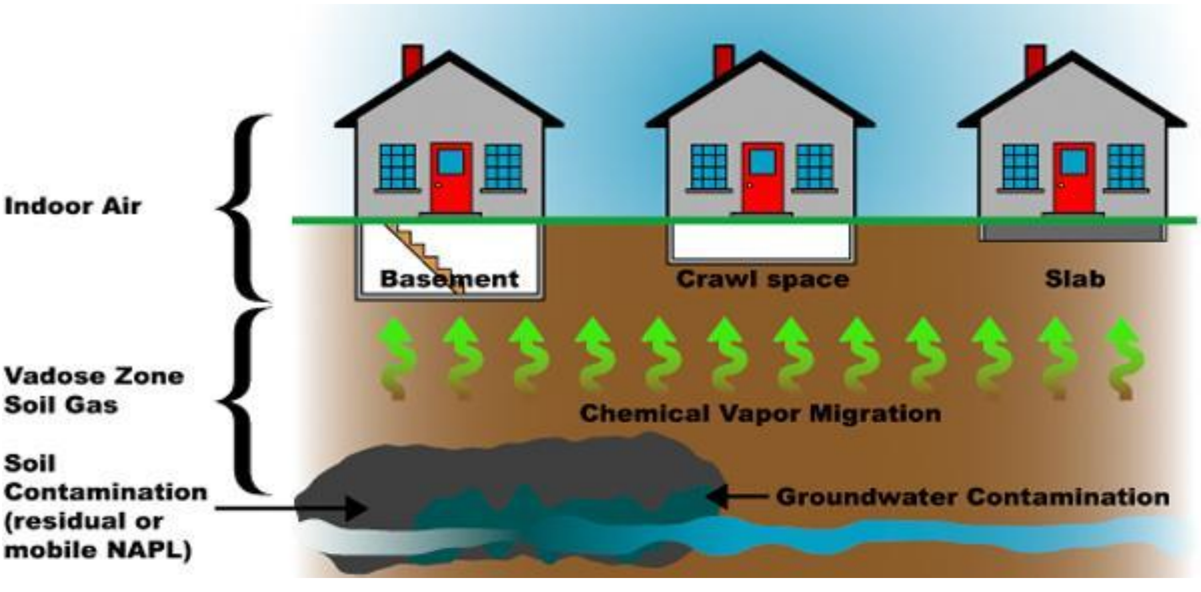
Ohio Environmental
Protection Agency

SAMPLE COLLECTION AND EVALUATION OF VAPOR INTRUSION TO INDOOR AIR

FOR REMEDIAL RESPONSE, RESOURCE CONSERVATION AND RECOVERY ACT AND VOLUNTARY ACTION PROGRAMS



Division of Environmental Response and Revitalization
March 2020

Acknowledgements

This updated guidance was developed by a workgroup of Ohio Environmental Protection Agency (EPA) staff.

Workgroup members included:

Michael Allen
Gavin Armstrong
Sarah Beal
Chris Bulinski
Dawn Busalacchi
Corin Fogle
Erik Hagen
Melissa Langton
Chuck Mellon
Chris Osborne
Carrie Rasik
Lisa Shook
Vanessa Steigerwald-Dick
Brian Tucker
Katie Weyrauch

The following guidance document represents an update to the May 2010 Ohio EPA document of the same title and supersedes any and all previous vapor intrusion guidance documents presented by the agency. This update reflects the Ohio EPA Division of Environmental Response and Revitalization's (DERR) latest understanding of appropriate policies regarding vapor intrusion. The document was developed using established guidance from the United States (U.S.) Environmental Protection Agency (EPA), the Interstate Technology Resource Council (ITRC), American Society of Testing and Materials (ASTM), and other states, modified for the purposes of complying with remedial response, resource conservation and recovery act and voluntary actions in Ohio. Special thanks to the California Environmental Protection Agency, Department of Toxic Substances Control, for permission to use the Interim Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air, December 2004, as a template. In some instances, exact phrasing from California's guidance was used.

Disclaimer

This guidance was developed solely for sites under the oversight of Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), the Resource Conservation and Recovery Act program (RCRA), and the Voluntary Action Program (VAP), carried out under the supervision of Ohio EPA DERR. In this document sites managed under CERCLA and RCRA will be characterized as remedial programs

(RP). Use of this guidance for other Ohio EPA programs or other state agency programs may not be appropriate.

The guidance serves as an instructional tool for the investigation and evaluation of vapor intrusion at sites in Ohio. It is not meant to be a regulatory document and any statements provided herein are not legally binding.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ACRONYMS

AC	Alternating Current
ADS	Active Depressurization System
AF	Attenuation Factor
APU	Air Purifying Unit
AST	Aboveground Storage Tank
ASTM	American Society of Testing and Materials
BGS	Below Ground Surface
BTEX	Benzene Toluene Ethylbenzene Xylene
BUSTR	Bureau of Underground Storage Tank Regulations
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COCs	Chemicals of Concern
CP	Certified Professional
CPRG	Closure Plan Review Guidance
CSM	Conceptual Site Model
CVAFS	Cold Vapor Atomic Fluorescence Spectrometry

CV/AA	Cold Vapor/Atomic Absorption
DERR	Division of Environmental Response and Revitalization
DNAPL	Dense Non-Aqueous Phase Liquid
DQOs	Data Quality Objectives
EC	Environmental Covenant
ECD	Electron Capture Detector
ELCR	Excess Lifetime Cancer Risk
EPA	Environmental Protection Agency
FFS	Federal Facilities Section
FID	Flame Ionization Detector
FSOP	Field Standard Operating Procedure
GC/MS	Gas Chromatograph/Mass Spectrometer
HASP	Health and Safety Plan
HEPA	High-Efficiency Particulate Air
HQ	Hazard Quotient
HRV	Heat Recovery Ventilation
HVAC	Heating, Ventilation and Air Conditioning
IDLH	Immediately Dangerous to Life and Health
IRIS	Integrated Risk Information System
ITRC	Interstate Technology Resource Council
J&E Model	Johnson and Ettinger Vapor Intrusion Model
LDPE	Low Density Polyethylene
LEL	Lower Explosive Limit
LNAPL	Light Non-Aqueous Phase Liquid
LPM	Liters Per Minute
MIP	Male Iron Pipe
NAPL	Non-Aqueous Phase Liquid
NCP	National Contingency Plan

NJDEP	New Jersey Department of Environmental Protection
O&M	Operation and Maintenance
OAC	Ohio Administrative Code
OD	Outer Diameter
ODH	Ohio Department of Health
Ohio EPA	Ohio Environmental Protection Agency
ORC	Ohio Revised Code
OSHA	Occupational Safety and Health Administration
OSI	Office of Special Investigation
OSWER	Office of Solid Waste and Emergency Response (U.S. EPA)
PCBs	Polychlorinated Biphenyls
PCE	Tetrachloroethylene
PDS	Passive Depressurization System
PEL	Permissible Exposure Limit
PHC	Petroleum Hydrocarbons
PID	Photoionization Detector
PPB	Parts per Billion
PPBV	Parts per Billion Volume
PPM	Parts per Million
PPMV	Parts per Million Volume
PTFE	Polytetrafluoroethylene
PVI	Petroleum Vapor Intrusion
QA	Quality Assurance
QC	Quality Control
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
RP	DERR Remedial Programs (CERCLA and RCRA)

