfs.state.wi.us/eh/HlthHaz/fs/moldindx.htm
(indoor air) http://www.dhfs.state.wi.us/eh/Air/

4. Evaluating Vapor Intrusion

With any concern about chemical vapor intrusion (including petroleum) **it is best to show the pathway is broken as far as possible away from residents**. This is consistent with the process of determining the degree and extent of contamination by starting at the source area, moving outward until the limits are defined. Follow the bulleted steps below in order until the pathway is successfully broken.

- Attempt to demonstrate that groundwater contamination doesn't extend to the residential area or other building. If not, move to next bullet.
- Attempt to show that contaminants are not found in shallow groundwater.
- Show that contaminants have not partitioned to soil vapor by collecting soil gas samples. A sample from the head space of a well screened at least partially in the vadose zone is not a perfect substitute, but will do if it's located at a "worst case" part of the plume. (**note: If shallow contaminated groundwater is occasionally in contact with building foundations, jump ahead to the building specific evaluation as contaminants can enter the building directly without partitioning first to soil gas.**)
- Demonstrate that the extent of soil gas migration does not reach the building foundation(s). This is shown by sampling soil vapor near the foundation or beneath the slab and finding no detectable VOCs.
- If soil gas indicates the presence of VOCs near the foundation, additional building specific evaluation will be needed. This evaluation can include a sub-slab sample and indoor air sampling, but would also focus on identifying the presence of building features that would influence vapor intrusion. If vapor intrusion cannot be ruled out there is room for both modeling and air monitoring. However, neither of these tools can be effectively used without a strong understanding of site specific conditions.

There is generally a significant reduction in concentration as contaminants partition across each medium (e.g. from groundwater to soil vapor and from soil vapor to indoor air). Additionally, as contaminants partition from one matrix to another and towards indoor air, concentration variability increases. Soil vapor concentrations are less variable than indoor air, though still affected by change in season and precipitation events. Likewise, groundwater concentrations are generally more stable over time than those of soil vapor. If soil vapor concentrations are already consistently below levels that would be of concern for indoor air, they would not be expected to re-concentrate in indoor air. Even in a home with little fresh air exchange, ambient outdoor air will make up the greatest proportion of indoor air. The EPA draft guidance discussed in section 8 of this document assumes a minimum reduction of a factor of ten from soil vapor to indoor air.

DHFS recommends a separate approach for evaluating vapor intrusion related to petroleum contamination sites from that used for chlorinated solvents and other VOCs. The difference in approach is based upon the different odor thresholds of the contaminants and expected co-contaminants in each group.

Petroleum-Related Vapors

For several years DHFS has used the presence or absence of odors to indicate the presence or absence of a public health concern for sites with petroleum contamination. Although a need for a practical approach was the basis for this policy, it is well supported by DHFS experience with petroleum contaminants. Odors are considered to be absent if they have never been noticed, or if they are no longer noticed following an action taken to mitigate a problem. Odors are considered to be present if they are noticed even occasionally. If odors are infrequent or only were noticed on one occasion, evidence exists that a migration pathway is present. To show that future exposures would not occur it is important to identify the conditions that resulted in the odors and demonstrate that those conditions no longer exist (e.g. a small release that's been removed).

DHFS involvement is almost always initiated by contact from consultants or agency staff because of the **presence** of a petroleum odor. Historically the detection limits for benzene and naphthalene were not low enough to assure that levels were below DHFS targeted 1 in 1,000,000 increased cancer risk threshold for indoor air. The type of investigation that could rule out the potential for long-term exposures of health concern was rarely practical in comparison to taking steps to mitigate the problem. When odors are present expense of air testing should be spared and redirected towards correcting the problem. Sampling and analytical technology has improved in recent years so that detection limits can be quite low. Nevertheless, there continue to be concerns about the variability of air quality over time and the reproducibility of sampling results.

