VERMONT

State of Vermont
Department of Environmental Conservation
Waste Management & Prevention Division
1 National Life Drive – Davis 1
Montpelier, VT 05620-3704
(802) 828-1138

AGENCY OF NATURAL RESOURCES

Vapor Intrusion Guidance

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Introduction

The Vermont Department of Environmental Conservation (VTDEC), Waste Management and Prevention Division (WMPD), Sites Management Section (SMS), developed this document to provide guidance on what is required to perform a vapor intrusion (VI) assessment, to determine if VI needs to be mitigated, and how to demonstrate that the VI mitigation is effective. Flowcharts are also provided to help illustrate the steps that should be taken when assessing the VI pathway.

This document does not include a discussion of strategies for treatment of contaminant sources that are causing VI. It should be understood that in most cases VI mitigation is considered an interim measure or is conducted in conjunction with treatment of the vapor source.

Chapter 1. Assessment of Vapor Intrusion Pathway

Per the Investigation and Remediation of Contaminated Properties Rule (IRule) Subchapter 3, a site investigation is required when a release of hazardous materials has occurred and is not being immediately addressed through an emergency response action. As required by and defined in the IRule, the first step of a site investigation is to develop a Conceptual Site Model (CSM). The CSM is used to inform or direct the evaluation of sensitive receptors that could be impacted by the release. **If a release has been identified and the contaminants of concern are volatile and toxic, the potential for vapor intrusion must be considered as part of the CSM,** and the steps described in this document should be followed to determine if a VI assessment is necessary.

In some cases, a VI assessment may need to be conducted even if a release of hazardous materials has not yet been identified. If the potential for vapor intrusion is identified as a Recognized Environmental Condition (REC) in a Phase I Environmental Site Assessment (ESA), or based on a review of property uses, a VI investigation is recommended to determine if there is a risk to current or future site occupants. If the property is enrolled in the Brownfields Reuse and Environmental Liability Limitation Act (BRELLA), evaluation of vapor intrusion risk is required in order to receive environmental liability protection from the State. In these cases, it is common to conduct soil gas sampling as the first step to determine if there have been any releases on a property, especially when potential release locations are within the footprint of a structure.

The following steps should be followed to determine if VI is occurring and if VI mitigation is necessary:

Step 1 – Determine if there is a Potential for Acute Risk or a Need for Emergency Response

Under certain conditions a rapid response may need to be implemented prior to developing a complete conceptual site model. This can include cases where chemicals of concern are detected in indoor air at concentrations exceeding short-term exposure criteria provided by the Vermont Department of Health (Incremental Lifetime Cancer Risk of 10^{-4} or Hazard Index of 3), or where site occupants or responders observe unsafe conditions without environmental sampling (e.g., explosive vapors, vapors that are causing immediate symptoms of exposure like headaches, nausea, illness).

The VTDEC must be notified immediately if an acute risk is present. Any building tenants or other users must also be notified as soon as possible.

In these cases, the vapor intrusion issue must be addressed immediately to mitigate the risk. Examples of immediate risk mitigation include ventilation, emergency soil vapor extraction system installation, and/or relocation of building occupants.

Additional information about emergency response options can be found in Chapter 3 (Section 3.2) and in ITRC's guidance here: https://vim-1.itrcweb.org/rapid-response-ventilation-for-vapor-intrusion-mitigation-fact-sheet/

In circumstances where indoor air concentrations are in excess of standards but do not exceed short-term exposure criteria, interim measures may need to be employed to reduce risk during the development of an Evaluation of Corrective Action Alternatives and a Corrective Action Plan, per the IRule (further discussed in Step 6).

Step 2 – Evaluate the Conceptual Site Model (CSM) and Refine

The CSM must include all criteria listed in Section 35-303 in the IRule. If the preliminary CSM indicates that VI should be evaluated, a VI assessment can be conducted right away (Step 4). If more information is needed to determine if a VI assessment is necessary, additional data should be collected to refine the CSM until separation distances can be evaluated (Step 3) and the potential for VI can either be ruled out or a VI assessment can be conducted.

If the CSM indicates a potential for VI, these elements of the CSM are particularly important to evaluate:

- Land Use History (focusing on activities that could lead to a release of Volatile Organic Compounds (VOCs), such as former drycleaning operations, industrial operations, service stations, etc.)
- Site type (geology, surface release, subsurface release, migrating contaminated groundwater)
- Vapor Source (VOC type, chlorinated hydrocarbons versus petroleum hydrocarbons)
- Degree and Extent of the source area, media being affected (soils, groundwater, non-aqueous phase liquids (NAPL))
- Other Considerations (**preferential pathways** (underground infrastructure, sewers, buried river channels), structure and foundation types, dried clays, perched groundwater conditions, etc.)
- Inventory of chemical storage and use at buildings being evaluated, if available

<u>Other Considerations</u>

Site variables that can modify lateral inclusion zones or vertical separation distances (see Step 3) include but are not limited to geologic preferential pathways such as fractured rock or very coarse geologic features (e.g., eskers), dried clays with high degree of cracking that create highly conductive preferential pathways, anthropogenic preferential pathways such as utility conduits, drains, sumps, and others. There may be multiple footings or frost walls below buildings that have been expanded that act as barriers to block vapor flow/migration. Large buildings or parking lots may affect vapor migration or oxygen recharge to the subsurface, thereby reducing the biodegradation or petroleum vapors and increasing the lateral inclusion zone or vertical separation distance.

These conditions should be fully understood and explained in the CSM, and if not fully understood, additional VI investigation must be conducted.

In cases where these variables cannot be fully investigated, it may be necessary to perform soil vapor testing closer to the nearby structure(s) or go directly to sampling sub-slab soil vapor in the nearby structure(s) (Step 4). If sub-slab soil vapor is shown to exceed an appliable standard, then indoor air testing can be conducted (Step 5) or mitigation measures may be evaluated and implemented (Step 6).

Step 3 – Assess Separation Distances

When the CSM has been refined enough to evaluate distances between volatile contaminant sources and a structure, both the lateral inclusion zone and vertical separation distances should be evaluated. These separation distances are different for different types of contaminants of concern (COCs) based on how much they degrade. Step 3 includes a decision-making process for both chlorinated or non-degradable VOCs (Step 3a) and petroleum or degradable VOCs (Steps 3b, 3c, and 3d).

The ***lateral inclusion zone*** is the horizontal area between a VI source and a structure. The distance of a lateral inclusion zone may differ based on the nature of the VI contaminant source (low levels versus high levels of contamination). If a structure is within the lateral inclusion zone, an evaluation must be conducted to determine if the vapor intrusion pathway may be complete. This is generally done using soil borings, soil vapor points, and/or monitoring wells. Additional site characterization to fully determine the degree and extent of soil, groundwater, and soil vapor contamination may be performed, as necessary, to determine if contamination is inside or outside the lateral inclusion zone.

The ***vertical separation distance*** is the distance between a VI source and a structure. For most sites the vertical separation distance is the distance from the source of the contamination (contaminated groundwater or a contaminated soil source) to the structure (basement slab, basement walls, or slab for slab-on-grade). The vertical separation distance may vary based on the nature of the VI contaminant source (low versus high levels of contamination).

Note: If there are preferential pathways for vapor transport such as utility trenches or coarse backfill around sewer lines, or highly transmissive geologic pathways, the lateral exclusion zone may need to be expanded along the preferential pathway and identified in the CSM. Conversely, if contaminated groundwater is located within the vertical separation distance of a structure but is in a confined aquifer or below clean groundwater, then it is possible that there will be no vertical pathway for migration of vapors. In cases such as these, the vertical separation distance may be revised on a site-specific basis and should be discussed in the CSM.

3a. Chlorinated Volatile Organic Hydrocarbons (CVOC) and non-degradable COCs within 100' of a Structure

Determine whether CVOCs are present within 100 feet laterally or vertically from a structure. This can be determined using groundwater monitoring wells, soil vapor points and/or soil borings (and perhaps all of these are needed depending on site specific conditions).

For CVOCs, if the contamination identified within 100 ft of a structure includes any of the following, a vapor intrusion investigation must be conducted:

1. Non-aqueous Phase Liquid (NAPL);
2. CVOCs dissolved in groundwater at concentrations above the standards listed in Appendix A of the IRule – Vapor Intrusion Standards – Groundwater;
3. CVOCs in vapor form at concentrations above the standards posted in Appendix A of the IRule - Vapor Intrusion Standards – Sub-slab Soil Gas; or
4. CVOCs sorbed to soils (any detection above laboratory reporting limits) in the unsaturated zone located laterally or vertically within 100 feet of a structure.

If none of the listed conditions exist within 100 feet of a given structure, then a Vapor Intrusion Investigation is not required.

3b. Petroleum Hydrocarbon (PHC)/degradable COCs within 30 horizontal feet of a Structure

Determine whether readily degradable COCs such as PHC's are present within 30 feet horizontally of a structure (lateral inclusion zone). This can be determined using groundwater monitoring wells, soil vapor points, and/or soil borings.

If the PHC contamination identified within 30 horizontal feet of a structure includes any of the following, additional evaluation per Step 3c must be conducted:

1. Light non-aqueous phase liquid (LNAPL)
2. PHCs dissolved in groundwater at concentrations above the values posted in Appendix A of the IRule – Vapor Intrusion Standards – Groundwater;
3. PHCs in vapor form in concentrations above the values posted in Appendix A – Vapor Intrusion Standards – Sub-slab Soil Gas; or
4. PHCs sorbed to soils in the unsaturated zone (any detection above laboratory reporting limits).

If none of the listed conditions are within 30 feet horizontally of a structure, then a vapor intrusion investigation is not required.

Note: If there are obvious preferential pathways for vapor transport such as highly transmissive geology, utility trenches, floor drains, sumps, or coarse backfill around sewer lines, the 30-foot horizontal exclusion zone may need to be expanded based on site specific conditions and as identified in the CSM.

3c. Determine if there is LNAPL within 18 feet of Structure.

If light non-aqueous phase liquid (LNAPL) is determined to be within 18 feet of a structure, then the user must perform a VI investigation. For this document, LNAPL is defined as:

- Current or historic presence of LNAPL (free product or sheens observed)
- UV Fluorescence (UV) or laser induced fluorescence (LIF) demonstrates the presence of LNAPL
- PID or FID detections >500 ppm

- Concentrations in groundwater:
  - Benzene > 1 mg/L
  - TPH (gasoline) > 30 mg/L
  - BTEX > 20 mg/L
- Concentrations in soils:
  - Benzene > 10 mg/kg
  - TPH (gasoline) > 250 mg/kg

If no LNAPL exist vertically within 18' of a structure, then it must be determined whether dissolved groundwater contamination is present or soil contamination exists closer to building, per Step 3d below.

3d. Determine if Dissolved Groundwater contamination or soil contamination is present within 6 feet of Structure.

If petroleum COCs are dissolved in groundwater or sorbed to soils within 6 feet of a structure, then a VI investigation must be conducted (Step 4). Dissolved petroleum COCs in groundwater or soil contamination is defined as:

- PHCs in groundwater at concentrations exceeding the values posted VI Table Values from IRule, Appendix A – Vapor Intrusion Standards – Groundwater

- PHCs sorbed to soil (at any concentration above laboratory reporting limits)

If there are no dissolved petroleum COCs in groundwater above VI Standards, or soil contamination within 6 feet of a structure, then a vapor intrusion investigation is not required.

Step 4 - Conduct VI Investigation

This step can be implemented at any time if the CSM indicates a potential risk from vapor intrusion or if the evaluation process conducted in Step 3 determines that assessment of the VI pathway is necessary.
The VI investigation may include sub-slab or near slab soil gas testing, sampling sump water, etc. Detailed strategies and methods for conducting a VI investigation can be found in Chapter 2.

If sub-slab or near slab soil vapor concentrations are found to exceed vapor intrusion standards, indoor air sampling should be conducted (Step 5) to determine if the vapor intrusion pathway is complete. Alternately, it can be assumed that the vapor intrusion pathway is complete and an evaluation of mitigation and/or treatment options can be evaluated.

If contaminated groundwater is determined to be infiltrating into a building, options should be evaluated to mitigate and/or remediate as discussed in Chapter 3.

Step 5 - Conduct Indoor Air Sampling

Detailed guidance for indoor air sampling strategies and methods can be found in Chapter 2.

If indoor air data is found to exceed the applicable indoor air standards, an evaluation of corrective action alternatives should be conducted to determine what mitigation and/or remediation strategies should be implemented to address the vapor intrusion risk. An interim mitigation system may need to be installed to treat indoor air during development of the ECAA.

If indoor air levels are found to exceed short-term exposure criteria provided by the Vermont Department of Health (Incremental Lifetime Cancer Risk of 10^{-4} or Hazard Index of 3), emergency actions may be necessary if the building is occupied (see Step 1).