RSL	Regional Screening Level
SARA	Superfund Amendments and Reauthorization Act
SCIA	Source Control Interim Action
SIFU	Site Investigation Field Unit (Ohio EPA)
SIM	Selected Ion Monitoring
SOP	Standard Operating Procedure
SSWP	Site-Specific Work Plan
STEL	Short-Term Exposure Limits
SVE	Soil Vapor Extraction
TCD	Thermal Conductivity Detector
TCE	Trichloroethylene
TPH	Total Petroleum Hydrocarbons
TSCA	Toxic Substances Control Act
UPUS	Unrestricted Potable Use Standards
U.S. EPA	United States Environmental Protection Agency
UST	Underground Storage Tank
VAP	Voluntary Action Program
VI	Vapor Intrusion
VISL	Vapor Intrusion Screening Level (U.S. EPA)
VOA	Volatile Organic Analysis
VOCs	Volatile Organic Compounds

EXECUTIVE SUMMARY

The intrusion of volatile chemicals from the subsurface into buildings is one of many exposure pathways that must be considered when assessing risk to human health from contamination. The Ohio EPA Division of Environmental Response and Revitalization (DERR) recommends a stepwise approach and sampling methodologies for evaluating vapor intrusion, as described in this document.

Ohio EPA DERR currently administers four environmental media clean-up programs: the Voluntary Action Program (VAP), the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) program, the Federal Facilities Section (FFS) and the Resource Conservation and Recovery Act (RCRA) program. In this document sites managed under CERCLA, FFS and RCRA will be characterized as Remedial Programs (RP).

The VAP is semi-privatized and operates under Ohio Revised Code (ORC) 3746 and Ohio Administrative Code (OAC) 3745. Site assessments and clean-ups in the VAP are conducted by Certified Professionals certified by the program. Site clean-ups under the RP are directed by Ohio EPA staff, and follow the requirements of CERCLA as modified by the Superfund Amendments and Reauthorization Act, and the National Contingency Plan. Corrective Actions and Unit Closures are directed by Ohio EPA staff and follow the requirements of RCRA and subsequent amendments. There are differences between the programs and their methods of assessment, decision points and remedy selection. However, this guidance applies to all Ohio EPA DERR clean-up programs unless explicitly noted.

Stepwise Approach

If volatile chemicals are present in the subsurface at a site, then the vapor intrusion pathway should be evaluated along with other complete or anticipated exposure pathways identified through the site assessment. Due to the complexity of vapor intrusion, many professional disciplines may be needed to evaluate and mitigate the exposure.

Ohio EPA recommends evaluating multiple lines of evidence in a systematic, stepwise approach depicted in Figure 1 (the flowchart) for the evaluation of the vapor intrusion pathway. It is not necessary to investigate a site for potential vapor intrusion risk in the order presented in this guidance. For sites where the environmental release history is unknown, the stepwise approach should be most useful and effective. However, many sites in Ohio EPA DERR programs have been assessed in some manner prior to investigating potential vapor intrusion issues. Therefore, entering the flowchart (Figure 1) at various steps may be appropriate.

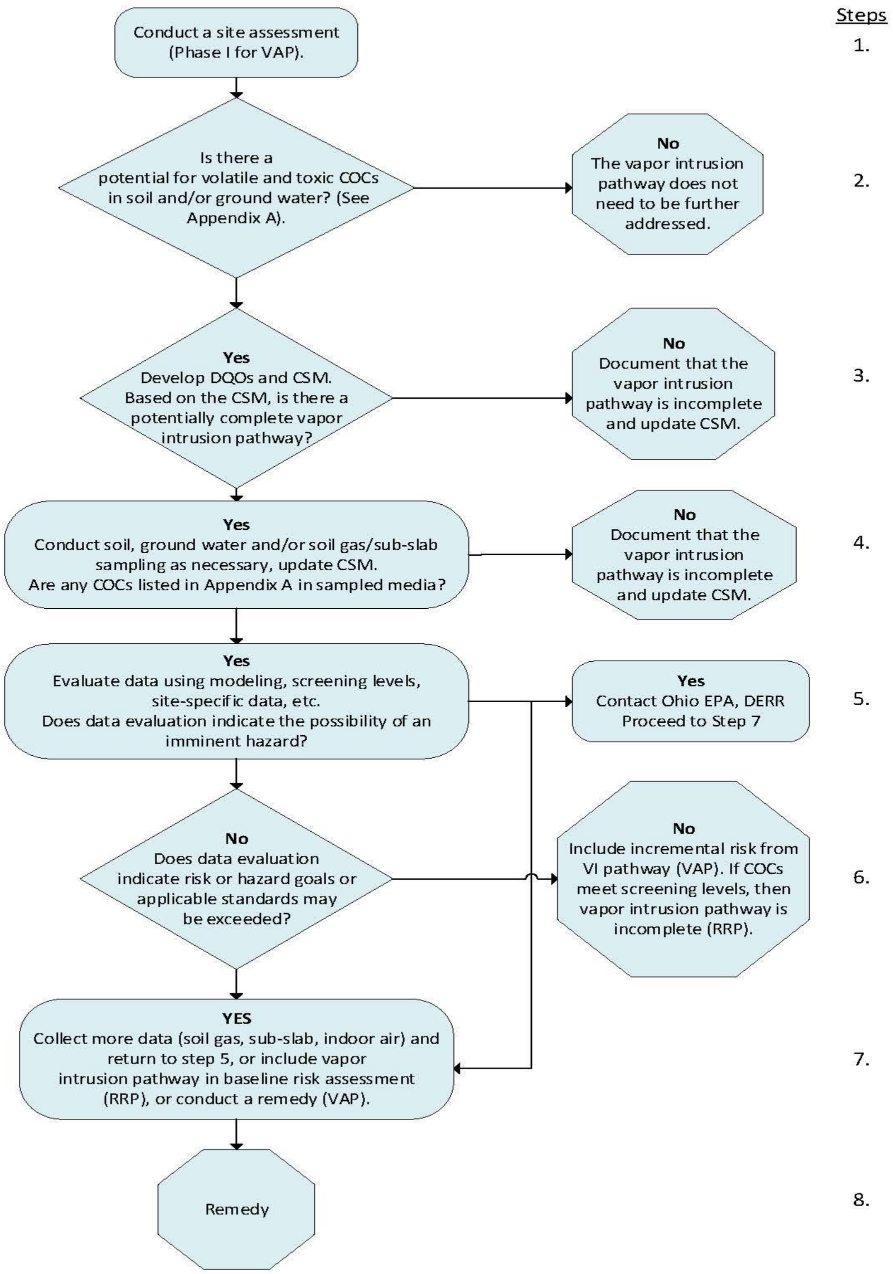


Figure 1. Stepwise Approach for Evaluating the Vapor Intrusion Pathway

Step 1 Conduct the site assessment.

The site assessment is paramount to determining whether the potential for the vapor intrusion pathway exists at a site. A site assessment involves examining current and former activities such as, the types of chemicals used, stored and managed at the site, as well as the administrative history to determine whether releases occurred or if there was potential for releases of hazardous substances or petroleum to environmental media (*i.e.*, soil, ground water, soil gas, sub-slab vapor or indoor air). A site walkover/inspection is also necessary.

Step 2 Determine if there is the potential for any volatile and toxic chemicals in soil or ground water.