Similarly, vapor intrusion modeling is of little value in the case where petroleum odors are already present. The presence of odors when a model shows no unacceptable risk is more likely to be an invalidation of the model than assurance that public health is protected.

The odors from petroleum products are familiar to most people. In fact, most people can readily distinguish between the odors of gasoline and diesel fuel. For this reason it is less likely that people will mistake chemicals in the air from other non-petroleum sources for impacts from a petroleum contamination. The primary situation that complicates the use of odors is when there are other petroleum sources in the home (e.g. heating oil tanks with leaks or improper venting, gasoline storage, etc.). In such cases these sources would need to be removed or corrected prior to fully evaluating the situation.

DHFS use of the **absence** of a petroleum odor to indicate the absence of a problem is primarily related to follow-up at sites initially discovered due to the presence of odors. Although people have not contacted DHFS staff to ask about cases where no odors are present, the lack of a petroleum odor can be a strong indication that public health is not threatened.

As mentioned previously, benzene is often the most toxic component of petroleum. The odor threshold for benzene alone does not provide adequate protection against exposures of public health concern. However, benzene from petroleum contamination is generally present with a complex mixture of other petroleum compounds with very low odor thresholds (benzene comprises about five percent of gasoline and a lower proportion of fuel oils). As a result, the odor thresholds of these other petroleum VOCs serves as a surrogate odor that indicates potential unsafe benzene exposures for gasoline and diesel fuel spills.

Although a subjective odor evaluation is far from perfect, there are a number of reasons why air sampling for petroleum cases is not generally recommended. Indoor air quality in a home varies from day to day and throughout the day. This is affected by wind speed and direction, temperature, barometric pressure, humidity, opening and closing doors and windows, and seasonal variation (frost, precipitation, etc.). An air sample will only tell the air quality at the time that it is collected. However, residents are in the home much of the time and the human nose is always *on*. There are hundreds of different chemicals found in gasoline and the various fuel oils. Many of these contribute to the odor but are not specifically identified by most analytical methods.

A variety of petroleum distillates, including the BETX (benzene, ethyl benzene, toluene, and xylenes) compounds, can be found in indoor air from a number of sources within and outside a typical home. Without a characteristic petroleum odor (at least occasionally), it is difficult to link the presence of low level petroleum chemicals to a vapor intrusion source. In addition, outdoor ambient air commonly contains detectable concentrations of these same chemicals (particularly near filling stations). These potential background concentrations generally fall below the odor thresholds for these chemicals.

It is possible to conceive of a situation where benzene was present at levels of health concern and no petroleum odors were ever noticed. Such a case would be most likely when benzene is migrating at high concentrations from a source without the typical petroleum co-contaminants. In such a case, odors would not be protective and a process similar to that for chlorinated solvents should be followed.

Talking with neighboring residents can be the most useful method for evaluating petroleum vapor intrusion. Determine if they or visitors to their home have ever noticed odors inside that aren't from an outdoor air source such as tank filling, or surface spills. Find out if they have a sump, and if they would mind it being inspected. Residents may not lift the lid on the sump very often and a quick check may warn of a problem before it becomes an issue. Don't be surprised if there is disagreement between individuals about the presence/absence of odor. This is a

Olfactory Fatigue and Petroleum Vapors

Because of the heavy reliance upon on the sense of smell when dealing with petroleum vapor intrusion it is important to recognize the potential for olfactory fatigue or odor desensitization. People exposed to petroleum vapors over a period time may gradually lose their ability to notice the odor. People can periodically get a *fresh nose* by leaving the home for a period of time (few hours) and returning to the home. A visitor entering the home would also have a *fresh nose*. When petroleum impacts are expected, it is important that residents and contractors avoid the use of air fresheners (cover scents), and avoid the use of paints or sealants as they diminish the ability to note odors when present.

demonstration of the individual variability in sensitivity to odor and not either party being disingenuous. At a minimum this can help determine that the levels are in the lower end of the range of odor thresholds. If trust is a problem at a site, a third party objective nose may be helpful. As a last resort in a dispute, testing may actually be helpful.