If indoor air concentrations are determined to be below indoor air standards, an additional sampling event is necessary to evaluate seasonal variation, especially if sub-slab soil vapor concentrations are well above vapor intrusion standards. In general, indoor air samples should be collected from two different seasons to ensure that data represents the worst-case scenario. In some cases, this is during the heating season when the stack effect causes vapors to be drawn up into a structure like a chimney. In other cases, vapor intrusion may be more likely when the ground is warm and the vapor source is able to volatilize and migrate more readily. Multiple rounds of data may be necessary to confirm that indoor air concentrations are consistently meeting standards.

Step 6 - Evaluate Options and Mitigate

If the vapor intrusion pathway is determined to be complete, an evaluation of corrective action alternatives (ECAA) must be conducted to evaluate options for mitigation and/or treatment. These options can also be evaluated when the potential for VI is determined to exist (based on exceedances to standards in soil vapor or other media), even if indoor air sampling is not conducted. Mitigation strategies are discussed in Chapter 3. Unless the mitigation work is occurring under an emergency action, a Corrective Action Plan is required before implementing an engineered mitigation system. During emergency actions, or in circumstances where indoor air concentrations are in excess of standards but do not exceed short-term exposure criteria, interim measures may be utilized prior to and during development of an ECAA, including installation of a portable air filtration unit, limiting use of areas where elevated concentrations of contaminants are present, as well as other short term response actions.

Chapter 2. Soil Vapor, Sub-Slab, and Indoor Air Sampling Procedures

2.1 Soil Vapor Survey as Part of a Site Investigation

Soil vapor surveys may be conducted as part of a site investigation if site information to help detect subsurface contaminant sources, contaminated soil, contaminated groundwater, potential preferential pathways for vapor transport, and to help refine the Initial Conceptual Site Model. These data can be useful to identify hotspots for more focused sampling and to help identify the extent of contamination.

Screening level surveys may include soil vapor data collected across an area with enough density of sample collection points to allow an initial estimate of contaminant distribution in soil vapor.

A screening level soil vapor survey will generally consist of collecting samples in a grid pattern in areas of interest. The size and shape of the grid is adjusted to site specific conditions and while generally conducted outside, screening soil vapor samples can also be conducted below buildings. The location of samples may also be oriented towards known preferential pathways such as sewer lines or building drains, if appropriate. The survey provides a one time "snapshot" of subsurface soil vapor conditions. Screening level samples are generally not collected from permanent sampling points.

The screening level soil survey data may be a cost-effective approach for determining the need for quantitative soil vapor contaminant concentration data. A soil vapor survey where the samples are analyzed to provide quantitative data may be used to help assess Vapor Intrusion potential and be part of a human health risk assessment.

Soil vapor characterization can be used to help identify source areas where a release location is unknown. In many cases conventional characterization methods with soil cores or monitoring wells are not effective when characterizing contamination from DNAPL. It is uncommon to find large pools of DNAPLs in the subsurface unless large amounts of DNAPL were discharged to the subsurface. The lack of observable DNAPL at some sites may lead to the erroneous conclusion that no DNAPL is present when, in fact, it may be present in substantial quantities at residual saturation[1]. It may not be possible to find DNAPL in the subsurface, but we can infer its presence and distribution based on the soil vapor concentrations.

2.2 Acceptable Soil Vapor Survey Methods

2.2.1 Passive Soil Gas Survey Sample Collection

Passive samples are collected with a device that uses sorbent media installed in the subsurface and left in place for a set period of time as specified by the manufacturer. The sorbent media are contained in a material that will allow vapors to diffuse through the membrane into the sorbent media where the vapors will sorb to the material. It may be necessary to use different sorbent media depending on the compounds of interest.
The data from a passive soil vapor survey can generally be considered semi-quantitative. A passive soil vapor survey is typically conducted as follows:

1. Shallow holes are drilled or direct pushed into the surficial soils to a depth no deeper than the top of the capillary fringe above the water table. The depth of the survey is site- specific, but it is common to deploy passive samplers from 1 to 2 feet below the ground surface, as directed by the manufacturer.

2. If the soils are competent, and the hole will stay open throughout the sample collection period, the sampling device may be installed in an open hole. If the soils are not competent or there are concerns for sample security, a slotted plastic or stainless-steel well screen or un-slotted well point with sacrificial tip may be installed in the hole, and the sampler can be installed in the screen or at the open portion of the bottom of the tubing if the tubing does not have a screen.

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[1] As DNAPL moves through the subsurface, small droplets of the DNAPL will be left behind in formation pore spaces. These suspended droplets are called "ganglia" (Cohen and Mercer, 1993). At most sites contaminated with DNAPLs, the DNAPL will generally be found as "ganglia" or in very thin lenses. These ganglia are essentially immobile and are "suspended" in the pore space of the formation. The capillary pressure/interfacial tension between the DNAPL and groundwater at the pore space throat is too high for the droplet of DNAPL to move through the formation even though it has a higher specific gravity than the groundwater (Cohen and Mercer, 1993). The size and location of the ganglia will be affected by the wettability characteristic of the DNAPL in the formation (Dwarakanath et al., 2002). Thus, investigators usually do not find DNAPL above residual saturation in soil cores or accumulating in monitoring wells using conventional characterization methods.

a. If a non-stainless-steel screen or tubing is used, care must be taken to ensure the screen or tubing material will not react with potential contaminants and will not generate gas that could provide false positive or negative sample results.
b. No glues or other volatile substances can be used on any sampling materials, tubing, or screens.
c. If a stainless-steel screen or tubing is used, the stainless-steel must be clean of solvents, grease, or other potential contaminants.
d. It is not acceptable to install an un-slotted well point in the subsurface without a sacrificial tip being in place during the time the tubing or piping is pushed into the subsurface as pushing an open pipe into the subsurface could allow soils to enter and clog the piping, limiting the ability to take a sample or have an accurate understanding of which soil horizon is being sampled.

3. The deployment of the device is dependent on the manufacturer’s directions. In most cases, the sampling device is activated by opening the protective packaging containing the sampling device, then lowering it into the hole on a string or wire to a depth within the screen, near the open end of the tubing or close to the bottom of the open hole, depending on what is used at the site. Some manufactures provide a stainless-steel insertion rod that can be used to push the sampling device to the desired depth and is then removed from the hole leaving the sampling device in direct contact with the soil in the area to be sampled.

4. Once the sampling device is lowered to the sample depth, the string or wire attached to the sampling device is attached to either a cork or plug that is driven into the open hole, or to a cap that is used to seal the hole if a screen or un-slotted well point is used.

5. The sampling device is left in the ground as per the manufacturer’s directions and retrieved after the proper time has passed. The device, once removed from the sample location, is sealed in protective packaging provided by the manufacturer and sent to the proper lab for analysis.

6. It is important to note that the contaminants of concern that can be identified by the sampler may be limited; and results may be reported in terms of mass, not concentrations. It is therefore essential to work with the vendor to ensure the correct passive sampling device is used for the contaminants expected at the site and the level of assessment needed.

7. If a passive soil vapor survey demonstrates that contaminants of concern are present in soil gas in a residential or commercial/industrial area, these data are integrated into the conceptual site model and assessed in conjunction with soil, groundwater, and other data to determine if there is a need for a Vapor Intrusion investigation or to expand the site investigation to more fully define contaminant source areas.

2.2.2. Screening Level Survey with a Photoionization Detector (PID) or Flame Ionization Detector (FID).

A PID or FID may be useful as a qualitative screening tool to locate some source areas when contaminant concentrations are high, but due to elevated detection limits for these tools, they cannot be used to help identify the extent of a soil vapor plume or identify the contaminant. These tools are typically used in the following way:

1. Shallow holes are drilled or direct pushed into the surficial soils to a depth no deeper than two feet.
2. The PID or FID may be used to screen the vapor directly above the hole or slightly in it, with care taken to prevent the tip from becoming dirty.

2.2.3. Active Soil Gas Survey Sample Collection (Rapid Results) for Semi-Quantitative Analysis

This method is the collection of soil gas samples from the subsurface to be analyzed by a field lab or field gas chromatograph (if appropriate for a known contaminant), for real time analytical data, or at a fixed laboratory with a quick turnaround time.

There are numerous methods to conduct active soil vapor surveys, as well as numerous manufacturers of equipment that may be used to conduct the active surveys. In general, an active soil gas survey will include these steps:

1. Active soil gas survey samples are generally collected with a temporary probe such as a thin stainless-steel tube that may be advanced into the soil with a device such as a direct push system or electric percussion hammer. The soil vapor samples are collected either through a slotted screen, or from the open space at the bottom of the tube after a sacrificial point has been pushed away. (As with collecting passive soil vapor samples within an open tube, it is not acceptable to collect samples from an open tube without using a sacrificial tip to prevent soils from entering the tube while driving it into the soil). It is also possible to collect soil vapor samples from direct push equipment that have specific equipment that allow collection of multiple soil gas samples at various depths in the borehole.

2. Once the sampling device reaches the desired depth, soil gas samples are collected by pumping soil vapor directly from the stainless-steel tubing pushed to depth, or from flexible, non-reactive tubing inserted into the steel tubing to the desired sample depth. Pump rates should be low (usually less than 0.2 liters of air per minute).

3. Prior to sample collection, the tubing must be purged of several tubing volumes (at a similar flow rate to sample collection) to ensure the sample being collected is actively collecting soil gas and not air introduced during installation of the probe.

4. Screening samples for semi-quantitative analysis may be collected either with a gas tight glass syringe or tedlar bag.

Note: As sample volumes are low, laboratory analytical detection limits may be higher than applicable standards as detailed in the Investigation and Remediation of Contaminated Properties Rule.

2.2.4 Active Soil Gas Survey Sample Collection for Quantitative Analysis.

Using this method, active soil gas samples may be collected for quantitative laboratory analysis. These data may allow further evaluation of soil vapor concentrations and contaminant distribution in the subsurface for the Conceptual Site Model. These data can also be used as part of an evaluation of the vapor intrusion pathway and be part of a human health risk assessment.

Soil gas samples to be analyzed in a laboratory for specific compounds are taken with a Summa canister with flow calibration for sample collection. The flow rate for sample collection is related to the amount of time used to collect the sample as specified by the laboratory supplying the Summa canister. These samples are typically collected using the following methods:

1. To assess soil vapor contaminated by groundwater, the depth of the probe should be approximately one foot above the estimated depth of the water table.

2. To assess plume distribution, the soil vapor probe(s) should be installed at depths specific to site conditions.

3. If conducted as part of a vapor intrusion evaluation, the soil vapor point should be installed directly next to the exterior of the slab or foundation to a depth of approximately one foot below the slab if there is no foundation, or to one foot below the depth of the foundation. If the water table elevation is above the bottom of the foundation, the point should be installed to a depth of one foot above the estimated depth of the water table.

4. The retractable vapor point will be connected to non-reactive tubing that will be run through the center rod of the Soil Vapor Probe.

5. Open the retractable vapor point and purge the sample tubing a flow rate adjustable pump or syringe a minimum of three volumes. Conduct leak testing. If onsite leak detection indicates a failed installation: DO NOT collect a sample. Correct failure if possible and if new leak test shows no leak, obtain sample.

6. Connect the non-reactive tubing to a Summa canister equipped with a flow controller calibrated to the appropriate sample collection time.

7. Record beginning pressure and open the Summa canister to collect the sample.

8. The sample will be collected with a sample flow rate in ml/min appropriate to a 1L, 2.5L or 6L Summa canister as specified in the Site Investigation Work Plan. The sample should be actively monitored throughout the sampling period.

    a. The Summa canister should be shut when the vacuum gauge reaches a residual vacuum between slightly above 0 inches of mercury and less than 15 inches of mercury. If vacuum remains high (above 15" Hg) at the end of the sampling period or does not appear to be dropping during the sampling period, the flow controller may be faulty, or the subsurface or tubing conditions are restricting flow. The sampling point construction should be evaluated and a new sample should be taken. If residual pressure drops to 0 inches, the sample is not acceptable, as the canister has likely drawn in more volume than its capacity. In these cases, a new sample with a new canister will be necessary.

    b. Pack sample container and ship to laboratory.

2.2.5 Soil Vapor Survey and Soil Gas Sampling Tools

2.2.5.a Tools for all Soil Gas Survey Work

1. Device to install soil vapor survey tubing or other sample collection device.
    a. Hand Auger
    b. Hammer
    c. Electric hammer drill
    d. Geoprobe™ or other drill rig as necessary depending on site conditions
    e. Tubing or screen as appropriate to site and sample type
2. Field Notebooks and non-VOC pens

2.2.5.b Passive Soil Gas Sample Collection Tools

1. Passive sorber sampler (Applied Geochemical Imaging™, Beacon™, or similar)

2. A tool to drive a hole into the soil to install the passive collection device

3. Stainless-steel or appropriate non-reactive tubing with screen or sacrificial tip.

4. Non-reactive tubing with sufficient length to reach sampling interval.

5. Manufacturers packaging to send passive sampler to laboratory

2.2.5.c Active Soil Gas Sample Collection Tools

1. Commercially available soil vapor probe (such as AMS™ or others approved by the WMPD) equipped with a stainless-steel vapor point to install the vapor probe. Alternate methods must be approved by the WMPD.