Chemicals in the subsurface must be both sufficiently volatile and toxic to present a vapor intrusion risk. If there is no reason to believe that a release of a volatile chemical may have affected the site, then the information supporting this decision should be documented and the vapor intrusion pathway does not need further evaluation.

Step 3 Determine if there is a potentially complete vapor intrusion pathway.

If there was a release, or a release of any sufficiently volatile and toxic chemicals was possible, then develop an investigative workplan that includes a Conceptual Site Model (CSM) for evaluating the vapor intrusion pathway. The potential for a complete vapor intrusion pathway depends on factors such as current or future land use, distance between contamination and existing or proposed buildings, preferential pathways, and whether contaminant plumes are at steady state. The CSM is not static, but continually refined and revised based on data and other information collected at the site.

Step 4 Sample environmental media.

After the vapor intrusion pathway is determined to be potentially complete, sample environmental media (*i.e.*, soil, ground water, soil gas, sub-slab vapor or indoor air) and determine if concentrations indicate a vapor source is present and/or if vapors have infiltrated a building. Data from only one environmental medium is generally not sufficient to fully assess the vapor intrusion exposure pathway. A multiple lines of evidence approach is preferred to evaluate pathway completeness from all environmental media, to assess the complete and potentially complete vapor intrusion exposure pathway to human receptors, and to reduce uncertainties.

Step 5 Evaluate data and determine if data evaluation indicates the possibility of an imminent hazard.

A number of tools can be used at this stage to determine if the vapor intrusion pathway poses a potential unacceptable risk for building occupants. Compare ground water, soil gas, and/or sub-slab vapor concentrations to vapor intrusion screening levels (VISLs) that correspond to a non-cancer hazard of 1 and an excess lifetime cancer risk (ELCR) of 1E-5. Update the CSM depending on the outcome of data evaluation. If data indicate the possibility of an imminent hazard, which is any condition which poses an immediate risk of harm to public health, safety, or the environment, Ohio EPA should be contacted as soon as possible and the volunteer should be prepared to move to Steps 7 and/or 8, as appropriate, in a timely manner.

Step 6 Evaluate the potential risk and hazard from the vapor intrusion pathway.

For RP sites, if data evaluation indicates that concentrations are below screening values, those chemicals of concern (COCs) are eliminated from further vapor intrusion assessment. For VAP properties, if the concentrations are below screening values the vapor intrusion pathway may not be complete for that COC, however the data and screening values must be used to calculate incremental site-wide risk.

Step 7 If data evaluation indicates risk or hazard goals are or may be exceeded, then additional data may be collected, or a remedy may be implemented (see Step 8).

If data evaluation indicates a potential for unacceptable human health risk, then additional data collection may be necessary to conduct a risk assessment, evaluate lines of evidence, and/or determine what, if any, remedy is needed. Further investigation may include the following:

- Collecting data to define physical and chemical parameters for site-specific soil using recommended test methods.
- Collecting soil gas samples to define the vapor plume at sites where buildings do not exist.
- Collecting sub-slab vapor samples or crawl space samples at an existing building.
- Collecting indoor air samples in conjunction with sub-slab vapor or soil gas samples.
- Additional evaluation of the environmental data may be needed to derive an exposure point concentration for use in a property-specific risk assessment.

Step 8 Remediation, Mitigating Indoor Air Exposure and/or Conducting Long-Term Monitoring.

If data evaluation indicates the potential for unacceptable human health risk, there are several remedies that may be considered to mitigate vapor intrusion to indoor air. For VAP sites, the volunteer selects the remedy. For RP sites, the remedy is selected following procedures outlined in CERCLA as amended by SARA and the NCP and may be defined by site-specific orders.

Potential remedies may include:

- Removing vapor-forming chemical contamination through site remediation.
- Installing passive or active vent systems (existing buildings).

- Installing passive and/or active vent systems/membrane systems (future buildings).
- Designing ventilation systems to mitigate indoor air concentrations (HVAC).
- Using institutional controls to restrict structures or land use on contaminated property.
- Implementing and monitoring of appropriate engineered remedies to prevent or mitigate exposure through vapor intrusion. Monitoring of engineered controls must continue until risk-based clean-up levels as measured in environmental media have been met.

For any remedy chosen for a site, long-term monitoring of soil gas and/or indoor air may be necessary under an Operations and Maintenance (O&M) plan. The frequency of the monitoring will depend upon site-specific conditions and the degree of vapor-forming chemical contamination.

1.0 INTRODUCTION

Volatile chemicals in soil or ground water can migrate through the subsurface, enter buildings, and potentially cause an unacceptable chemical exposure for building occupants. If volatile chemicals are present at a site, Ohio EPA DERR requires that potential risk from vapor intrusion be included in the CSM and the potentially complete pathway investigated. This guidance provides a framework for site characterization and investigation of the vapor intrusion pathway.

Evaluation of the vapor intrusion to indoor air pathway may involve sampling environmental media to evaluate and characterize subsurface chemical releases, using screening models to predict indoor air concentrations, and usually includes conducting indoor air sampling. This guidance outlines the technical aspects of evaluating the vapor intrusion pathway and provides recommendations for elements that should be included in a site investigation. This guidance is not intended to provide detailed information on conducting a baseline or property specific risk assessment.

Due to the complexity of vapor intrusion, many professionals of varying disciplines may be needed to evaluate and mitigate exposure, such as geologists, risk assessors, engineers, HVAC specialists, Certified Industrial Hygienists, and risk communication specialists. Accordingly, an appropriate project team should be gathered when evaluating vapor intrusion issues. Ohio EPA DERR anticipates that this guidance will be used by regulators, responsible parties, environmental consultants, community groups, and property developers.

Vapor intrusion is a developing field and it is anticipated that some of the procedures and practices within this guidance will change as understanding of vapor intrusion progresses. Ohio EPA DERR will update this document as needed to accommodate refinements and advances in the field of vapor intrusion.

2.0 SCOPE

This guidance provides options of technically defensible and consistent approaches for evaluating the vapor intrusion to indoor air pathway, but it is not comprehensive, nor does it impose any requirements or obligations on the regulated community. Other technically equivalent sampling and engineering procedures exist and those investigating vapor intrusion may use other technically sound approaches. Furthermore, this guidance does not alleviate a volunteer or potentially responsible party from any obligations that U.S. EPA may require.

This guidance document provides procedures to evaluate the vapor intrusion to indoor air pathway only. All other media characterization and evaluation of complete exposure pathways at a site must be done in accordance with the rules or procedures of the appropriate Ohio EPA DERR programs. This guidance is meant to provide information to fully characterize the potential risk from vapor intrusion at DERR sites.

This guidance assists in addressing, but is not limited to, the following questions:

- What sites are candidates for potential risk from vapor intrusion to indoor air?
- What site-specific data are needed to conduct a vapor intrusion evaluation?
- What methods are recommended for sampling subsurface media and indoor air?
- Should indoor air sampling be conducted?
- What are the data requirements for an evaluation of the vapor intrusion pathway?
- What measures are available to mitigate indoor air exposures?

3.0 VAPOR INTRUSION EVALUATION

The following text describes the stepwise approach for evaluating vapor intrusion found in Figure 1 (the flowchart). The stepwise approach in this guidance document is meant to be flexible and may be tailored to site-specific circumstances. Pathway evaluation may begin at any step in the flowchart provided that the data collection and the CSM clearly justify entry into that step. However, most vapor intrusion pathway evaluation decisions and determinations regarding the need for remedial activities and long-term mitigation are not made using indoor air sampling results alone because a vapor intrusion exposure pathway is assumed to be complete unless demonstrated otherwise. For this reason, it is preferred to also have data collected from soil, ground water, soil gas, and/or sub-slab vapor when making decisions and drawing conclusions about a potential vapor intrusion pathway from indoor air sampling results.