Chlorinated Solvent Vapors

In contrast to petroleum vapors, the odor thresholds for most chlorinated solvents provide little warning at concentrations relevant to protecting public health. Unlike benzene in a petroleum release, chlorinated solvents do not necessarily migrate with other chemicals that have low odor thresholds. The variability and uncertainty mentioned in the previous section also applies to vapor intrusion with chlorinated solvents. However, when chlorinated solvent vapors cannot be smelled at low enough levels, and sampling doesn't give much additional confidence, much can still be done. The following sections regarding Vapor Intrusion Modeling, and Screening Values for Environmental Media refer primarily to chlorinated solvents and other contaminants with insufficient odor warning properties. To increase confidence in the evaluation of this pathway, an approach using multiple lines of evidence, including both direct measurement and modeling, is recommended.

5. Vapor Intrusion Modeling

Vapor intrusion models can assist in evaluating the pathway for chlorinated solvents and other high odor threshold VOCs. However, they are not intended to serve as the only part of the evaluation. Used in combination with site-specific information and the site investigation, the results add to the overall weight of evidence used to either establish or rule out the exposure pathway. The Johnson and Ettinger (1991) Model for Subsurface Vapor Intrusion into Buildings available on the EPA website (http://www.epa.gov/superfund/programs/risk/airmodel/johnson_ettinger.htm) is one of the most commonly used models. Guidance for selecting model inputs is also available on the website.

The most common vapor intrusion models are deterministic, having single point inputs and outputs. They are strongest under homogeneous site conditions with uniform building construction features, and weakest under variable conditions. Using the range of potential input assumptions that match the range of site conditions (various soils encountered, ranges of contaminant concentrations, etc.), these models can predict wide range of indoor air impacts spanning orders of magnitude.

To function properly, the input assumptions must be adjusted to match the conditions at each site. It is important to understand the sensitivity of the variables in the model being used. These models are based on the basic principles of contaminant fate and transport, contaminant partitioning between media, and the physical and chemical properties of the contaminants themselves. It is also important to note that vapor intrusion models do not incorporate preferential migration pathways such as foundation drain tile and sumps (dirt floors, compromised floor drains, field stone or limestone foundations, etc.). Each of these conditions has the potential to significantly increase the rate of vapor intrusion beyond what the model would predict.

Despite their weaknesses, models allow the user to quickly screen site data (particularly for large areas and preliminary data). For properties proposed for development they may be the only tool available for predicting future problems and the need for additional remediation or altered building design.

6. Air Sampling and Interpretation

By the time the decision is made to monitor indoor air, other attempts to rule out unacceptable vapor intrusion (soil vapor, etc.) have probably failed. Therefore, one time or even repeated sampling may not provide enough confidence that unacceptable exposure cannot occur. In such cases the cost of mitigation should be weighed against the cost of long term monitoring (which could result in the need for mitigation anyway). There are a variety of monitoring methods available, each of which has its own strength and weakness. Table 1 contains a basic summary of the air monitoring methods commonly considered.