2. Gastight glass syringe

3. Tedlar Bag Method
   a. Non-reactive plastic tubing with sacrificial tip (sufficient length to reach sampling interval).
   b. Certified pre-cleaned, 1.6-liter Tedlar bags complete with influent fitting and extraction septa.
   c. One, 4-liter Pelican® case or similar "lung box" with barbed fittings to attach to two Tedlar bags and the effluent line to the pump (for split samples).
   d. One low-flow air sampling pump capable of pumping rates between 100 and 200 ml/minute with power source.

4. Summa Canister Method (TO-14, 15, or other approved methodology as appropriate to site specific conditions:
   a. Certified pre-cleaned, 1L, 2.5L or 6-L Summa Canisters (specified by sampling objectives and laboratory requirements).
   b. Flow controllers calibrated for a collection period as specified within the Site Investigation Work Plan.

2.3 Sub-slab Soil Vapor and Indoor Air Sampling

2.3.1 Building Inventory/Assessment

2.3.1a General Considerations

Prior to conducting any sub-slab or indoor air sampling, **a building inventory and assessment must be conducted using the WMPD building inventory forms included in Appendix B or a proprietary form approved by the WPMD prior to use**. The inventory-assessment will help determine if there are existing issues in the building that will interfere with interpreting indoor air sampling results.

Examples of potential issues which may interfere with indoor air sampling results include, but are not limited to:

- Sampling indoor air for (tetrachloroethene) PCE in a residential or commercial property that is located next to or above a dry-cleaner that uses PCE, in the house of an employee of a dry-cleaner that uses PCE, or a home where dry-cleaned clothes (cleaned with PCE) are kept may make it difficult to conduct an accurate assessment of the impact of a subsurface source of PCE to the indoor air.
- Sampling indoor air for volatile compounds other than PCE near commercial or industrial buildings where the compounds are used may make assessment of these compounds in indoor air difficult.
- Residents or workers who smoke in a building will increase levels of benzene and potentially interfere with laboratory detection limits for other contaminants.
- Chemicals associated with hobby projects (model planes, arts and crafts) may contain VOCs that impact the sampling analyses.
- Old solvents such as carbon tetrachloride stored in containers in residential basements or commercial properties.
- An attached garage, which may increase indoor air concentrations of benzene or other compounds in the living space of the residence.

The building assessment may also demonstrate the presence of preferential vapor pathways such as cracks in the slab, field stone foundation walls, or areas where utilities enter the building.

2.3.1.b Cross-contaminant removal

Ideally the building inventory is completed at least 48 hours in advance of planned indoor air sample collection. If any chemicals that might contribute contamination to indoor air are noted during the building inventory assessment, these should be removed from the building at least 48 hours prior to collecting any indoor air samples.

If recently dry-cleaned clothing is present in the building, ask the owner to either move them to a second floor, if it exists, or ideally, store them away from the house during the indoor air sampling event starting at least 48 hours prior to collecting the indoor air sample.

2.3.1.c Assessing Sump Pumps in Basements

If a sump pump is present and operating, a water quality sample must be taken from the sump as it will be unlikely that a sub-slab sample can be collected. In some cases, the sump pump may only operate during the wet season. If that is the case, it may be possible to collect a sub-slab sample, but it is important that if there are contaminants in the sub-slab sample, that the sump water be sampled when the sump pump is operating. If there is other open water in the basement, consider taking a sample for analysis if possible.

2.4 Sub-Slab Soil Gas Sampling Guidance

The WMPD may determine that sub-slab soil gas sampling is necessary if the following conditions are present:

- The presence of volatile compounds in soil vapor, soil and/or groundwater are within the Lateral Inclusion Zone or Vertical Separation Distance
- The presence of geologic or anthropogenic preferential pathways that may allow soil vapor migration near a building
- The presence of other factors that may reduce the biodegradation of volatile compounds at the site
- Other conditions as determined by the WMPD

The following steps should be followed to conduct sub-slab soil gas sampling. Site-specific details and explanations of deviations from this SOP (if applicable) should be included in the sub-slab soil gas sampling work plan.

2.4.1 Determine Sample Locations

The following sections include site-specific information that must be considered when planning the number and location of sub-slab soil gas samples related to various types of building construction.

2.4.1.a Concrete Basement or Slab-on-Grade

1. The following site-specific information must be considered when planning the number and location of sub-slab soil gas samples:

   a. Building spatial footprint – a minimum of 1 to 2 sampling locations may be sufficient in a typical, single-family residential building. Large residential buildings and commercial buildings may require additional locations to assess spatial variability.
   b. Foundation construction – multiple building foundations may affect the distribution of concentrations in soil gas and necessitate that sub-slab samples are taken from each portion of the subsurface that is isolated by multiple foundations/frost walls or other subsurface obstructions.
   c. The site-specific sub-slab soil geology should be considered, if possible, when determining locations for sub-slab samples.
   d. The actual number of sub-slab samples that are necessary to take during a vapor intrusion investigation is site-specific and must be approved by the WMPD.

2. The sample location should be located in the center of the area being sampled, if possible.

3. The sample location should be located away from large cracks or utility openings in the basement floor.

4. The sample location should be located away from any furnace, hot water heater, clothes dryer, chimney, heating fuel storage, paint, or other household chemical storage.

5. In commercial or industrial buildings where volatile compounds may have been spilled on the floor, or where heavier than air vapors may have infiltrated porous flooring such as concrete, the WMPD may require the use of a flux chamber to determine if off-gassing from the flooring is causing an indoor air issue or contributing to a VI issue.

2.4.1.b Basement with Dirt Floor

If there is a dirt floor in a basement and the collection of accurate sub-slab soil gas samples is not possible, the WMPD may require the use of a sampling flux chamber placed over the soil to collect a sample of soil gas advecting from the subsurface into the chamber.

Even if there is a dirt floor in the basement and sub-slab samples cannot be taken, it still may be useful to take soil samples at depths deeper than one foot below the basement floor to assess the presence or absence of subsurface contaminant sources. A subsurface grab sample may be sufficient to assess soil vapor quality.

If part of the basement has a dirt floor and part has a concrete floor, it may be necessary to collect a sub-slab sample under the portion of the floor that is concrete.

2.4.1.c Crawl Space with Concrete Floor

Sample locations and number of samples should be considered in the same manner as a full basement with a concrete floor.

2.4.1.d Crawl Space with Dirt Floor

Indoor air samples in a crawl space with a dirt floor can be taken as an alternative to soil gas in rare situations and only in the event that soil gas samples are unable to be collected. Alternately, the WMPD may require the use of a sampling flux chamber placed over the soil to collect a sample of soil gas advecting from the subsurface into the chamber.

2.4.2 Sampling Point Installation

2.4.2.a Temporary vs. Permanent Sampling Points

Sub-slab soil gas sampling points may be installed as either temporary or permanent sampling points. A temporary sampling point may be more appropriate during the initial phases of investigation when the VI pathway is being evaluated. However, a permanent sample point may be appropriate as part of the remedial investigation or for long-term monitoring of sub-slab soil gas or the subsurface.

2.4.2.b Required Materials

Materials required for sub-slab sample point installation include:

- Hammer drill with drill bit sized for the specific tubing, coupling, and any "casing" that will be installed. (It may be necessary to use a concrete core saw or larger drill bit to make a shallow hole in the concrete large enough to install a protective cover around a permanent sample point).
- ¼" OD Stainless-steel or non-reactive tubing with sufficient length to reach sample collection depth
- Clean silica well sand.
- Bees-wax, or non-VOC plumber's putty or modeling clay, for temporary sample collection points.
- Non-VOC plumber's putty or modeling clay and/or hydrated bentonite for permanent sample collection points.
- Cap for the sample tubing.
- Protective "well box" and cover for permanent sample collection point.
- Hydraulic cement, as appropriate, to either abandon temporary sample point or complete installation of permanent point.

2.4.2.c Installation Methods

The method to install a temporary or permanent sampling point is detailed as follows:

1. Drill a hole through the concrete slab to a depth of no more than 5 inches below the bottom of the slab. (It may be necessary to use a metal detector or other device to locate re-bar in the slab if drilling through a

commercial building slab or slab on grade). An electric rotary hammer drill with a drill bit sized to install the specific tubing and coupling that will be used for the project is a standard tool.

2. If installing a permanent sampling point it may be necessary to drill a hole around the sampling point wide enough to install a flush-mounted cap to protect the permanent sampling point. It may be necessary to cement this with hydraulic cement.

    a. Install ¼ inch OD stainless-steel tubing (preferable) or other appropriate tubing approved by the WMPD (such as Teflon or nylon or copper as appropriate to the site-specific contaminants) to a depth no more than 2-4 inches below the bottom of the slab.
    b. Install clean silica well sand in the annular space between the sample tubing and the sub-slab soils. Fill to center the tube in the hole.
    c. Use hydrated bentonite to create a seal between the sample tubing and the hole through the slab in order and prevent infiltration of indoor air when sampling the sub-slab soil gas. For a temporary point non-VOC plumber's putty, non-VOC modeling clay, or bee's-wax may be used.
    d. If installing a permanent sampling point, install "well box" (protective cover) using hydraulic cement or other non-VOC material necessary to prevent the protected cover from being easily removed from over the sample point.
    e. Once cement has cured (if used) and immediately before any sampling event, attach an adjustable-rate pump or plastic or glass gas tight syringe to the sample tubing and purge 3 volumes of the tubing to ensure indoor air is not in the sample tubing prior to sampling (Purging rate should be no more than 0.2 liters per minute).
    f. Before or during purging, a purge check may also be performed to confirm that sample extraction will not create significant vacuum in the sub-surface. A plastic or glass gastight syringe may be attached to the sample point and the plunger pulled to extract a small volume of vapor from the subsurface. If the soil gas is relatively easy to extract (i.e., the plunger is easy to pull) then sub-slab soil gas sampling will not generate significant vacuum in the sub-surface. If the soil gas is not easy to extract (the plunger cannot be pulled or it is difficult to pull) then the sampling point should be checked for blockages or moved to another location. A purge check should be performed after sample installation as well as prior to each sampling event (for permanent sampling point installations).
    g. A photoionization detector (PID) can be used to purge the entrained air within the sample tubing. Peak PID readings also can provide valuable information to the laboratory for dilution purposes.
    h. For petroleum sites, collection of CO/CO_2 measurements can also be collected as part of the purging of the sample line to evaluate degradation of hydrocarbons under aerobic conditions.
    i. Cap the tubing to prevent indoor air from infiltrating through the tubing into the sub-slab soil gas until ready for sampling.

Note: A commercially available sampling device such as a Vapor Pin® may be used as an alternative for either temporary or permanent sub-slab sample points. This will require a hole to be drilled and the device installed as specified by the manufacturer.

2.4.3 Leak Testing Procedures

Every sub-slab sample point must be leak tested prior to a sample being taken. Leak testing procedures may include the following:

2.4.3.a Helium Leak Testing

Required materials for helium leak testing include:

- Compressed non-balloon-grade helium cylinder
- Helium cylinder regulator
- ¼" OD appropriate tubing
- Shroud: Plastic bucket or Tupperware™ with two fittings installed, one to allow introduction of helium into the shroud, and one to connect to the sample point
- Portable helium detector

Helium Leak Testing Procedures:

1. Turn on portable helium detector to allow time for it to warm up.

2. Connect sample point tubing to inside sample fitting on the leak testing shroud.

3. Connect helium regulator to the outside sample fitting on the leak testing shroud (this will allow the helium detector to measure the air from the subsurface).

4. Place leak test shroud over sample collection point. Make sure shroud is in full contact with the ground surface and there are no open spaces for outside air to flow into the shroud.

5. Turn on helium regulator and allow helium to purge the ambient air inside the leak detection shroud (3 to 5 minutes). Target helium concentration inside the leak testing shroud should be ~10-20% (to be checked by helium detector).

6. Allow helium detector (attached to sample tubing) to run for 3 to 5 minutes. The flow rate of the helium detector's pump should be set to the lowest setting to minimize the subsurface flow rates. It is also possible to set up a purge train to the sample tubing with separate pump that allows for subsurface vapors to be collected in a Tedlar bag. The Tedlar bag is then attached to the helium detector for measurements to be collected.

7. If helium in the sample tubing (or Tedlar bag) is less than 10% of the concentrations of helium in the leak test shroud, it can be assumed that the seal around the sample point is competent for the sampling event.

8. If helium is detected in the sample tubing (or Tedlar bag) above 10% of the concentration within the leak test shroud, check the sampling train and sample point for loose seals and correct these. If these cannot be corrected and helium continues to leak into sample point, the sample point may need to be re-drilled and reinstalled.

9. Collect the sample after successful helium leak testing.

2.4.3.b Shroud Leak Test using Non-reactive Tracer Gas Without a Field Detector

If helium is not available for leak testing, another non-reactive gas may be used. With this method, the tracer gas is not tested on-site, but analyzed for by the laboratory during sample analysis.

The required materials are the same for the helium leak test, but a non-reactive gas is substituted for helium. Ensure the gas is not the same gas that the laboratory uses to clean the laboratory sampling equipment or used as the carrier gas in laboratory analyses.