3.1 Initial Vapor Intrusion Assessment

The steps outlined in the flowchart apply at sites whether or not buildings are currently present and/or occupied. Current buildings and future building scenarios, as appropriate, will determine sampling strategy and data evaluation. While the assessment process is presented in a stepwise fashion, the vapor intrusion pathway is generally evaluated in an iterative manner and steps may be repeated.

Flowchart Step 1 and Step 2: Conduct the site assessment and determine if there is a potentially complete vapor intrusion pathway

A comprehensive evaluation of the current and historical operations at a site should be conducted to identify potential or known releases of volatile chemicals to subsurface environmental media. A complete compilation of site information is essential for identifying all potential vapor intrusion exposure pathways. For VAP properties, a complete Phase I property assessment must be conducted in accordance with the Ohio Administrative Code (OAC) 3745-300-06. RP sites may use ASTM E1527-13 (or most recent version) Standard Practice for Environmental Site Assessments: Site assessment Environmental Site Assessment Process (ASTM, 2013), DERR's Closure Plan Review Guidance (CPRG) (Ohio EPA, 2017) or other relevant CERCLA and RCRA guidance.

For simplicity, this guidance will not repeat the requirements necessary to conduct a site assessment. However, using the site assessment information when developing a CSM is a necessary component of this guidance. See the discussion in Step 4 for more details on CSM components for evaluating the vapor intrusion pathway.

U.S. EPA's June 2015 *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* (VI Guidance) (U.S. EPA, 2015b) states that the chemicals in the subsurface must be both sufficiently volatile and toxic to present a vapor intrusion risk. A chemical is considered "volatile" if its:

- Vapor pressure is greater than 1 millimeter of mercury (mmHg); or
- Henry's law constant is greater than 10^{-5} atmosphere-meter cubed per mole (atm m^3 mol^{-1}).

In addition to being sufficiently volatile, a chemical must be potentially toxic to present a vapor intrusion risk. A volatile chemical may be considered toxic in regard to vapor intrusion if:

- The vapor concentration of the pure component exceeds the target indoor air concentration, when the subsurface vapor source is in soil; or
- The saturated vapor concentration exceeds the target indoor air risk level, when the subsurface vapor source is in ground water.

In addition to researching a chemical's physical-chemical properties, the most recent version of the U.S. EPA Vapor Intrusion Screening Level (VISL) calculator can be used as a tool to help determine if a chemical meets the criteria of sufficiently volatile and toxic and should be included in a vapor intrusion investigation. Chemicals that are sufficiently volatile and toxic in regard to vapor intrusion are referred to in this guidance document as vapor-forming chemicals. For additional information on identifying vapor-forming chemicals, please refer to Chapter 3 of U.S. EPA's June 2015 OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air (U.S. EPA, 2015b).

If any chemicals that meet these criteria were potentially released, then the site should be evaluated for vapor intrusion. This includes evaluating the history of adjacent properties for potential releases of vapor-forming chemicals that may have affected the subject site. If there is no reason to believe that a release of a vapor-forming chemical may have affected the site, then the information supporting this decision should be documented and the vapor intrusion pathway does not need further evaluation.

Please note, polychlorinated biphenyls (PCBs) and PCB mixtures (*i.e.*, Aroclors) are considered sufficiently volatile and toxic in the U.S. EPA VISL calculator. However, only lighter PCB mixtures and degradants would be expected to volatilize at a site. In most cases, PCBs do not need to be evaluated in a vapor intrusion (VI) assessment; please contact Ohio EPA if the site assessment identifies PCBs for vapor intrusion on a site.

Based on the site assessment decide if further investigation and understanding of the vapor intrusion pathway is warranted. The potential for a complete vapor intrusion pathway depends on factors such as current or future land use, distance between contamination and existing or proposed buildings, preferential pathways, and whether contaminant plumes are at steady state. A potentially complete or complete vapor intrusion pathway exists if there is: 1) a potential or confirmed source of a sufficiently volatile and toxic chemical or chemicals; 2) a current or future mechanism to transport the chemical; and, 3) a current or future human receptor. Please note, future buildings are to be reasonably anticipated. If a determination is made that there is no complete or potentially complete vapor intrusion pathway, this determination must be documented. If the three factors listed above are present at a site, an investigative workplan that includes a CSM for evaluating the vapor intrusion pathway should be developed. The CSM is not static, but continually refined and revised based on data collected at the site.

Flowchart Step 3: Develop a conceptual site model and data quality objectives

3.2 Conceptual Site Model

Site investigations should include the development and refinement of a CSM. The purpose of a CSM is to provide a conceptual understanding of the potential for exposure to hazardous contaminants based on knowledge of the sources of contamination present, release mechanisms to the environment, transport mechanisms, exposure pathways, and potential receptors. The CSM should include a diagrammatic or schematic representation that relates the source of contamination to human and ecological receptors and identifies all potential sources of contamination, the potentially contaminated media, and exposure pathways. The CSM should evolve as site-specific conditions are better understood and additional data becomes available, thus the CSM should not be static. The CSM organizes and communicates information about the site characteristics and is not only a necessary component of any vapor intrusion site investigation, but an essential decision-making and communication tool for all interested parties.

For vapor intrusion sites the CSM is integral to the development of a sampling plan. The CSM will focus on the potential receptors and pathways and is updated as additional data and information is obtained. Ohio EPA recommends that the following items be included in a CSM for the vapor intrusion pathway. However, in the early stages of investigation, not all components listed may be available.

- <u>Primary Sources of Contamination.</u> Provide a list of all volatile chemicals for each potential source. For each potential contaminant source, describe the release and provide a list of volatile chemicals released into the environment.

- <u>Secondary Sources of Contamination.</u> Include all the environmental media potentially contaminated by the primary sources, such as surface soil, subsurface soil, and ground water. Contaminated building materials, such as concrete foundations, can be a source area for a potential release to an environmental medium and should be considered.

- Contaminant Transport Mechanisms. For each potentially contaminated environmental medium, describe the transport mechanism to indoor air, (usually advection and diffusion through the vadose zone), and describe the characteristics of the subsurface.

- Exposure Routes. Describe current buildings, potential future building scenarios, as appropriate, and areas where vapors may accumulate, including smaller enclosed areas in larger buildings. Discuss any preferential contaminant migration pathways associated with the buildings, such as foundation cracks, voids, utility ports, pipes, elevator shafts, sumps, and drain holes.

- Potential Receptors. List all the current and potential future receptors, as appropriate, that could potentially be exposed to contaminated indoor air from the vapor intrusion pathway.