Table 1
Summary of Air Monitoring Methods

How to Sample	***Why***
Evacuated Sampling Canisters (*Summa*)– Evacuated canisters that collect a measurable volume of air for TO-14 or TO-15 lab analysis.	This is currently the most reliable method for analyzing a wide range of chemical contaminants in indoor air. Grab samples or time integrated samples can be collected with calibrated regulators. Because of detection limits – more background VOCs will be identified. This method can be costly and results are not available for several weeks.
Charcoal Tube Samples – Air is drawn at a constant rate over a known period of time through glass tubes packed with activated carbon absorbent media.	The detection limits are lower than real-time options and specific VOC analysis is possible. Pump flow calibration and periodic testing is very important.
Colorimetric Tubes – Air is drawn through glass tubes containing reactive media. Change in color compared to graduated charts representing concentration.	Detection limits similar to a PID but are also chemical or chemical group specific. Used more for spill response when levels of exposure may be high and quick answers are needed. May be of some use in worst case monitoring, but not useful for low level residential exposure.
PID/FID – Photo ionization detectors and flame ionization detectors are real-time hand held monitoring devices that are useful for measuring total VOC concentrations in air.	Useful for quick screening in worst case areas, points of vapor entry (sumps, cracks, etc.) or other potential VOC sources (household chemicals, heating oil tanks, etc.). A measurement of "no detect" does not by itself rule out vapor intrusion. Primary limitations are relatively high detection limits and lack of chemical specificity. Important to have an outdoor measurement.
Passive Badges – Passive collection media in an open cassette or badge that can be carried around by the individual.	More popular in an occupational setting, not as useful for low level residential exposure concerns due to detection limits. Not recommended. Detection limits in the range of a PID but can be chemical specific.
Explosivity Meter – Hand held meter for measuring combustible gases. Sensors read both oxygen and combustible gases.	Useful for assessing fire and explosion. Use at points of entry where odors are strong. If fire and explosion is a concern, contact fire department or Hazmat Team for assistance. Does not rule out acute or chronic health threats.

Indoor air sampling is most useful when the question being answered is clear and sampling is tailored to the specific situation. When planning an indoor air investigation, begin with three basic questions: 1) Are chemical vapors are entering the building? To answer this question a sample should be collected from a worst-case sampling point, such as a sump opening or area of basement floor or wall where major cracks are present. In general a grab sample taken during worst case conditions is best for answering the first question. However, if worst case conditions aren't known, a time-integrated sample (collected over several hours) should be taken. 2) What is in the outside air? The majority of indoor air is made up of the ambient air outside rather than soil vapor. Indoor air samples without outdoor air samples can be difficult to interpret because it is common to have detectable VOCs in the ambient air of urban areas. 3) Is there a chemical exposure hazard? This is the most difficult question to answer, as the results of individual samples cannot be directly translated to either past or future exposures. A time-integrated sample should be used when answering this last question. Table 2 describes the rationale for selecting sampling location.

Table 2
Rationale for Selecting Air Sample Location

Where	***Why***
Soil vapor – Install sampling probes near the building foundation to a depth near the base of the basement foundation, or where most of the source vapor would enter the basement.	Provides worst case point of monitoring as it will become only a fraction of indoor air volume. Chemical levels tend to vary less than in indoor air. Levels are not representative of indoor air concentrations.
Sub-slab vapor – EPA currently recommends that a sample be collected from soils beneath the slab at a central location away from walls. A sample from a crawl space can also be used if present.	This sample provides the last point of monitoring to demonstrate whether contaminants are in fact migrating from the source to the home. A small hole must be drilled in the slab in order to collect this sample.
Sump headspace vapor – Cover the sump for several hours if possible prior to sampling. Draw air into SUMMA canister or charcoal collection media from beneath cover.	Can be a good surrogate for sub-slab sample and can be representative of the soil vapor entering the basement. This sample can be somewhat diluted by ambient air entering along the foundation.
Sump water – Hold VOC vials directly beneath water entering sump. A stagnant sump sample is of almost no use at all.	If sump is actively flowing this can help to identify chemicals of concern. VOCs volatilize from the water on the way to the sump. Results cannot be use to predict exposure.
Basement Air – Collect a sample from an area where vapor entry is expected, or from a central location if an obvious point of entry is not known.	A sample of basement air can be used to demonstrate whether soil vapor is impacting the air of the home.
Air from lowest part of living area – Collect a sample from a tabletop height in a living area of the home. If the basement is finished and used, a sample should be collected there. Avoid other sources of VOCs such as cleaners and air fresheners.	This sample represents the air quality at a common point of exposure. However, multiple samples over time, taken at multiple locations (bedrooms, kitchen, bath, etc.) would be needed to estimate actual exposure.
Outdoor air sample – Collect a sample from an upwind location of the house away from obvious VOC sources (parked cars, lawn mowers, garage, etc.).	This sample is very important, as indoor air contaminants may originate from outdoor air.