Procedures:

1. Connect the tracer gas cylinder to the leak test shroud as described for helium leak testing.

2. Connect the sampling device (Summa canister, etc.) to the outside sample fitting on the leak testing shroud.

3. Connect sample point tubing to inside sample fitting on the leak testing shroud.

4. Place leak detection shroud over the sample point.

5. Turn on the leak detection gas and allow it to run to purge ambient air from inside the shroud (being careful to not induce high pressure in the shroud).

6. When the sample is analyzed, the laboratory will also analyze for the leak detection gas. If the tracer gas is less than the detection limit, the sample can be assumed to be sub-slab soil gas. The sample may be valid if the detection of tracer gas in the sample is less than 10 to 50 times the laboratory reporting limit. If the detection of tracer gas is too high the sample may not be valid and the sample may need to be retaken.

Other tracer tests such as liquid tracer tests may also be acceptable.

2.4.3.c Water Dam Leak Test

A water dam test can be used to determine if there is a leak in the surface seal of a sub-slab soil gas sampling point. A photo of a water dam in use is provided below. A water dam leak testing includes the following steps:

1. The water dam is a length of 2" diameter PVC piping approximately 2" in length. The water dam is placed over the sampling point with the sample tubing running through the center.

2. The water dam is sealed to the floor surface with non-VOC plumber's putty, Play-Do©, non-VOC modeling clay, or similar.

3. Once sealed to the floor surface, water is placed in the water dam and the level of the water is monitored for approximately 5 minutes.

4. If the water level inside the dam drops, then the sampling point is not sealed properly to the floor surface and the point will need to be reset.

5. If the water level remains constant inside the dam, then the sampling point is properly installed.

6. The water in the water dam may remain in place throughout the sampling event to further provide an airtight surface seal for the sampling point.

An example of water dam leak testing

2.4.3.d Shut-in Test

A shut-in test should be performed prior to each sampling event for each sub-slab sampling location. The shut-in test allows for a check of the integrity of the sample tubing train from the top of the sample point to the inlet of the sampling container (i.e., Summa canister). A shut-in test includes the following:

1. The shut-in test is performed by generating a vacuum inside the sample tubing while keeping the sampling port and the sampling canister closed.

2. A vacuum of approximately 100 inches of water is generated using a plastic syringe attached to a ‘T’ in the sample tubing train.

3. The vacuum in the tubing should be monitored for 1 minute. If the vacuum is maintained for the observed period, then the sampling train is deemed adequate and sampling can begin. If the vacuum is lost during the observation period, then tubing connections should be tightened/altered until there is no observable loss in vacuum during the test.

4. After the shut-in test is validated, the sampling train should not be altered prior to sampling.

2.4.4 Sub-slab Soil Gas Sample Collection

Sub-slab soil gas samples should be collected after completion of proper quality control procedures (e.g., leak testing). Specific sub-slab soil gas sampling procedures should be based on project-specific data quality objectives. The length of the sample collection time should be designed based on the size of the summa canister, ensuring that flow rates do not exceed 200 ml/min. This may range between 30 minutes to several hours.

Details regarding acceptable sampling processes are included in the following sections.

Note: Sub-slab sampling points must not be opened or installed before or concurrent with the collection of indoor air samples as exposing sub-slab contamination to indoor air can affect indoor air quality and can lead to inaccurate indoor air sample results. If indoor air samples will be taken at a site, sub-slab samples should be taken immediately after indoor air samples are collected to allow comparison of sub-slab data to indoor air data.

2.4.4.a Summa Canisters

Required materials:

- Certified pre-cleaned, 1 to 6-Liter Summa Canisters
- Laboratory instructions & shipping materials
- Flow controllers calibrated for a specific collection period. This should be communicated to the laboratory prior to the sampling event. Flow rates should not exceed 200 ml/min.

Procedures:

1. Connect Summa canister to sample port (Summa canister may already be connected from completion of the shut-in test).

2. Summa Canister flow rate should be calibrated to the sample collection period.

3. Open canister and record initial vacuum.

4. Periodically check vacuum gauge during sample collection period The Summa canister should be shut when the vacuum gauge reaches a residual vacuum between slightly above 0 inches of mercury and less than 15 inches of mercury.

    a. If vacuum gauge goes to zero, and the sample collection period is unknown, the sample must be retaken with a clean Summa canister. In some sampling procedures (low volume Summa canisters and short sampling times) it may be appropriate to allow the canister vacuum to reach zero.
    b. If the vacuum does not drop more than 15 inches of mercury during the sampling event, longer collection time may be needed to ensure that the sample volume is sufficient to reach the desired reporting limit (RL). Contact the laboratory to determine appropriate action.

5. At the end of the sample collection period, shut the canister and record final vacuum.

    If vacuum remains high (above 20" Hg) and does not drop during the sampling period, the flow controller is faulty or subsurface or tubing conditions are restricting flow. Contact the lab to understand the amount of volume needed in the Summa canister to allow for proper analysis (vacuum may need to be at or below 5" Hg for sufficient volume to be collected for analysis). Resampling may be necessary.

6. Pack sample container(s) as per laboratory instructions.

7. Fill out Chain of custody forms.

8. Ship package to laboratory as per laboratory instructions accompanied by chain of custody form.

2.4.4.b Sorbent Tube Samples (Method TO-17)

- Connect pump and sample tube to sample collection tubing.
- Operate the pump at the rate specified by the manufacturer

2.4.4.c Tedlar Bag Sampling Method

The following sections detail the methodology used when collecting soil gas samples in to 1-liter Tedlar bags using a vacuum lung box and a personal air sampling pump (such as those from SKC).

Calculating flow rate:

- To calculate a flow rate for the pump, with the pump disconnected from the lung box, affix a digital flow meter to the effluent (positive) side of the pump and turn on the pump. Adjust the pump speed to 200 mL per minute.
- With the unrestricted flow, the 200 mL/minute represents the high end of the sample collection rate (1 liter over 5 minutes). However, it is important to periodically check the flow rate during each of the sampling events to ensure the 200 mL/minute rate is not exceeded.

Procedures:

1. Following successful leak and shut-in testing and flow setting, disconnect the sample tubing from the leak testing apparatus and connect it to the Vacuum Box. Install a new Tedlar bag and open the bag valve. Close box and begin collecting sample. Record start time on field logs.

2. Periodically inspect the bag through the window in the top of the vacuum box. Once full, stop pump, record final time, and close valve on Tedlar bag. Label bag and store in a cooler and transport to laboratory as soon as possible. Disconnect vacuum box and repeat at next location.

    a. Field duplicates can be collected by using a "T" fitting to split flow between two bags, filling them simultaneously within one lung box.
    b. Purge sample train using ambient air or compressed nitrogen between samples.

2.5 Indoor Air Sampling

2.5.1 General Considerations

Indoor air sampling is the most challenging method for assessment of the vapor intrusion pathway since data interpretation can be complicated by background sources of contamination that are present in outdoor ambient air or from items that are common in both residential and non-residential structures. Many household items and/or building materials can contain chemicals that are similar or the same as site-specific Contaminants of Concern (COC). If these items are present during sampling, they can lead to false positives. For example, indoor air may be affected by volatile or semi-volatile compounds from consumer products or building materials (dry-cleaning solvents on clothing, cleaning products, carpeting, exhaust from cars or vapors from stored petroleum products in attached garages, e.g.). Outdoor ambient air can sometimes contain VOCs at concentrations greater than the levels found in indoor air, thereby affecting the concentrations identified in indoor air samples.

It may be difficult to determine what contamination is due to vapor intrusion from a hazardous materials release versus other sources that VTDEC does not regulate. For this reason, indoor air sampling should be conducted after other lines of evidence (contaminated groundwater and/or soil gas data) indicate the potential for vapor intrusion. However, in certain situations indoor air sampling can occur before a groundwater or vapor investigation occurs, such as when contaminated groundwater is entering buildings, before, during, or after corrective actions have been taken at a site, at residential fuel oil spill sites, or where there are odor complaints.

A building assessment and inventory is imperative whenever indoor air sampling is planned. In addition to identifying potential items in a building that could complicate data interpretation, building characteristics should be evaluated to help design an appropriate sampling strategy. Prior to collecting any indoor air samples, the building assessment and inventory forms supplied in Appendix B of this document **must** be filled out.

Other important considerations for indoor air sampling include:

- Indoor air sampling should be collected **before** sub-slab sampling is being conducted if sub-slab samples are also being taken to avoid contaminating the indoor air while the sub-slab sample port is being purged.
- Outdoor ambient air samples must be collected concurrently with any indoor air samples.
- Differential air pressure measurements between the sub-slab and indoor air may be required during the indoor air sampling event. Recording barometric pressure during the sampling event may also be required.

2.5.2 Indoor Air Sampling Methods

2.5.2.a Sampling with Summa Canisters

Summa Canisters are the preferred method to collect indoor air samples. These provide time-integrated indoor air samples collected in specially prepared six-liter Summa canisters. Air flow into the canister is regulated by a flow controller.

Flow controllers for indoor air can be pre-calibrated by the laboratory to a specified flow rate that usually corresponds to an indoor air sampling duration of between 8 and 24 hours. Residential spaces should be sampled for 24 hours, while other sample durations can be tailored to the length of a typical workday or other exposure scenario. Larger canisters are available for sampling periods in excess of 24-hours. Canisters will be individually certified (or batch certified, if approved) as clean by the laboratory as per EPA Method TO-14A or TO-15 guidelines. Due to the generally low chemical concentrations in the indoor air standards and EPA RSL's for chemicals in indoor air, the WMPD recommends that individually certified canisters be used for indoor and outdoor air samples to ensure the highest level of canister cleaning.

When planning the sampling event, the laboratory will need information on the contaminants of interest, the analytical method, and the reporting limits required for the project so that appropriately cleaned canisters can be selected. The sampling team should also consider requesting extra canisters and flow controllers from the laboratory due to the potential for equipment failure.

Active radon mitigation systems should be *off* during Summa canister sampling events if you are evaluating whether or not vapor intrusion is or could be occurring.

Vacuum gauges are either connected directly to the sampling canister or to the flow controller supplied by the laboratory. Vacuum gauges are utilized to measure and record the initial canister vacuum. Initial vacuum measurements should be compared to measurements provided by the laboratory and canisters should not be used if the initial field measurement is out of acceptable range from the laboratory measurement. Please note that due to the inherent difference between the laboratory digital gauges and the analogue gauges used in the field, difference of between 1 to 2 inches Hg are not uncommon. Some deviation is also possible due to temperature differences.

A post-sampling vacuum reading should also be taken to ensure that a sufficient sample has been collected and that some residual vacuum remains in the canister. A residual vacuum of up to 5 inches mercury should remain in the canister upon completion of the sampling event. Since the sample is designed to be collected over a designated period of time (i.e., 8 – 24 hours), the residual vacuum ensures that the sample was collected over that time period. The flow controller inlet may be sufficient to collect the air sample, however, if necessary, stainless-steel, Teflon, or nylon tubing can be attached to the filter to obtain samples from the breathing zone or a remote location.

2.5.3.b Collecting Real-time Indoor Air Data

Additional indoor air and sub-slab sampling methods may be required which include "real time" vapor pathway assessment with a portable field gas chromatograph (GC) if the contaminants are known, or a portable field gas chromatograph – mass spectrometer (GC/MS). An advantage of assessing indoor air in "real time" is that many samples can be collected and analyzed over a short time frame. This can help identify and assess the strength of specific vapor intrusion pathways such as locations where pipes enter the building, floor drains, cracks in the walls or floors or other locations.

2.5.3.c Indoor Air Sampling with Passive Samplers

As Summa canisters provide indoor air data collection over limited periods of time, the WMPD may require use of sample collection techniques that assess air quality over a period of days to a month. Passive samplers are available to collect data that will represent indoor air quality over the longer period of times that may be necessary for assess long term exposure to contaminants in indoor air.

The WMPD may determine it is acceptable to sample indoor air with passive samplers such as the AGI Sorber™, Ultra III™, Radiello™, Beacon, Waterloo Membrane™ or other passive sampler on a case-by-case basis when the sampler will be able to collect a sample that can be analyzed for the site-specific contaminants of concern with detection limits lower than the contaminant standards. The WMPD may determine it is acceptable to sample indoor air with passive samplers such as the AGI Sorber™, Ultra III™, Radiello™, Beacon, Waterloo Membrane™ or other passive sampler on a case-by-case basis when the sampler will be able to collect a sample that can be analyzed for the site-specific contaminants of concern with detection limits lower than the contaminant standards.

Passive samplers have a limited suite of analytes and as such may be better suited for long term monitoring as opposed to initial VI assessment.

Some passive samplers may be able to collect samples with sample collection periods longer than 24 hours. If so, these might provide a better approximation of long-term exposure than a sample collection period of 24 or fewer hours.

- Passive samplers should be handled, deployed, collected, and shipped as per manufacturer instructions.
- Samplers should be located in the breathing zone and in locations as with active samplers as described above.