A preferential contaminant migration pathway is a pathway of less resistance than typical pathways available for transport through environmental media, taken by chemicals of concern (COC) while undergoing diffusion or advection. These pathways, which can be natural or anthropogenic, are a result of disturbance in natural soil layers, (such as installation of underground utilities or fractures in bedrock), are more porous and transmissive, and enable more rapid COC transport. Early in the development of a CSM and sampling plan, preferential pathways need to be considered, located and potentially sampled for. For example, it has been observed that utility lines are able to influence the flow of shallow ground water contaminated with vapor-forming chemicals, and either block the flow of such ground water, or conversely, facilitate flow of soil gas and contaminated ground water through the porous bedding material or the pipes themselves. Sewer lines in particular, due to their construction, have been known to convey vapor-forming chemicals for long distances from a source. Older sewer lines may be composed of clay, cast iron or Orangeburg pipe, which may have cracks and voids at joints depending upon their age. Infrastructure present in older cities and towns may be cracked or detached at joints due to settling. Utility lines are surrounded by bedding material which is typically more porous than the surrounding native soils. The presence of any preferential pathway necessitates an examination of whether vapor-forming chemicals can be transmitted beyond the assumed 100-foot buffer zone. A study by McHugh, et. al. (2017) showed that concentrations of vapor-forming chemicals were higher in the basement than the sub-slab vapor concentrations. Therefore, if a sewer line is within the zone of influence (less than 100 feet) from a source of vapor-forming chemicals, or there is reason to suspect that a ground water plume contaminated with vapor-forming chemicals above U.S. EPA VISLs is interacting with the sewer line, then sampling the line and bedding material should be planned and included in the sub-surface investigation and field sampling plan.

To document current site conditions, the CSM should be supported with maps, subsurface cross-sections, site diagrams, and any other site-specific details which may be pertinent, such as building characteristics. The narrative should clearly describe known site conditions and state what assumptions were made to generate the CSM. The narrative should include a description of ambient sources and the presence of nearby potential sources of volatile organic compounds (VOCs) and other volatile chemicals, such as neighboring dry-cleaning operations. Additional information on the development of a CSM can be found in guidance published by various entities, including the U.S. EPA Risk Assessment Guidance for Superfund (U.S. EPA, 1989), Standard Guide for Developing Conceptual Site Models for Contaminated Sites ASTM E1689 – 95 (ASTM, 2014), Ohio EPA DERR Conceptual Site Models Guidance Document (Ohio EPA, 2015), and U.S. EPA Guidance on Systematic Planning Using the Data Quality Objectives Process (U.S. EPA, 2006).

The site evaluation may lead to the conclusion that the vapor intrusion pathway is incomplete. The following are examples of instances where the vapor intrusion pathway may be considered incomplete:

- No buildings are present at the site and there is a prohibition on building structures at the site in the future;
- Absence of sufficiently volatile and toxic chemicals;
- The distance between contamination and existing or proposed buildings is greater than 100 feet leading to low probability of vapor intrusion, as confirmed with soil gas data;
- Lack of preferential pathways; or
- Contamination plumes (*e.g.*, ground water, soil gas or sub-slab vapors) are confirmed to be at steady-state and contaminant concentrations are and will remain below screening levels.

A checklist of information to assist in the development of a CSM for vapor intrusion and for planning a soil gas sampling strategy for a site can be found in Appendix A**.**

3.3 Data Quality Objective Process and Developing a Sample Plan

The scope and objectives of environmental media sampling should be established before the vapor intrusion investigation is conducted by working through the Data Quality Objective (DQO) process. For voluntary actions, the DQO process is part of the Phase II Property Assessment (see OAC 3745-300-07(C)). For RP sites, the CERCLA RI/FS guidance, RCRA Corrective Action Guidance, Closure Plan Review Guidance and general U.S. EPA Quality Management documents should be followed when designing a sampling plan and developing DQOs. The DQOs are qualitative and quantitative statements that:

- Clarify the study objective.
- Identify the chemicals of concern (COCs).
- Define if the sample will provide qualitative or quantitative information.
- Define the type, quantity, and quality of each piece of data collected in the study.
- Determine required analytical detection limits.

- Define how each sample will be used to assess whether vapors are intruding into buildings.
- Determine the most appropriate locations, sampling method, and sampling duration for data collection.
- Specify the amount of acceptable uncertainty in the sampling results.
- Specify how the data will be used to test the exposure hypothesis.

Additional information on the DQO process can be found in U.S. EPA. *Guidance on Systematic Planning Using the Data Quality Objectives Process* (February 2006) at https://www.epa.gov/quality and Ohio EPA, Data Quality Objectives Process Summary, DERR-00-DI-32, Internal Guidance Document, January 2002 at https://www.epa.ohio.gov/portals/30/rules/Data%20Quality%20Objectives%20Process%20Summary.pdf.

The type of environmental media sampled and sampling strategy for the evaluation of the vapor intrusion pathway is dependent on release history, prior site investigations, the CSM, and whether the site is being evaluated under the VAP or RP programs.

For RP sites, the sampling strategy is directed by the RI/FS, RFI/CMS or unit closure site characterization process. For VAP sites, the Phase I will direct the sampling with the results presented in the Phase II. For RP sites, the sampling strategy should be sufficient to characterize the complete nature and extent of contamination. For VAP sites the sampling strategy may be tailored to the remedy selection. During site characterization, the sampling and analysis plan that was developed during the project planning is implemented and field data are collected and analyzed to determine if a complete vapor intrusion pathway exists and to what extent the site poses a threat to human health and the environment. This is an iterative process and the resulting data and information will be used for selecting a remedy for the site.

The U.S. EPA *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* (June 2015) recommends collecting multiple rounds of sampling at multiple locations to evaluate spatial and temporal variations of the concentrations of COCs in environmental media. Spatial and temporal variability factors to consider include depth to ground water, heterogeneity in subsurface materials, weather conditions, building operations, building construction and age, interior compartmentalization, preferential contaminant migration pathways (such as foundation cracks, sumps and utilities), and whether the site is developed or undeveloped.

In most cases, soil gas data is part of the multiple lines of evidence approach to determine whether the vapor intrusion pathway is potentially complete from contaminated soil or ground water. For existing buildings, sub-slab vapor concentrations best reveal the potential for vapor intrusion directly into the building. The flow chart in Figure 1 does not require that environmental media be sampled in a linear fashion (*i.e.*, soil and ground water, then soil gas, then sub-slab vapor, and finally indoor air). However, where receptors are potentially being exposed, the preference is to determine impacts from soil gas, soil, and ground water first to determine if a potential for vapor intrusion exists. A more detailed discussion of the relative importance and iterative sampling of different media is provided in Sections 4.3, 4.5, and 6.4. If soil gas, soil and/or ground water data indicate a potential risk to building occupants, then sub-slab vapor and indoor air data should be collected and used in the risk evaluations. Special considerations are advisable when evaluating residential properties and/or imminent hazard situations and are discussed in Appendix B and Section 11.0, respectively.

Ambient air and sub-slab vapor should be collected when sampling indoor air to aid in data interpretation and determining if vapor intrusion is occurring. Although measuring indoor air concentration is a direct measurement at the exposure point, many factors can influence indoor air results, including materials used or stored indoors, disturbance of sampling equipment during testing, and the possibility of ventilating the building during the sample event (*i.e.*, opening doors/windows). Additionally, indoor air values can be influenced by concentrations of volatile chemicals in ambient outdoor air that are unrelated to releases in soil or ground water.