When VOC air sampling is needed, DHFS recommends a 24 hour time-integrated sample (evacuated canister) using EPA Method TO-15 analysis. Before indoor air samples are collected it is important to take a chemical inventory to make note of other potential VOC sources in the home. It is helpful to note weather conditions, and activities in the home so that the results can be more fully understood. The EPA guidance document referenced in section 8 contains an inspection questionnaire in Appendix H that provides a useful checklist. When results are received, they should be considered along with other equally important factors such as variability of the contaminant source, how representative the sample location is to other areas of the home, how the areas are used, and other site specific issues that all combine to shape the level and frequency of long-term exposure.

If the home is served by a private well, it is important to note that any VOCs in the well water will enter the indoor air through normal water use. It may be difficult to distinguish between the two potential sources of contaminants to indoor air.

Further Reading: The State of Massachusetts Department of Environmental Protection has compiled a useful and detailed guidance document on indoor air sampling and evaluation. The full document, "Indoor Air Sampling and Evaluation Guide," released in April, 2002 is available on their website at: http://www.state.ma.us/dep/ors/orspubs.htm#air

The State of California has developed advice on soil gas investigation available at: http://www.dtsc.ca.gov/PolicyAndProcedures/SiteCleanup/SMBR_ADV_activesoilgasinvst.pdf

7. Use of Screening Values for Environmental Media

A number of states use tables of screening values to determine if the vapor intrusion pathway warrants further consideration. These table values contain minimum groundwater or soil contaminant levels and are generally calculated from a vapor intrusion model using a set of generic assumptions. Although DHFS does not discourage the use of these tables as another tool to consider at a site, DHFS does not have a similar set of screening values. For these values to be applied generically across the state, they would have to be very conservative and based on assumptions that do not make sense for most sites. It is important to note that site specific conditions that invalidate the use of vapor intrusion models (presence of sumps, etc.) would make the use of the tables inappropriate as well. Therefore it is important that these values not be considered in the absence of knowing site specific conditions.

8. EPA's Subsurface Vapor Intrusion Guidance

EPA has recently released a document for public comment entitled "Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils." DHFS staff have reviewed the EPA guidance and find that it is generally consistent with DHFS guidance. The EPA document includes tables of screening values for indoor air, groundwater, and soil vapor based on three different health protective thresholds. Table 2c of the EPA document contains the values consistent with the health protective threshold used by DHFS (1 in 1,000,000 cancer risk and hazard index of 1.0). When site media concentrations exceed the table values by a factor of 50, the guidance recommends an expedited evaluation, as entering site specific information is not expected to reduce predicted exposures by that much. EPA has stated in training about the guidance that adjusting the Johnson and Ettinger model using site specific data could increase yield a groundwater value as much as 20 times the table value (which is based on default assumptions). Adding site specific data could also yield a soil vapor level as much as 100 time the screening table value. This EPA guidance does not address sites involving petroleum contamination.

The general intent of the EPA document is to move contractors toward active investigation of the pathway when it cannot be obviously and easily ruled out. Because the document is relatively long (178 pages), contractors should not be tempted to simply use the table values for screening their sites. The EPA document contains a sound process for decision-making. The tables are not intended for use outside that decision process. People investigating vapor intrusion should take the time to become familiar with the guidance and use it as intended. A full copy of this guidance is available on the EPA website at: http://www.epa.gov/correctiveaction/eis/vapor.htm

9. Preventing Vapor Intrusion

The two separate but equally important approaches to preventing chemical vapor intrusion are source control and air quality mitigation. How the two approaches are used together depends on the conditions of the site and whether or not the pathway is already completed. As a general concept DHFS recommends interrupting the migration pathway as far away as possible from points of human exposure. It is important to note that any action taken to remediate environmental contamination must be done in coordination with the DNR or Department of Commerce (Commerce).