2.5.3 Considering High Volume Air Exchange Rates

At commercial facilities where the HVAC System causes a high air exchange rate, two separate sets of indoor air testing before and after remediation may be required; one with the air handling system turned on, and one with it turned off. This is to allow an assessment of the potential that the air exchange rate is diluting the indoor air. If so, the remedial system may need to be upgraded to work with a lower air exchange rate or institutional controls be developed that require a high air exchange rate to be maintained.

2.5.4 Collecting Representative Indoor Air Samples

Due to seasonal variability, it is generally recommended that indoor air samples be collected during at least two seasonally disparate times (e.g., warm and colder-weather months). Samples that are intended to be representative of "worst case" conditions should be collected when the indoor air concentrations are likely to be higher due to operation of the heating system with doors and windows closed.

Indoor air samples should be collected in a manner that will likely produce a representative estimate of the exposure to contaminants by occupants of the building. Samples should be collected from areas where the highest contamination is likely, with consideration of where the building occupants currently spend their time, and where they might spend their time in the future. Because lower floors are closer to where contamination is likely entering the building, concentrations are usually higher on lower floors. This is generally due to less air mixing and dilution as compared to upper floors. If the building has a basement or crawl space, indoor air in these areas must be sampled as well as in the first floor.

Indoor air concentrations vary over time, so longer sampling durations will tend to average this variation and likely produce a better representation of the exposure experienced by building occupants than short duration air samples. All residential indoor air samples should be taken for a period of 24 hours. For commercial/industrial indoor air spaces, an 8 to 10-hour sampling period may be appropriate to be completed during regular business hours.

A representative indoor air sample should be collected at breathing zone height between 3 to 5 feet above ground/floor surface. Sampling locations should consider both the occupied areas as well as basement areas to help evaluate the differences in concentrations between the basement and first floor. Sampling locations may also be modified based on location of the source or locations of preferential pathways. Samplers should be located generally towards the center of a space away from exterior door and windows. Windows should remain closed during the sampling event. Samples shall be taken in an open area and not an enclosed space such as a closet. Basement doors, if present, should be closed during the sampling period. Building ventilation systems should not be altered during the sampling period. If exhaust fans are typically in use, such as in a restaurant kitchen, the fans should remain on during the sampling event to simulate normal use conditions and typical exposure scenario. The operation of an exhaust fan would also most likely represent the worst-case scenario. Large ventilation hoods create large negative pressures in the building, potentially increasing advective flow, thereby drawing greater amounts of make-up air from the subsurface into the building.

If the vapor intrusion evaluation includes both indoor air and sub-slab soil gas samples then indoor air samples should be collected first, and then sub-slab soil gas samples can be completed immediately following indoor air sampling. This may reduce the possibility of cross contamination but will allow the results to be comparable as they were collected over a similar timeframe under similar conditions.

2.5.5 Number of Indoor Air Sampling Locations

The rate and number of sampling locations should be established by evaluating the building construction as well as the location of the sources. The number of samples should be collected at a rate of approximately one indoor air sample per 1,500 – 2,000 ft^2 of building footprint; however, the number of samples could be adjusted based on the following:

- A smaller number of samples may be appropriate for larger open spaces
- Multiple building levels may need to be assessed.
- If the basement contains multiple rooms that are generally closed off, it may be necessary to take multiple samples.
- If a basement contains both utility and living areas, samples should be taken in both areas.
- Samples should be taken away from furnaces and any known chemical storage areas that were not able to be removed from the building.
- The location of the source of vapors, and preferential pathways such as cracks in the slab should be considered when selecting sample locations.
- Sample locations in the living area should reflect where the inhabitants spend their time indoors and be centrally located to be representative of as large an area as possible, such as living rooms or family rooms.
- Avoid locations where dilution air enters the building (e.g., near outside doorways) or where indoor emission sources may be nearby (e.g., utility rooms connecting the house to the garage).
- Samples may not need to be collected from the entire structure, and instead, sample locations could be based on the location of the source of vapors, preferential pathways, etc.

Note: Regulations for radon testing in multifamily buildings provides a good framework for sample locations. It has been shown that impact to ground-floor units can vary depending on the sub grade construction (i.e., footings, piers etc.) and a larger number of ground-floor sample locations should be considered at larger multifamily buildings. Variable air distribution and ventilation systems can greatly affect room air pressures. Some buildings may require a more in-depth assessment of the building systems and will result in more sample locations.

2.5.6 Indoor Air Quality Control Samples

2.5.6.a Duplicate Samples

At least one duplicate indoor air sample should be taken for every set of indoor air samples collected, or as outlined in an approved QA/QC Plan.

2.5.6.b Outdoor Ambient Air Sample

Outdoor ambient air samples can be used to evaluate the influence of outside air on indoor air quality. At least one outdoor ambient air sample should be collected simultaneously with the indoor air sampling event. The outdoor ambient air sample should be collected for the same sampling period as the indoor air samples (i.e., 24 hours for residential properties; 8 to 10 hours for non-residential properties).

The outdoor ambient air sample(s) should be collected in a secure outdoor location determined at the time of sampling to be in an upwind position relative to the building being assessed. Weather conditions will need to be accounted for, and sampling events may need to be adjusted so that predicted extreme rain/wind events are avoided. Outdoor ambient air sample canisters should be located, if possible, at least 5 to 15 feet away from building walls, trees, or other structures that may obstruct or influence wind direction. Outdoor ambient air samples should be collected using the same procedure as the indoor air samples.

2.5.7 Indoor – Sub-slab Pressure Differential Measurement

The pressure differential between the sub-slab and indoor air, and/or indoor and outdoor air should be assessed while collecting indoor air and sub-slab samples (but after allowing the sub-slab environment to stabilize from putting in the soil gas point). The pressure differential should be measured directly before collecting the sub-slab sample if a short direction sub-slab sample is taken. If a long-term sub-slab sample or indoor air sample is taken, (8 to 24 hours), it may be necessary to measure the pressure differential continuously throughout the sampling event with recording pressure transducer or barograph, as appropriate.

If the differential pressure is measured during a sampling event, the hole where the sub-slab pressure is being measured must be sealed and leak-proof to prevent mixing of the indoor air and sub-slab air during the sample collection period. The hole should also be located far enough away from the summa canister such that the pressure is not affected by the flow of soil vapor into the summa collection tubing.

Indoor-outdoor air pressure differential may need to be measured during the sampling to determine airflow between the indoor and outdoor spaces.

While continuous pressure differential monitoring with a data logger throughout the sampling event is preferable, other methods may be considered, if appropriate for the site.

2.5.8 Tools Needed to Sample Indoor Air

2.4.8.a Summa Canister Method (TO-14, 15 analyses as appropriate)

- Certified pre-cleaned, 6-Liter Summa Canisters
- Laboratory instructions & shipping materials
- Flow controllers calibrated for a specified collection period (8 to 24 hours)
- Vacuum gauge (either separate or attached to flow controller)
- Appropriate tubing to collect samples as required
- Recording pressure gage to measure pressure differential throughout sampling period.

2.5.8.b Sorbent Tube Method (TO-17)

- Air pump
- Appropriate sample tube

Note: Analytical detection limits available by TO-17 method may be too high to allow indoor air data to be compared to indoor air standards

2.5.8.c Passive Sampler Method

- Passive Samplers in manufacturer packaging that:
    - are appropriate to the contaminants of concern
    - have appropriate detection limits
    - have sample collection periods appropriate to site and sampling goals
- Laboratory instructions and shipping materials
- Sample deployment equipment/holders (supplied by the manufacturer)

2.5.8.d Other Tools

- Camera to take photos of sampling locations and setup

- Field notebooks
- Non-VOC pens/markers etc.

2.5.9 Analytical Methods

Recommended Analytical Methodologies for Indoor Air Sampling:

Method No.	Collection Device	Type of Compounds	Detection Limit Range
TO-3	Cryotrap GC/FID	VOC	0.2 - 400 μg/m^3 (0.1 - 200 ppbv)
TO-13A	Polyurethane foam GC/MS	PAH	0.5 - 500 μg/m^3 (0.6 - 600 ppbv)
TO-15	Summa Canister GC/MS	VOC (polar/non-polar)	0.4-20 μg/m^3 (0.2-2.5 ppbv)
TO-15	Summa Canister GC/MS	VOC Selective Ion Method analysis	Compound specific low detection limits
TO-17	Single/multi-bed sorbent tube GC/MS FID	VOC	0.4 - 20 μg/m^3 (0.2 - 2.5 ppbv)
8021B	Tedlar Bag – Summa Canister GC/PID	VOC (VT DEC Petroleum compounds target list)	4.0 - 60 μg/m^3 (0.3 - 30 ppbv)
8260	Tedlar Bag – Summa Canister GC/MS	VOC	10.0 - 50.0 μg/m^3 (0.6 - 25 ppbv)
8270	Tedlar Bag – Summa Canister GC/MS	SVOC	1000 μg/m^3 (20,000 - 100,000 ppbv)
Compound specific	Passive sorbent samplers	VOC SVOC	Compound and sampler specific

Chapter 3. Vapor Intrusion Mitigation Strategies

3.1 Introduction

There are a number of methodologies that can be used to prevent contaminated soil vapors from entering existing or future structures. References in the literature to help design a Vapor Intrusion Mitigation system include, but are not limited to:

- U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, June 2015, "OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air" OSWER Publication 9200.2-154. https://www.epa.gov/sites/production/files/2015-09/documents/oswer-vapor-intrusion-technical-guide-final.pdf

- Interstate Technology & Regulatory Council (ITRC). 2007. Vapor Intrusion Pathway: A Practical Guideline. ITRC Vapor Intrusion Team. https://itrcweb.org/teams/projects/vapor-intrusion

- Interstate Technology & Regulatory Council (ITRC). 2014. Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation and Management. ITRC Petroleum Vapor Intrusion Team. https://projects.itrcweb.org/PetroleumVI-Guidance/

- Interstate Technology & Regulatory Council (ITRC). 2020. Technical Resources for Vapor Intrusion Mitigation https://vim-1.itrcweb.org/

Several helpful checklists exist from ITRC that can be tailored to each site and be used at the design, implementation and monitoring stages of mitigation:

- Design and documentation checklists for both active and passive systems can be downloaded here: https://vim-1.itrcweb.org/wp-content/uploads/2021/01/1-Design-Considerations-VIMT_Design_Checklist-Final.pdf
    - More information can be found here: https://vim-1.itrcweb.org/system-design-and-documentation-checklists/

- ITRC's Operating, Monitoring, and Maintenance Checklist is here: https://vim-1.itrcweb.org/wp-content/uploads/2021/01/3-Operations-VIMT_OMM-Checklist-ForWebDev-2020-11-2.pdf
    - More information can be found here: https://vim-1.itrcweb.org/operations-maintenance-monitoring-checklist/

- ITRC has a Post Installation Verification Checklist that can be downloaded here: https://vim-1.itrcweb.org/wp-content/uploads/2021/01/2-Post-installation-VIMT_Post-Installation-Checklist-ForWebDev-2020-11-2.pdf

3.2 Interim VI Mitigation Strategies to Address Immediate Acute Risk

If soil vapor is entering a building and is present in indoor air at concentrations that may cause an immediate acute risk, emergency response actions must be taken. In circumstances where vapor intrusion is occurring and concentrations are in excess of indoor air standards but do not exceed short-term exposure criteria, interim measures may need to be employed to reduce risk during the development of an Evaluation of Corrective Action Alternatives and a Corrective Action Plan.

There are a number of activities that can be quickly implemented as an interim action to address any risk to inhabitants of structures. The primary strategy is to block the pathways that are allowing vapors to enter the structure. Several rapid response actions strategies for vapor mitigation can be found here: https://vim-1.itrcweb.org/rapid-response-ventilation-for-vapor-intrusion-mitigation/

An initial and quickly implemented method could be to manage the air flow in the building to create a positive pressure in the basement or building with respect to the sub-slab vapor. In large commercial buildings this could include balancing heating and ventilation system (HVAC) to create positive air pressure in the building. In a residence this could include placing a fan in a basement window to blow outdoor air into the basement or crawl space.

Other strategies include:

- sealing major openings and cracks in the slab with caulk or expanding foam (volatile compound free)
- repairing compromised areas of the slab
- covering and sealing exposed earth
- covering and sealing sump pits and venting them to the outdoors
- enhancing natural ventilation of the building
- limiting access to the building or area of impact (i.e., basement)

If the vapor intrusion is causing an immediate threat to human health, it may be necessary to immediately remove any occupants from the structure until an interim system can be installed.

It may be possible to conduct indoor air treatment using carbon air filtration fan units. This will require testing of indoor air quality before and after installation of the treatment unit or units to ensure the filters are adequately treating indoor air. It will also be necessary to periodically test the indoor air and treatment system to ensure the system is maintaining treatment efficiency. For more info, see: https://vim-1.itrcweb.org/indoor-air-treatment-tech-sheet/

3.3 Active Mitigation Strategies

Active mitigation includes several strategies that utilize mechanical means powered by electricity to interrupt the VI pathway. Some of the most common methods are described below and in the ITRC guidance here: https://vim-1.itrcweb.org/active-mitigation-fact-sheet/.