For all vapor-forming chemical releases, if the data collected during the site investigation indicates existing or future buildings at a site or near the site are greater than 100 feet laterally from the known extent of subsurface contamination above screening levels and there are no preferential pathways (*e.g.*, sewer lines) that can be a direct conduit from a vapor source to a building, then vapor intrusion is not likely under the current site conditions, and no further consideration of the exposure pathway should be needed until such time site conditions change in a way that warrant a vapor intrusion investigation (*e.g.*, a building is built directly above the source area). For relatively small releases compromised of only petroleum hydrocarbon (PHC), such as underground storage tank (UST) sites, a lateral separation distance of 30 feet and a vertical separation distance of 15 feet (above LNAPL) or 6 feet (above dissolved sources) can be applied instead of the default 100 feet. Sites with a potential for larger petroleum releases, such as bulk plants, refineries, petrochemical plants, or pipelines, or sites where lead scavengers were used or stored should use the 100 feet lateral separation distance recommended for non-PHC VOCs. See Sections 9.2 and 9.3 for additional information regarding PHC lateral and vertical separation distances.

Evaluations of building distance from contamination should only be conducted if the movement of subsurface contamination has reached steady-state conditions (*i.e.*, when the maximum migration potential of the subsurface plumes has been reached). For ground water, the migration potential can be evaluated with data from routine sampling of ground water monitoring wells. If COCs in ground water indicate stable or decreasing contaminant trends, the maximum contaminant migration for ground water has probably occurred. For soil gas, a similar evaluation can be conducted if routine sampling data is available from permanent or temporary sampling points. If sufficient time has passed since the chemical release to allow for diffusional movement to the building in question, then steady-state conditions have probably occurred. If soil gas or ground water contaminant plumes are increasing, 100 feet is not an appropriate distance for potential pathway elimination.

When evaluating the distances between subsurface contaminant plumes and buildings, it is important to consider whether preferential pathways exist which could allow vapors to migrate beyond the lateral separation distance. These preferential pathways could be either natural or anthropogenic. Examples of preferential pathways include fractures, macropores, gravel base for utility conduits, and subsurface drains, etc.

Flowchart Step 4: Sample environmental media

4.0 SOIL GAS AND SUB-SLAB VAPOR SAMPLING PROCEDURES

The following section provides basic guidelines for conducting soil gas and sub-slab vapor sampling for assessing the vapor intrusion pathway. Soil gas sampling refers to samples collected outside of a building footprint and sub-slab vapor sampling refers to samples collected from directly underneath an existing building. Appendix C contains Ohio EPA DERR’s standard operating procedures for installing soil gas probes, sub-slab vapor probes and direct push techniques for collection of soil gas.

Soil gas and sub-slab vapor sampling can be used for a number of purposes including initial site characterization, delineation of impacts from ground water plumes, identification of source areas and potential receptors, remediation and post-remediation monitoring, and for developing and refining a CSM.

4.1 Soil Gas and Sub-Slab Vapor Sample Collection and Analysis

Depending on the scope of the study and the DQOs, samples may be collected using devices such as gas-tight syringes, Tedlar® bags, passive sorbent samplers or Summa canisters. Gas tight syringes are appropriate only when an on-site field laboratory is used, and samples are analyzed immediately following sample collection. Field screening and use of a mobile lab are acceptable in order to refine DQOs by conducting on-site, real time field analysis. Alternative soil gas and sub-slab vapor sampling options can be proposed to Ohio EPA for considerations.

Prior to collecting the sample for analysis, Ohio EPA DERR recommends purging three tubing volumes or conducting a purge test until parameters (*e.g.*, oxygen, carbon monoxide, or VOCs) stabilize in order to determine the optimal purge volume for the location. The purge volume should be consistent for all samples collected from the study area. An approximate 10-minute delay should occur between purging and sampling. When purging or collecting samples using a vacuum pump or an evacuated canister, the vacuum applied to the probe should not exceed ten inches of mercury or 100 inches water and the flow rate generally should not exceed 200 milliliters per minute. This should limit the potential for ambient air being drawn into the sample from the ground surface and it should limit desorbing of vapors from contaminated soils.

To maintain sample integrity:

- The recommended maximum holding times for samples should not be exceeded. The laboratory should be contacted for holding times and to ensure the sampler uses the best collection method.
- If stored samples are to be subjected to changes in ambient pressure (such as shipping by air), canisters are recommended (ITRC, 2007).
- Samples should not be chilled during storage unless specified by the method.
- Tedlar® bag samples should be kept out of direct sunlight.
- All sampling records should be completed and maintained (*e.g.,* chain of custody, sample data forms).

The appropriate sample method is dependent on the DQOs developed for the project. The contract laboratory can provide information on appropriate sample volume for analysis. Samples should be analyzed for the appropriate COCs, including breakdown products. Syringe samples and Tedlar® bags generally are only acceptable for qualitative and possibly semi-quantitative analyses. Quantitative analysis by TO-15/8260 or TO-17 should be used for human health risk assessments. The analytical method used should be able to identify and quantify the target analytes and be capable of meeting program specific requirements. Sample results submitted to Ohio EPA DERR should be reported in units of ppbv and/or µg/m^3. Lower explosive limit (LEL) percentages should be used for explosive gas determinations. Soil gas and sub-slab vapor sampling field data should be recorded on either the Soil Gas Probe Field Data Report Form (Appendix D) or the Indoor Air/Sub-Slab Vapor Sampling Form (Appendix E) or equivalent forms, as applicable, and submitted with the results.

Utility and sewer lines should be located prior to conducting sampling for safety and to aid in locating samples. Contact a local municipal utility authority to obtain accurate layout of utilities and sewer lines in immediate vicinity of the site before a subsurface investigation. In Ohio, it is 8-1-1, the Ohio Utilities Protection Service, which coordinates with local utility contacts. The utilities and sewer lines should be depicted on the cross section of the CSM, and a determination should be made if there is a potential for utility or sewer lines to interact with shallow ground water. Utility lines within 100-feet of a known vapor-forming chemical release should be screened via a Photoionization detector (PID) or equivalent field screening instrument.

A utility line preferential pathway investigation should take into consideration the type, depth, diameter and construction specifications of all lines and bedding material, utilizing historical resources. Screen sewer gas and determine depth of lines through manhole apertures if possible, using a PID. Sampling in sewer lines and the bedding around utilities requires caution and expertise given the risks involved if utilities are pierced or damaged. The following resources discuss techniques which can be utilized to sample for soil gas in and around utilities:

- Indiana Department of Environmental Management (IDEM): Investigation of Manmade of Preferential Pathways, Office of Land Quality, August 2015: https://www.in.gov/idem/cleanups/files/remediation_tech_guidance_investigation_mpp.pdf

- Massachusetts Department of Environmental Protection (MassDEP) Vapor Intrusion Guidance, Site Investigation, Mitigation and Closure, October 2016: https://www.mass.gov/files/documents/2016/10/nu/vapor-intrusion-guidance-10-14-2016.pdf

4.2 Analytical Detection Limits

Analytical detection or reporting limits for soil gas samples should be sufficiently low to adequately evaluate the vapor intrusion pathway per the project's DQOs. For VAP sites, an estimate of the applicable standard, adjusted for the presence of multiple chemicals, provides the basis for the minimum detection limits. For screening at Ohio EPA DERR RP sites, the minimum detection limit is determined by the appropriate screening value. More information on the analytical methods and reporting limits can be found in Appendix F.