The first and most traditional approach is to control the source of contamination so that the contaminant migration pathway does not reach the buildings in question. This source control activity is usually designed to prevent groundwater contamination that would exceed groundwater and drinking water standards. The same approach applies to preventing vapor intrusion originating from contaminated groundwater. Controlling soil gas migration is also an important source control activity, especially when the contaminants are migrating through soil gas directly from the source. When contaminants have reached buildings, source control is still necessary and important but mitigating indoor air impacts becomes a more immediate priority. Ultimately, source control efforts should result in removing the need for mitigation at the building.

When contaminants are entering a basement, steps should be taken to close off any gross openings that allow for direct soil vapor intrusion. These include openings in the slab, major cracks in walls, gaps around utility lines, sumps lids that do not fit tightly, compromised floor drains, etc. If odors are apparent, the basement air should be ventilated separately, as much as possible, from the remaining occupied portions of the building (closing cold air returns and heat vents in the impacted area). The remaining mitigation steps involve creating a pressure differential between indoor air and soil gas that prevents vapor migration into the basement. The most commonly recommended mitigation techniques utilize sub-slab depressurization systems developed to prevent radon gas migration. These systems tend to be relatively inexpensive (compared to an indoor air investigation and other aspects of site remediation) because they can be adapted to take advantage of existing building features. The most common technique involves sealing the sump connected to the foundation drain tile and actively ventilating the head space of the sump to the outside air with a low flow, low energy use blower. A list of radon contractors can be obtained at the following DHFS web site: http://www.dhfs.state.wi.us/dph_beh/RadonProt/Lists/MitigProf.htm

For cases involving landfill gas or the migration of other explosive gases it is important to intercept the gas migration as far away from buildings as possible. Preventing intrusion of methane directly into the indoor air may not always completely eliminate the potential for a fire and explosion hazard. Gas collection trenches are commonly used for this purpose along with combustible gas meters/alarms in individual homes.

As discussed earlier, vapor intrusion concerns are more common when the home has a water intrusion problem. In these cases questions commonly arise as to who is responsible for addressing which part of the problem. There are certainly compelling public health reasons for correcting such problems and homeowners clearly have that responsibility when chemical contamination is not present. However, mitigation is very difficult if not impossible without also addressing this water intrusion condition. For this reason it is important to work together with the homeowner to address both problems simultaneously.

Useful information on mitigation techniques (a.k.a. Radon Resistant New Construction - RRNC) is available on the following US EPA web site and in related documents such as "Building Radon Out" http://www.epa.gov/iaq/radon/construc.html

10. Vapor Intrusion and Brownfield Redevelopment

Questions about vapor intrusion can come up as part of brownfield redevelopment on properties with residual VOC contamination. When the issue is addressed prior to final building design and construction more options are available. Good characterization of degree and extent of contamination is important. With knowledge of the extent of contamination additional remediation work can be done to accommodate building construction, or building design can be modified to accommodate the residual contamination left in place. The ideal situation would involve complete remediation of the contaminant source(s) coupled with vapor mitigation built into building construction. Reuse of existing buildings with contaminants in contact with the foundation is more problematic. It is important for prospective developers to know that a very good investigation and remediation is necessary to ensure that public health is adequately protected for a residential redevelopment. More comprehensive information about Brownfield redevelopment can be found on the DNR web-site at: http://www.dnr.state.wi.us/org/aw/rr/.