3.3.1 Sub-slab Depressurization Systems (SSDS)

The objective of a SSDS is to create lower air pressure in the sub-slab than in the building therefore create a negative pressure differential between the building and the sub-slab. This will prevent vapors in the sub-slab from entering the building. An active SSDS can be configured to also work as a soil vapor extraction system to help actively remediate shallow soils and soil vapor. In order to help ensure success there are a number of issues that need to be considered.

3.3.1 a Design Considerations for Basements

1) If the SSDS will be installed in a basement or crawl space, determine if the floor a poured slab or a dirt or rock floor. If the basement floor is not a slab, either a slab will have to be poured or other mitigation method used.

2) Determine if the slab is competent or cracked. In order for a SSDS to be effective, any cracks will need to be filled.

3) Determine if the basement walls/foundation are poured concrete, concrete block, or field stone. If the walls are block or poured foundation, observe if there cracks or if it is crumbling. If the basement walls/foundation are field stone walls or is a block or poured foundation that is in poor shape and crumbling with lots of cracks, an active SSDS will likely not be able to maintain a pressure field under the slab as the vapor flow will short circuit through the open spaces in the in the walls.

4) Determine where utilities penetrate the slab or basement walls, and whether these are sealed or if they can they be sealed to prevent short circuiting of vapor flow.

5) Determine if the basement is wet. If the groundwater table is high enough to be within three feet of the slab, an active sub-slab system may not be able to be installed.

6) Determine if a sump is present in the basement. The presence of a sump may indicate a high groundwater table.

7) If there is a sump in the basement with standing water, the water quality should be tested as it may be the source of the vapors in the basement.

8) A sump may be dry during parts of the year and may act as a pathway for vapors to enter the building.

3.3.1 b Design Considerations for Slab-on-grade Foundations

1) Determine the condition of the slab if it is able to be inspected. Cracks or other pathways may need to be sealed.

2) Determine if the building has had additions added to it over time. There may be frost walls or foundations that are not readily visible but may create barriers to sub-slab vapor flow both for contaminant migration and mitigation.

3.3.1.c Demonstration of Effectiveness of SSDS Active VI mitigation

SSDS focuses on removing the pathway for contaminated soil vapors to enter the structure. To demonstrate that the VI mitigation is preventing VI, the system must generate negative air pressure with respect to indoor air pressure. This will force indoor air in the building to flow into the sub-slab thereby preventing VI.

A negative pressure field of at least 2 pascals (or -0.008 inches of water column) must be generated between the indoor air and the subsurface under the building.

If the building where the SSDS system is being installed is a large building and the contamination is not present under the entire building, the SSDS system can be limited to the portions of the building where the subsurface soil vapors may be creating a VI issue. In these cases, the 2 pascals negative pressure field must encompass the entire contaminated portion of the subsurface. This must be demonstrated with pressure monitoring points.

The 2 pascals negative pressure differential must be demonstrated to be continuous throughout the year by a minimum of quarterly monitoring occurring during the spring, summer, fall, and winter. It is common to monitor the pressure field monthly for the first year of operation converting to quarterly after one or more years of quarterly monitoring.

If 2 pascals cannot be achieved at pressure differential monitoring points, indoor air sampling may be conducted to demonstrate effective SSDS operation at negative pressures less than 2 pascals.

The design of the SSDS must also take into account the presence of utilities that can create a large chimney effect that could override the SSDS. An example of this could be a wood or gas fired pizza oven or restaurant range hood. The air that these systems use, may need to be supplied by outside air to prevent overriding the SSDS.

3.3.1.d Considerations for System Exhaust

Depending upon concentrations of volatile chemicals in subsurface vapors and the expected mass removal rate of the system, treatment (e.g., granular activated carbon) of the SSDS or SVE system effluent may be necessary to minimize ambient outdoor air impact. Points of discharge from an exhaust stack must always be located above roof lines and away from any air intake location or openings to occupied spaces.

During the design phase of vapor mitigation, estimates for contaminant concentrations in system exhaust should be calculated to determine if treatment may be necessary. If there is a potential that the exhaust could exceed Action Levels provided by the Air Quality and Climate Division (AQCD), treatment should be incorporated into the design. Action Levels are expressed in pounds/8 hours and are emission levels that trigger the AQCD Rule and allow the Division to take action to impose control measures, such as adding carbon treatment to a system.

If treatment is incorporated into the design of an SSDS or SVE system, a monitoring and maintenance plan should be prepared to test the actual influent and effluent concentrations and calculate when breakthrough may occur so that the treatment system can be maintained as needed.

System exhaust can also be compared to the Hazardous Ambient Air Standards (HAAS), but it is not expected that the in-stack concentration meets the HAAS. In general, there will be 2 to 3 orders of dilution between the in-stack concentration and the ambient air that someone may breathe. The Action Level is more important for determining if treatment should be added to a mitigation system.

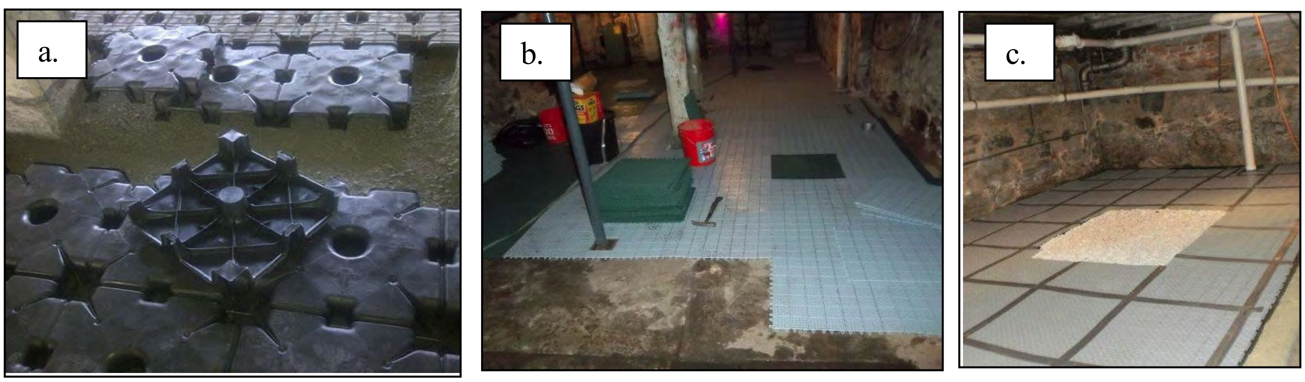
3.3.1.f Alarms

To ensure that an adequate pressure field is continuously maintained on an active system, alarms can be installed as a best practice method. Without an alarm, frequent visual inspection of manometers must be conducted by building occupants or maintenance staff and this method can be highly unreliable and is not encouraged. Alarms are particularly important if the concentrations of vapors under the building slab are high enough where short-term exposure may be a risk to human health, or when certain contaminants are present that can cause impacts from short-term exposure.

3.3.2 Aerated Floor Systems

Where a slab is cracked and can't be repaired, where there is no slab, or where there are multiple frost walls, sub-slab depressurization may be impractical. An alternative to a sub-slab depressurization system is an aerated floor system. This is a system of interlocking blocks that have channels to allow air to flow through laterally. These blocks can be installed on top of an existing slab, dirt floor, or vapor barrier. Once the aerated floor is installed and vent piping installed, a concrete slab is poured over the blocks. These systems are generally considered a form of active vapor mitigation and include vertical vent pipes and a powered fan to move air from the blocks below the slab, through the vent pipe, and discharge it to the outside. More information about these systems can be found here: https://vim-1.itrcweb.org/aerated-floors-tech-sheet/.

Installation of an Aerated Floor System



(a) Example of aerated floor blocks;
(b) Aerated floor being installed;
(c) Floor installation complete;
(d) Concrete slab poured on top of aerated floor blocks;
(e) vertical vent pipes and fan discharge air above the roof line.

3.3.3 Sump Pump Pit Remediation

Many basements have sump pumps to prevent shallow groundwater from entering into the basement. If the water in the sump is contaminated with volatile compounds, these can volatilize from the sump water into the indoor air. To remedy this issue, the sump must be sealed and vented to the outdoor air. The discharge line must be plumbed to an appropriate discharge location. In many cases it is appropriate to have a backup pump in the sump so if the active pump ceases working, the backup pump will take over and prevent discharge of water to the basement.

Sump remedial system under construction with two water discharge lines and one vent line (left); Sump air vent and discharge lines (right).

To demonstrate that sealing the sump pit and venting it to the outside air is effective in preventing vapors from the sump from entering the indoor air in the structure, the air quality must be tested directly above the sump before and after construction of the seal and ventilation system. The sump can also be tested for a complete seal.

3.3.4 HVAC Balancing

Heating, ventilation, and air conditioning (HVAC) systems can be used to mitigate VI both by creating positive pressure in a building and by increasing the air exchange rate. For positive pressure systems, a tight building envelope is necessary, and it is important to ensure that the HVAC system is running continuously as elevated indoor air concentrations may result if the system is shut off. There is a high potential for human interference, and it can take long periods of time and multiple rounds of testing indoor air and/or building pressures to ensure a system is effective during different seasons. For more information about HVAC modification as a mitigation strategy, see:
https://vim-1.itrcweb.org/heating-ventilation-and-air-conditioning-hvac-modification-tech-sheet/

3.4 Passive VI Controls

Passive VI control integrated into the structure of a building's foundation may be an acceptable method to prevent VI in a new building, and in some cases, in existing buildings. Several Passive VI controls are discussed in the ITRC guidance here: https://vim-1.itrcweb.org/passive-mitigation/

However, these will only be acceptable where the seasonal high groundwater table is a minimum of three feet below the slab.

Structural VI mitigation controls installed during new building construction should include a dual VI prevention system strategy consisting of an impermeable vapor membrane combined with either a passive sub-slab depressurization system or a passive sub-slab ventilation system.

The purpose of the two-system strategy is, in part, due to the difficultly in assessing the efficacy of the passive mitigation system. Unlike with active sub-slab depressurization, it can be difficult to demonstrate a pressure gradient from the building to the sub-slab. A pressure differential between the structure and sub-slab could be measured, but that would involve penetrating the vapor membrane so is not suggested.

For existing buildings where passive VI controls are retrofitted, and a two-system strategy is not possible, indoor air sampling or other methods to demonstrate effectiveness may be necessary. In circumstances where dual VI mitigation methods are utilized, follow-up indoor air sampling will not be necessary.

3.4.1 Impermeable Vapor Membranes

All new structures built must be constructed with an impermeable vapor membrane between the slab and the subsurface. This should cover the bottom of the slab and if the building has a basement, the vapor membrane may extend up the sides of the basement to directly below the frost depth. Standard spray on water proofing material above the frost line will act as a vapor barrier in the shallow subsurface.

Utility penetrations of the membrane must be minimized and sealed with a site specific chemical resistant sealant. Vapor membranes may be separate material or sprayed onto the underside of the slab. The materials in the membrane must be resistant to the chemicals of concern at the site.

For more detailed information about types of passive barrier membranes and best practices, see: https://vim-1.itrcweb.org/passive-barrier-systems-tech-sheet/

3.4.2. Epoxy Floor Coatings

Epoxy products can be applied to existing concrete slabs as a passive VI barrier. The long-term costs for maintenance of these coatings are important to consider when evaluating this option. It is also important to make sure the surface is prepped so that the epoxy will adhere properly to the surface. In general, multiple coats of epoxy with different colors should be applied to provide a visual cue for when maintenance is necessary. Annual inspection will be needed to ensure that epoxy coatings remain protective for as long as a vapor intrusion risk exists at a site. For more information, see: https://vim-1.itrcweb.org/epoxy-floor-coating-tech-sheet/.

3.4.3 Passive Sub-slab Depressurization System

A passive sub-slab depressurization system is installed below a vapor membrane in permeable sub-slab materials. Slotted piping can be installed in the permeable materials and are connected to a vent pipe that moves vapors from the sub-slab to the outdoor air. This pipe draws vapors from the subsurface to above the roof line. It must be installed in the building so the air in the pipe is warmer than the soil vapor below the building. This helps create an upwards draft and promotes flow from the subsurface through the vent pipe. The vent pipe exits the building through the roof. The vent pipe should have a wind-powered turbine to help induce vacuum. Solar-powered wind turbines are available and can increase the efficiency of the turbine by creating a vacuum when the wind isn't blowing. This does not change the system from a passive to active system. A passive system can be converted to active with the installation of a mechanical blower.

Wind turbine used as part of a passive system.

3.4.4 Passive Sub-slab Ventilation System

A passive sub-slab ventilation system uses a high permeability venting layer located under the slab and membrane. This allows soil vapor to move laterally to the outside of the slab. Slotted collection piping can be installed to collect soil vapor and channel it to discharge to the atmosphere or shallow soil gas outside of the sub-slab area. The movement of vapor through the permeable material will also draw in air from outside of the foundation to dilute the vapors in the ventilation layer. Some designs also have piping that brings outside air into the ventilation layer to dilute the vapors.