4.3 Soil Gas Sampling

In many cases, soil gas sampling is essential in evaluating the vapor intrusion pathway. There are a variety of techniques for obtaining these samples, from placing probes using boring devices to measuring soil gas using passive-type samplers. Whatever technique is chosen, the soil lithography and stratigraphy should be determined using on-site data from previous investigations, data from nearby sites, or based on information from county soil surveys to aid in characterizing the source and transport mechanisms. Other pertinent information that should be considered when planning a soil gas investigation include depth to ground water and the presence of perched impermeable zones. This information should be used to determine appropriate sampling depths. Ohio EPA generally expects that initial soil gas samples should be taken above the capillary fringe to determine if a contamination source is of sufficient concentration to warrant additional soil gas sampling or to conduct sub-slab vapor sampling. It may be necessary to install probes at multiple depths to evaluate the vertical distribution of contaminants in soil gas. For vertical delineation, soil gas samples could be collected at various depths (*e.g.*, 5 feet, 10 feet, and 20 feet below ground surface (bgs)) to demonstrate attenuation and the likelihood that the vapor intrusion pathway is complete. Ohio EPA DERR recommends that vadose zone monitoring points for sample collection be installed to evaluate the temporal variations in soil gas concentrations. Soil gas sampling should be postponed at least 24-hours after a major rain event (one-half inch or more) and the sampling area must be free of ponded water.

Soil gas sample locations should be biased toward the source, if known, or toward highest expected concentrations. If a property is developed, sub-slab vapor sampling rather than soil gas sampling is preferred to evaluate the potential vapor intrusion pathway to the building. If sub-slab vapor sampling is not practical, then soil gas samples should be collected as close to the building as possible. However, keep in mind that soil gas samples may exhibit a high degree of spatial and temporal variability (U.S. EPA, 2015b). According to U.S. EPA (2015b), "…soil gas concentrations measured exterior to a building may not be representative of sub-slab concentrations measured directly beneath the building foundation sub-slab. The bias introduced by these factors may be high or low depending on climatic and building conditions and the extent to which the samples accurately represent the spatial and temporal variability of concentrations under the building.” If soil gas samples are being collected in lieu of sub-slab samples, then bias should be given to preferential pathways, such as utilities and fill materials located at the site to account for this potential variability. It is important to note that situations may exist where vertical fractures may provide preferential pathways, in such instances sub-slab vapor sampling may be necessary to adequately evaluate the indoor air pathway.

Ohio EPA DERR recommends that a minimum of two rounds of soil gas data be collected to evaluate the vapor intrusion pathway. However, early or interim response actions may be required following one round of sampling. The two rounds will begin to estimate temporal and seasonal variations at the site and other site-specific factors which may influence vapor migration. Since two rounds constitute a limited database, the maximum concentration detected should be used to evaluate potential risk. Based on these results, additional samples may be required depending on the source strength, plume movement and how soil gas concentrations compare to screening levels. If soil gas samples exceed screening values and buildings are within 100 feet of the sample location for non-petroleum vapor-forming chemicals and within 30 feet of PHC vapor-forming chemicals, then sub-slab vapor samples and/or indoor air samples should be collected to further evaluate the vapor intrusion risk pathway. For further information on evaluating petroleum releases and their inclusion zones see Section 9.0.

For undeveloped sites with vapor-forming chemical contamination, soil gas samples should be collected to evaluate the potential for vapor intrusion should the property be developed in the future. The number and depth of soil gas samples should be sufficient to evaluate concentrations in soil gas and attenuation of soil gas as it migrates to the surface. Reassessment of the vapor intrusion pathway may be warranted once structures are built on the site to evaluate the site-specific situation.

Generally, soil gas samples should not be collected at depths shallower than five feet bgs due to the potential for atmospheric interference. Ambient air may infiltrate the soil column and could result in dilution of the soil gas sample near the surface. For sites where the depth to ground water or the soil source is less than five feet, but sub-slab sampling beneath an enclosed structure is not an option, an attempt should be made to collect soil gas samples from beneath existing impermeable surfaces such as outdoor patios, parking lots, or roads. When shallow (< 5 feet bgs) soil gas sampling is performed, leak testing is a critical element of the sampling to verify the integrity of the vapor probe seal and the quality of the data (Section 4.7). If an impermeable surface is not present beneath a structure or in outdoor areas, then it may be more appropriate to rely on other lines of evidence such as passive soil gas sampling, ground water sampling, crawl space or indoor air sampling to evaluate the vapor intrusion pathway.

4.4 Soil Gas Probes

Soil gas sampling probes are either temporary or permanent. Temporary soil gas probes are only sampled once, and all equipment is removed upon sample completion. Permanent soil gas probes are sampled over time to evaluate seasonal, temporal or other variations in concentrations. When possible, permanent soil gas probes should be installed when collecting soil gas samples for risk assessments. Figure 2 shows several types of soil gas probes (NJDEP, 2005). Whether installing a temporary or permanent soil gas probe, it is necessary to prevent ambient air from diluting the soil gas sample. A leak test should be performed to verify the integrity of the vapor probe seal. For further information on leak testing refer to Section 4.7.

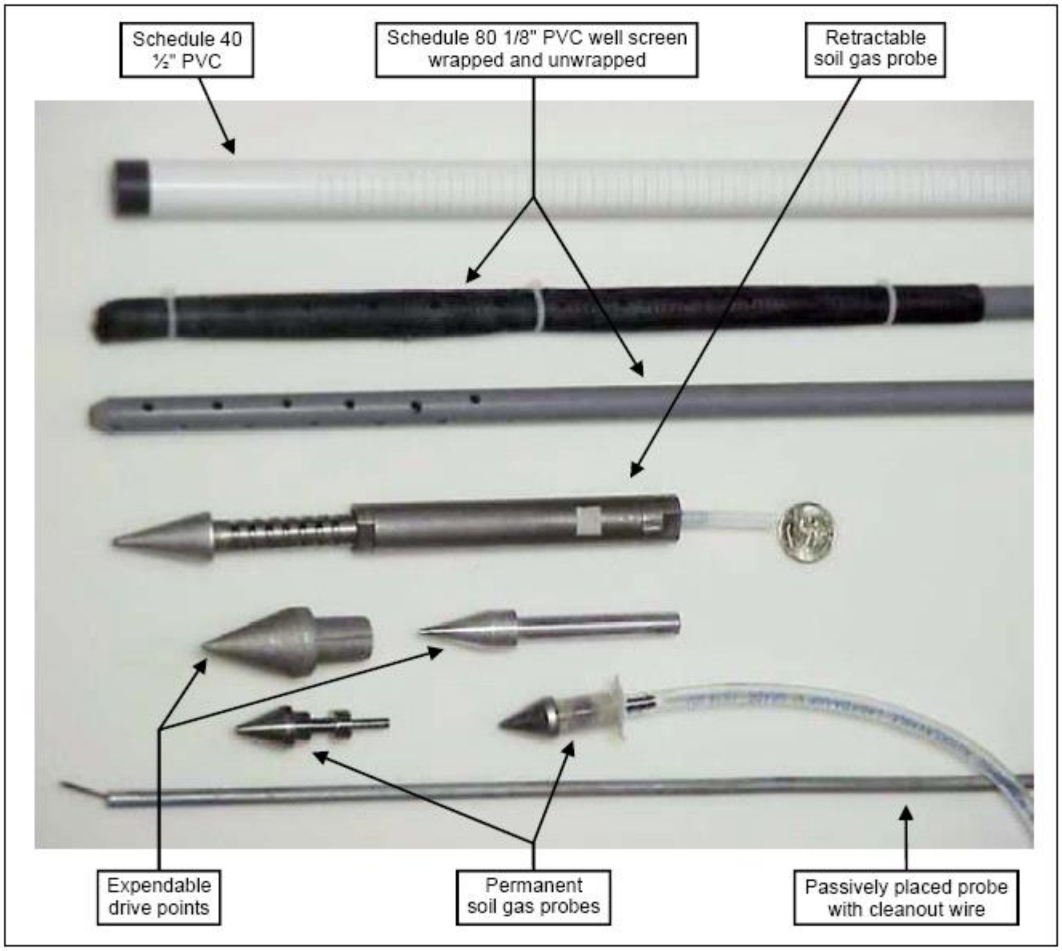


Figure 2. Examples of Soil Gas Sampling Probes (NJDEP, 2005)