As with vapor intrusion concerns involving existing residences, a soil gas survey can be an effective means of identifying the presence or absence of a vapor migration pathway. Unless the proposed development significantly changes current conditions (increased paved areas, added fill material inconsistent with current soil type, change in water table, etc.), the results should be reasonably good predictors of future potential conditions.

Prior to any redevelopment contaminants of concern must be evaluated for each pathway of potential human exposure. In cases involving residual VOCs, groundwater impacts and vapor intrusion tend to be the primary pathways to investigate. The mitigation features can vary according to the extent of remaining contamination prior to construction. The following general mitigation approaches can be considered depending upon the level of cleanup and contamination remaining:

No special construction features needed – If the contaminant source area has been completely removed and follow-up sampling indicates that residual VOCs are not present, vapor intrusion mitigation measures would not be needed. Because current building construction methods already incorporate vapor mitigation features, a developer may wish to more deliberately include them as an added protection without much additional cost.

Basement construction with passive mitigation – Passive mitigation is composed of two components, 1) creating a competent vapor barrier, and 2) providing an alternate route for vapors to vent to the atmosphere. The second of these components may be the only one that needs to be more deliberate with existing construction practices. In most current construction a gravel base beneath the concrete floor provides a preferential flow path for soil vapors. Adding a layer of plastic sheeting is also recommended to prevent concrete mixture from clogging the gas permeable gravel layer and to provide additional barrier to soil vapor migration. With some construction, this gravel layer may be vented to indoor air via the foundation drain tile and collection sump. Instead, the gas permeable gravel layer should be vented to the atmosphere directly and there should be no openings to the basement air. This construction is appropriate for residual VOCs unlikely to contribute to unacceptable air impacts (e.g. soil vapor concentrations already below levels of health concern).

Basement construction with active mitigation – The primary difference between active and passive mitigation is the addition of forced ventilation of the soil vapor to the atmosphere. A low flow vent fan is installed in the vent pipe to create and maintain a slight vacuum on the outside of the basement foundation. The vent fans themselves are energy efficient and do not add significant operating costs for the building owner. This active measure ensures that soil vapors do not enter buildings in the event that pressure gradients change temporarily and the vapor barrier is compromised. These systems are appropriate when unacceptable impacts to indoor air cannot be ruled out. Construction requiring active mitigation also requires ongoing monitoring and maintenance of mitigation system. It is important to locate the vent stack opening so that the vented air does not get drawn back into the building through air intakes or open windows. Because of the difficulty in coordinating long-term maintenance activities with individual homeowners, single family residential redevelopment that relies upon an active vapor mitigation system is not desirable.

Slab-on-Grade with passive mitigation – The construction of a concrete slab on top of a permeable gravel layer (vented to the atmosphere) further reduces this unlikely pathway. This method is most appropriate when the water table is well below the gravel layer. The gas permeable layer should incorporate a conduit to the roof-line to ventilate the vapor beneath the slab and take advantage of the existing stack effect. It can also be used to avoid adding active mitigation when residual VOCs are high enough to warrant it for basement construction. It is important to ensure that any openings in the slab where utilities enter from the subsurface are properly sealed.

Slab-on-Grade with active mitigation – This method incorporates a ventilation fan with slab on grade construction. This method may appropriate when the building has a particularly large footprint making it difficult to provide adequate ventilation to the atmosphere. This technique may also be used when a portion of the building is constructed below grade and would be part of the same active system.

When the vapor intrusion pathway is ruled out contingent upon maintaining a specific engineering control or landuse for the property, changes in landuse should trigger a reassessment of the pathway.

For more information, contact the following DHFS staff:
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For project specific questions, also contact the DNR or Commerce project contact for the case.

If while reviewing this document you have thought of helpful tips for addressing this pathway that you have learned from your past experience, please forward your suggestions to Chuck Warzecha at warzecj@dhfs.state.wi.us for incorporation into future revisions of this document.

This document will be available on the web along with other fact sheets currently on environmental topics at http://www.dhfs.state.wi.us/eh.

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