3.4.5 Assessing Effectiveness of Passive VI Prevention

The documented construction of dual passive remedial actions in existing structures (e.g., passive SSDS and vapor barrier) is acceptable to demonstrate the system will prevent VI. An example could be filling in the basement of a home with ongoing VI with flowable fill, installing a passive sub-slab depressurization system, covering it with more fill, covered with a vapor membrane that is covered with structurally sound concrete. In these cases, no follow-up sampling or long-term maintenance is required.

In cases where only one passive technology is feasible in an existing building, additional indoor air sampling or other data collection will be required to demonstrate system effectiveness. This includes cases where an active system is modified to a passive system, but the risk for VI still exists.

Chapter 4. Indoor Air Issues from Contaminated Building Materials

4.1 Building materials and off-gassing issues

While not strictly vapor intrusion from the subsurface, contaminated building materials can off-gas VOCs and cause impacts to indoor air. Spills of materials containing volatile compounds can also create secondary sources and off-gas to indoor air. This can also happen when vapors are heavier than air and sink into porous flooring such as concrete.

In structures where there has been a long-term use of materials containing volatile compounds, the compounds can be caught in building materials such as insulation or wall board and continue to off gas into the indoor air at high concentrations. VOCs may even be trapped in furniture or other personal belongings.

VTDEC does not regulate building materials, but the conceptual site model should consider the possibility of this issue so that risk to building occupants can be mitigated. A responsible party may be investing a great deal of resources into mitigating vapor intrusion and still have a building with contaminated indoor air if they do not consider other sources of contamination.

4.2 Mitigation Strategies

In cases where a concrete slab is contaminated and off gassing VOCs, the floor can be removed and re-poured, or an aerated flooring system can be installed. It may also be possible to paint a chemical- resistant epoxy sealant on the floor (see Section 3.4.2). Increasing ventilation may be an option but may be difficult in the winter months.

Remedial options for other building materials can include encapsulating the material, increasing ventilation of the building, or running air filtration units until vapor levels are reduced. The permanent option may be to remove and replace the building materials and clean the frame of the building.

4.3 Assessing effectiveness of remediation of indoor air issues from contaminated building materials

A flux chamber can be used for sampling indoor air before and after encapsulation of contaminated building materials to demonstrate off-gassing is not occurring. This must be conducted at a minimum quarterly frequency to account for changing indoor air temperatures. Indoor air quality testing before and after encapsulating materials may also be beneficial to demonstrate the efficacy of the encapsulation.

If building materials are removed to mitigate this scenario, indoor air quality testing conducted after removing the materials should be conducted to demonstrate that enough contaminated materials were removed to mitigate the issue. This testing should be conducted under the worst-case situation, during hot weather with the building closed and no ventilation or cooling occurring.

Chapter 5. Strategies for Achieving Site Closure

As stated earlier in the document, vapor mitigation is often an interim remedy to address the risk to receptors until the vapor source can be remediated. The mitigation systems will need to be operated and maintained until such time it can be demonstrated that they are no longer necessary.

5.1 Site closure with a SMAC

If an active vapor mitigation system is necessary to ensure that a risk to a receptor is addressed, the site cannot be closed with a Sites Management Activities Completed (SMAC) designation. In some cases, it may be possible to convert an active mitigation to a passive system once the level of contamination is reduced.

Sub-slab soil vapor samples can be collected to demonstrate that a source has been remediated enough to convert an active SSDS to a passive system, or to dismantle it completely.

Another option is to conduct some shut down tests to see if indoor air quality is met even after the SSDS fan is shut down. In some cases, a wind-powered fan on the vent pipe will be adequate to ensure that indoor air standards are met. In other cases, an HVAC system may be adequate to ensure that indoor air standards are met. Multiple rounds of indoor air sampling under different seasonal conditions will be necessary to demonstrate that the site can be closed with exceedances of soil vapor standards under the slab. Institutional controls will be necessary to ensure that current building conditions are maintained and that VTDEC is notified before work occurs if it may affect the vapor intrusion pathway (e.g., changes to HVAC system or slab penetrations).

5.2 Site closure with a COC

Only BRELLA Applicants that enroll as prospective purchasers are eligible to receive a Certificate of Completion (COC) if an active vapor mitigation system is in use. If a site is eligible for closure upon substantial completion, the COC will outline the long-term requirements to ensure the active system is being maintained. Annual inspection checklists will be required and will need to be submitted to VTDEC.

A copy of the Annual Inspection Checklist can be downloaded here:
https://dec.vermont.gov/sites/dec/files/wmp/Sites/LUR.annual.inspection.checklist.frm_.pdf

BRELLA applicants that enroll as innocent current landowners will only be eligible to receive a COC in cases where an active mitigation system is not necessary.

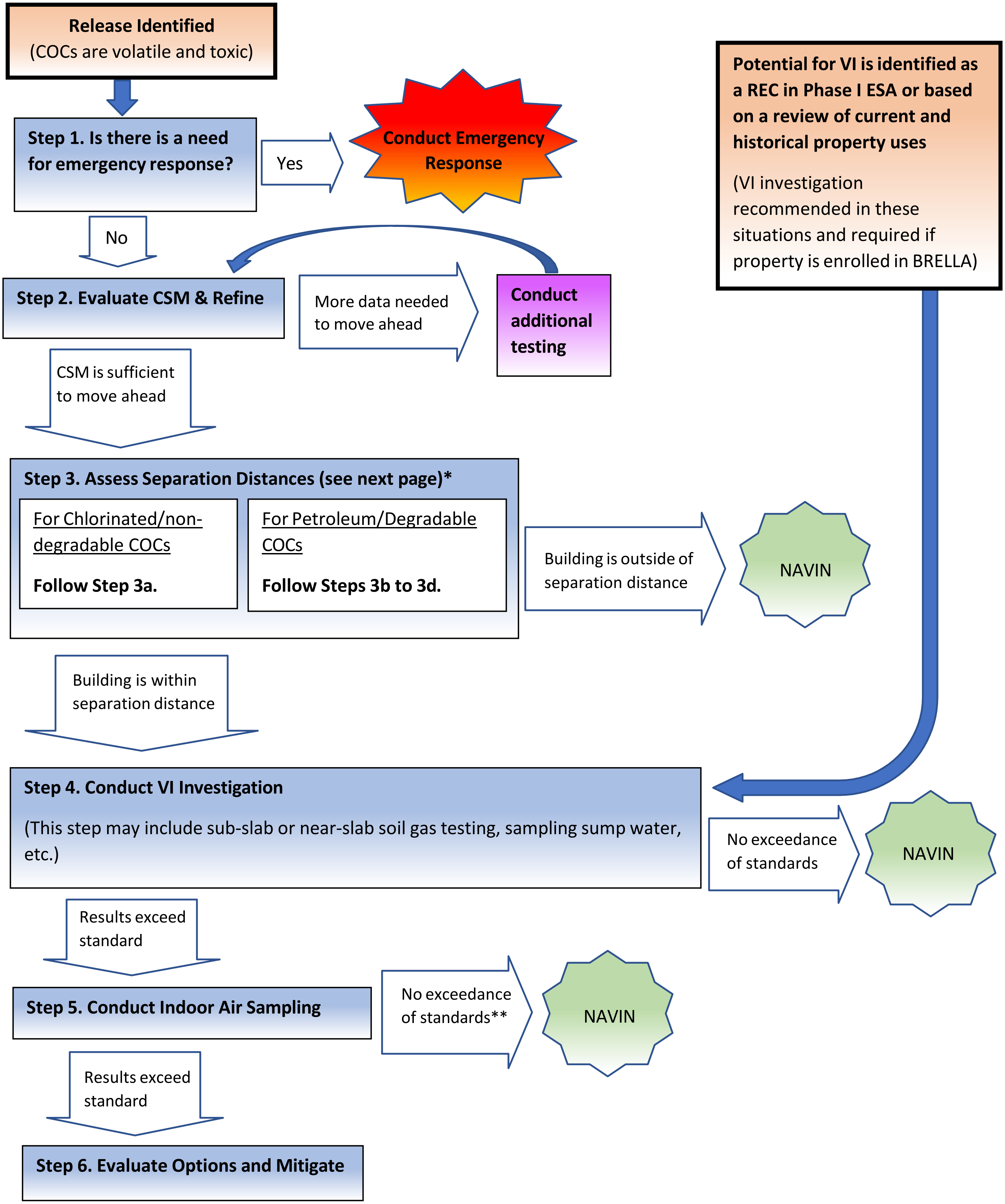
5.3 Future Construction and Institutional Controls

Potential future land uses are important to consider if a vapor plume is located in an area of potential development. Where subsurface volatile contamination exists at a site at concentrations that could cause indoor air quality to exceed standards, institutional controls (ICs) must be put into place that require any new structures to be constructed in a manner to prevent VI.

ICs can include a Notice to the Land records to ensure that present and future owners are aware of residual contamination and any applicable land use restrictions on the property and ensure that VTDEC is notified prior to any work that could disturb the contamination, including construction of a new building. An Environmental Easement between a state or local municipality and the property owner can impose land use restrictions that require any new construction to include structural controls that will prevent vapor intrusion. These can include vapor barriers and sub-slab venting systems. Environmental Easements may also include land use restrictions requiring that VTDEC is notified prior to any work that could disturb the contamination, such as the construction of a new building. As an alternative to an easement, a municipality or state could change building codes to require all new structures regardless of location to be constructed with structural controls that prevent VI.

If new construction is proposed in an area where residual contamination may lead to vapor intrusion, remediation options may need to be revaluated. For example, it may be possible to excavate all contaminated soils prior to constructing a new building. This will prevent VI, but may not be practical, or cost effective and may require off-site disposal of hazardous soil.

Appendix A: Flowcharts



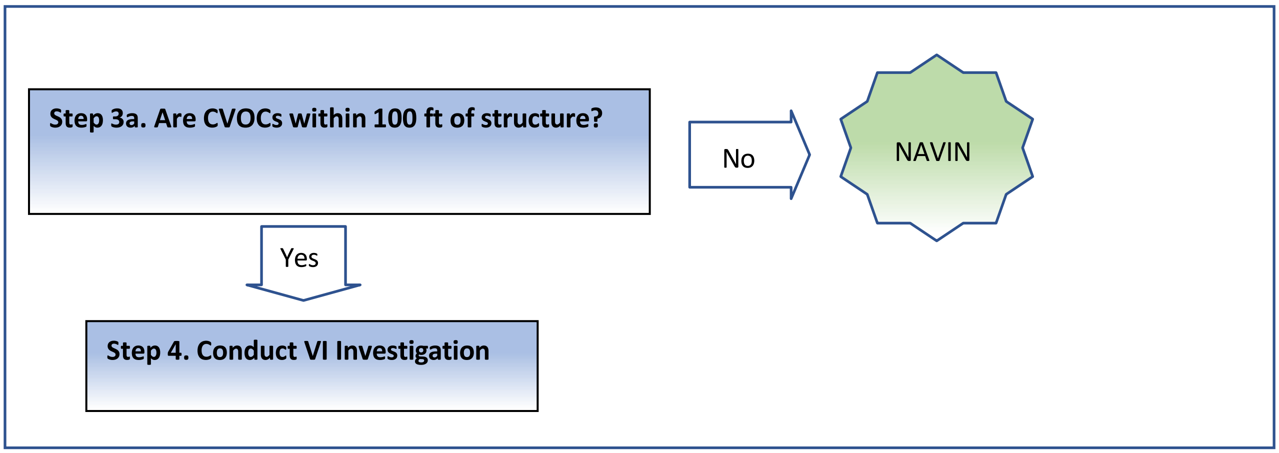
* Consider preferential pathways, potential sources under buildings, or other site-specific conditions

**additional sampling may be needed to assess seasonal variation

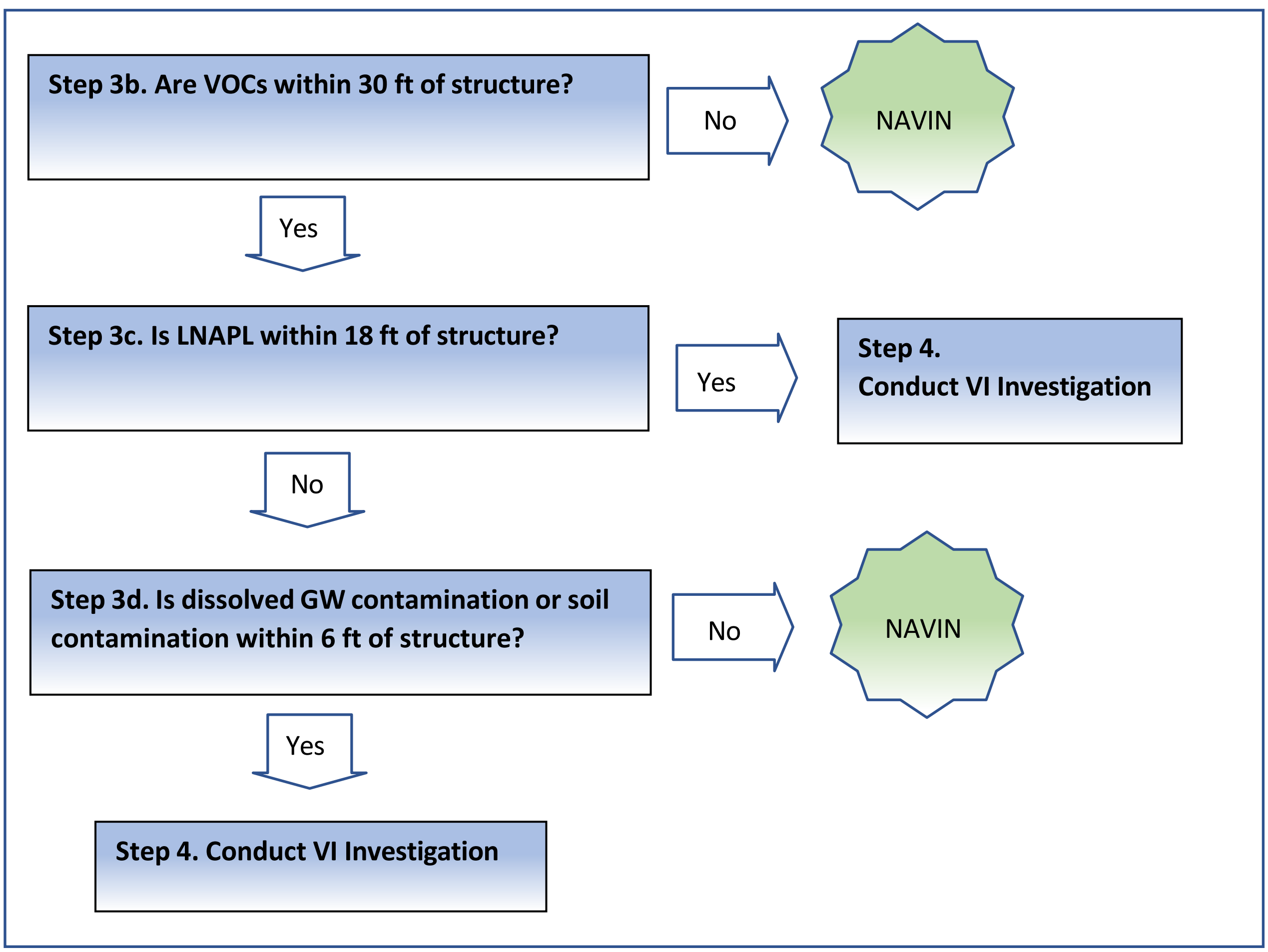
NAVIN = No Additional VI Investigation Needed

Step 3. Assess Separation Distances*

For Chlorinated/non-degradable COCs



For Petroleum/Degradable COCs



* Consider preferential pathways, potential sources under buildings, or other site-specific conditions

NAVIN = No Additional VI Investigation Needed

Appendix B: Forms

INITIAL BUILDING ASSESSMENT & INVENTORY

A survey of the presence of possible indoor air contaminant sources (dry cleaned clothing, etc.) needs to be conducted prior to indoor air sampling. While this may not be possible in all buildings being assessed, if at all possible, this survey using this document should be completed at least 48 hours prior to sampling the indoor air.

This document will be used during all future indoor air sampling events to help document changes in the indoor conditions and any changes that might affect indoor air quality.

Preparer's Name: ____________________________ Date/Time Prepared __________________

Preparer's Affiliation: _________________________________ Phone No. _________________

Purpose of Investigation ____

____

OCCUPANT:

Interviewed: Y/N

Last Name: ___________________________ First Name:_______________________________

Address: ____

____

Home/Cell Phone: ______________________ Office Phone: ____________________________

Other Contact Information ____

# of Occupants/persons at this location ______ Ages of Occupants: _______________________

OWNER or LANDLORD (Check if same as occupant :__________)

Interviewed: Y/N

Last Name: ___________________________ First Name:_______________________________

Address: ____

____

OWNER or LANDLORD (continued)

____

Home/Cell Phone: ______________________ Office Phone: ____________________________

Other Contact Information ____

BUILDING CHARACTERISTICS:

Type of Building: (Circle appropriate response)

Residential	School	Commercial/Multi Use
Industrial	Religious	Other: __________________________

Year Constructed:______________________________________

If Property is residential (Circle type)

Ranch	2-Family	3-Family	Farmhouse
Raised Ranch	Split Level	Colonial	Historic
Cape Cod	Contemporary	Mobile Home	Modular
Log Home	Apartment House	Townhouse/Condos	

Other: ____

If multiple unit, how many? ____

If Property is Commercial:

Business Type/s ____

Does it include residences? Y/N If yes, how many: __________________

If Property is Industrial:

What type of Industry? ____

Chemicals used on site: ____

____

Other Characteristics:

Number of Floors ____________ Is building insulated? Yes No Unknown

Building Age: _______________ Does building appear air tight? Tight Average Not Tight

Are there any obvious airflow patterns in building? Yes No If yes, where: _______________

Notes:

RESIDENTIAL BASEMENT AND CONSTURCTION CHARACTERISTICS
(Circle those that apply)

Above grade construction:	wood frame	concrete	stone	brick ________
Basement type:	full	crawlspace	None: slab	other ________
Basement floor:	concrete	dirt	stone	other ________
Basement floor:	uncovered	covered	covered with ______________	
Concrete floor:	unsealed	sealed	sealed with ______________	
Foundation walls:	poured	block	stone	other ________
Foundation walls:	unsealed	sealed	sealed with ________________	
The basement is:	wet	damp	dry	moldy
The basement is:	finished	unfinished	partially finished	

Is a sump or sumps present? Y / N How many? ________

Is there water in the sump or sumps? Y / N Are Sump/Sumps actively pumping? Y/N

Where do sumps discharge? ____

What is the condition of the slab: ____

What is the condition of the walls: ____

(If possible, the condition of the walls and slab should be photo documented)

If there is a basement, what is the approximate lowest depth below grade? _ (feet)

Identify potential soil vapor entry points and approximate size (e.g. cracks, utility ports, drains)

____

____

____

Notes:____

____

____

____

HEATING, VENTING and AIR CONDITIONING
(Circle those that apply)

Type of heating system(s) used in the building (Circle all that apply)

Hot air circulation	Heat pump	Hot water baseboard
Hot water radiators	Steam radiators	Space heaters
Radiant floor	Electric baseboard	Wood/Coal stove
Vented Kerosene Heater	Unvented Kerosene Heater	
Outdoor wood boiler	Other ____________________	

Describe heating system: ____

____

If more than one heating system is used (e.g. wood stove & oil fired furnace), provide an estimate of what percent of total heating demand is supplied by each heating system: ___________________________

Primary Fuel Type:

Natural Gas	Fuel Oil	Kerosene
Electric	Propane	Solar
Wood	Coal	

Other ____

Is there an outdoor supplied air vent/fan to the furnace? Yes No

Is there a whole house fan? Yes No

The Boiler/Furnace is located: Basement Main Floor Outdoors Other ____________________

Is there fuel storage in the basement or garage Y/N

If so, describe: ____

Look for abandoned fuel lines from previous tanks, underground or aboveground.

Describe any: ____

Is a radon mitigation system installed and operating? Yes No

Is there air conditioning? Central Air Window Units None

Locate exhaust fans (cooking, bathroom, etc.: ____

Notes____

____

____

____

OCCUPANCY

Is basement/lowest level occupied? Full-time Occasionally Seldom Never

General Use of Each Floor (e.g., family room, bedroom, laundry, workshop, storage)

Basement: ______________________________

____

____

1st Floor ______________________________

____

____

2nd Floor ______________________________

____

____

3rd Floor ______________________________

____

____

Other: ______________________________

____

____

FACTORS THAT MAY INFLUENCE INDOOR AIR QUALITY

a. Is there an attached garage? Yes No

b. Does the garage have a separate heating unit? Yes No NA

c. Are petroleum-powered machines or vehicles stored in the garage (e.g., lawnmower, ATV, car) Yes No NA
Specify: ______________________________

d. Has the building ever had a fire? Yes No Unknown When____________________

e. Is a kerosene or unvented gas space heater present? Yes No Where____________________

f. Is there a workshop or hobby/craft area? Yes No Where & Type ____________________

g. Is there smoking in the building? Yes No

h. Has painting/staining been done in the last 6 months? Yes No
Where & When? ______________________________

If so: what type (latex, oil, etc.):______________________________

i. Is there new carpet, drapes or other textiles? Yes No
What Type, Where & When:______________________________

j: Have carpets, drapes or other textiles been professionally cleaned recently: Yes No

If so, how? ______________________________

k. Have air fresheners been used recently? Yes No Unknown
When & Type? ______________________________

l. Is there a kitchen exhaust fan? Yes No
If yes, flow rate (if known) and where vented? ______________________________

m. Is there a bathroom exhaust fan? Yes No
If yes, where vented? ______________________________

n. Is there a clothes dryer? Yes No
If yes, is it vented outside? Yes No

o. Has there been an interior or exterior or pesticide application? Yes No

If yes, when & type? ______________________________

Are there any odors in the building? Yes No

If yes, please describe ______________________________

FACTORS THAT MAY INFLUENCE INDOOR AIR QUALITY

Do any of the building occupants use solvents at work? Yes No
(e.g., chemical manufacturing or laboratory, auto mechanic or auto body shop, painting, fuel oil delivery, boiler mechanic, pesticide application, cosmetologist, dry cleaning)

If yes, what types: ____

If yes, are their clothes washed at work? Yes No

Do they wear a uniform at work that they do not bring home? Yes No

Do any of the occupants work at a dry cleaners? Yes No

Do any of the occupants dry clean their clothes? (Circle appropriate response)

No
Yes, use dry cleaner weekly
Yes, use dry cleaners infrequently (monthly or less)

INDOOR CONTAMINANT SOURCES (IF INDOOR AIR SAMPLING IS OCCURRING)

Identify all potential indoor sources found in the building (including attached garages), the location of the source (floor and room). If possible, any potential sources should be removed from the building 48 hours prior to the sampling event. Please note whether or not the potential source was removed. Any ventilation implemented after removal of the items should be completed at least 24 hours prior to the commencement of the indoor air sampling event. Use either of the two tables below as appropriate.

Potential Sources	**Description/Location(s)**	**Removed** (Yes / No/ NA)
Gasoline storage cans		
Gas-powered equipment		
Kerosene storage cans or lanterns		
Paints / thinners / strippers		
Cleaning solvents		
Oven cleaners		
Carpet / upholstery cleaners		
Other house cleaning products that might contain contaminants of concern		
Moth balls		
Polishes / waxes		
Insecticides		
Furniture / floor polish		
Nail polish / polish remover		
Hairspray		
Air fresheners		
Cologne / perfume		
Fuel tank (inside building)		NA
Wood stove or fireplace		NA
New furniture / upholstery		
New carpeting / flooring		NA
Hobbies - glues, paints, etc.		

List specific products found that have the potential to affect indoor air quality (if indoor air samples are to be collected). Do not open a container to determine the contents or to take a field instrument reading. If field measurements are collected they will be from around the closed container only. Photo document and describe unlabeled containers and fixtures.

Location	Product Description	Size (units)	Chemical Ingredients	Field Instrument Reading (units)	Removed? Y/N

***** Describe the condition of the product containers as Unopened (UO), Used (U), or Deteriorated (D)

****** Photographs of the front and back of product containers can replace the handwritten list of chemical ingredients. However, the photographs must be of good quality and ingredient labels must be legible

FLOOR PLANS

Basement Layout: Identify furnace and water heater, chemical storage, utility entrances, major cracks in floors/walls, sumps, chimney, etc., and sample locations if appropriate. Identify which direction is north.

First Floor Layout: Identify furnace and water heater, chemical storage, vent locations, preliminary screening locations, and sample locations. Also identify which direction is north.

Indoor Air Sample Collection Record

Site Name____ Site Number__________________

Site Location _________________________ Sample Intake Height ______________________

Sampler Name: ____

Site Sketch or photograph

Weather Conditions

Start of sampling period:

Cloudy/Fair/Raining/ Snowing (Circle those that apply) Temperature ________˚F

Rain within last 24 hours Y N Amount_____________

Snow within last 24 hours Y N Amount ___________

Barometric Pressure __________

Where was pressure measured: Site Nearby Airport Weather Observation Station

End of Sampling Period

Cloudy/Fair/Raining/ Snowing (Circle those that apply) Temperature ________˚F

Rain within last 24 hours Y N Amount_____________

Snow within last 24 hours Y N Amount ___________

Barometric Pressure __________

Where was pressure measured: Site Nearby Airport Weather Observation Station
(Circle those that apply)

Sample Information

Sample Location ____

Sampling Method: Summa Canister Y N   Other (describe):______________________

Sample ID	Sample Times	Dates	Beginning Pressure Gauge Reading	Ending Pressure Gage Reading	Flow Rate	Analysis Required
	Beginning Ending	Beginning Ending				
	Beginning Ending	Beginning Ending				
	Beginning Ending	Beginning Ending				
	Beginning Ending	Beginning Ending				
	Beginning Ending	Beginning Ending				
notes:						