Temporary vapor probes can be installed by a variety of methods. The most common methods are direct push and manual slide hammer. These methods allow sample tubing to be placed at the desired depth for sampling then removed once a sample is collected. Temporary vapor probes use a retractable or removable drive tip. Typically, ¼” nylon, Teflon or polyethylene tubing is used to collect subsurface vapors for sampling in temporary applications.

Figure 3 is a schematic of a permanent soil gas probe. Samples from permanent soil gas probes should be collected over an appropriate seasonal or temporal time frame in order to adequately evaluate the risk from the contaminants detected. Permanent soil gas probes typically consist of a screen or sample port installed at the tip or near the bottom of the tubing. Stainless steel, Teflon or nylon tubing are preferred in permanent applications. Tubing selections should be based upon duration of sampling, type of COCs, and how long the sampling point needs to remain in place (see Appendix G for comparison of sample tubing type to vapor absorption). Common installation methods include direct push equipment (*e.g.*, Geoprobe®), hollow stem auger and manual slide hammer (see Appendix C for the standard operating procedure for advancing soil gas probes). The soil gas probe is installed to a specific depth in a bore hole created with a slide hammer, direct-push system or a hollow stem auger. Sand is placed in the annulus around the sampling port screen and the remainder of the bore hole is sealed with hydrated bentonite. The tubing is usually labeled and capped at the surface. The bore hole is completed with a protective cover at the surface.

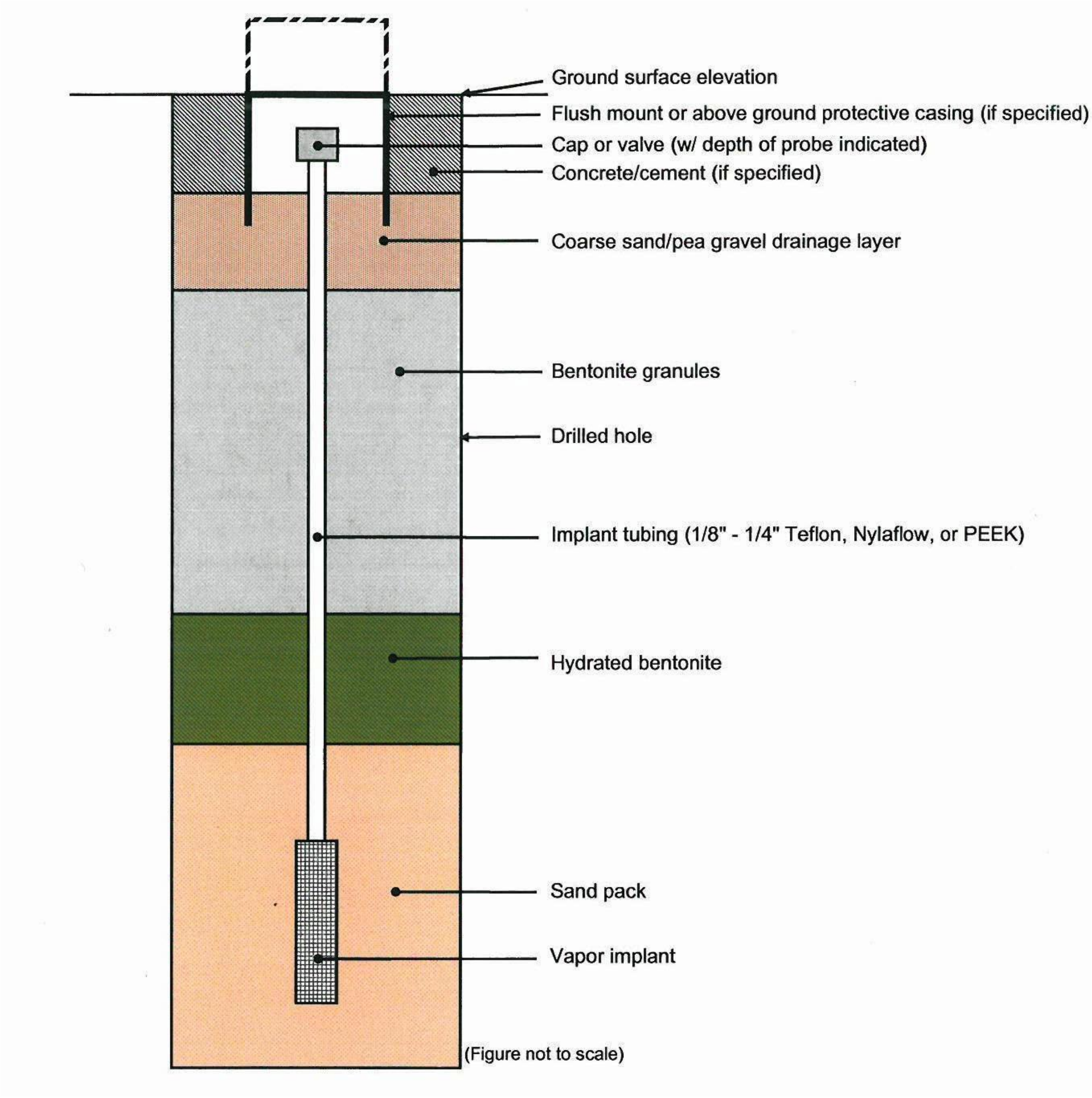


Figure 3. Permanent Soil Gas Probe Schematic

4.5 Sub-Slab Vapor Sampling and Data

Sub-slab vapor data, which is collected from under the foundation floor and is within the advective envelope of building-driven depressurization, indicate whether contaminants have accumulated directly under the building. Analytical detection limits should be low enough to effectively evaluate the indoor air risk posed by the vapor intrusion pathway. See Section 12.0 for more information on evaluating the indoor air risk from vapor intrusion by calculating risk levels.

When there is an indication of a potentially complete exposure pathway, proceeding directly to sub-slab vapor sampling may shorten the investigation. However, if the purpose of an investigation is to directly link a known or suspected source to vapor intrusion, then sub-slab vapor sampling is only one step in the process. In this situation, it is important to also consider collecting soil, ground water, soil gas, sub-slab vapor, utility or sewer line, and indoor air samples, as applicable, in order to link the source to the exposure point (*i.e.*, the indoor air). When collecting sub-slab vapor samples, Ohio EPA DERR recommends the event be paired with indoor air samples and an ambient air sample in order to compare the chemicals detected in these samples to aid in vapor intrusion assessment data interpretation and conclusions.

If COCs are detected in sub-slab vapor samples above screening levels, then installation of permanent sampling ports may be necessary to determine the temporal variability of the data. However, the collection of sub-slab vapor samples can be inconvenient to building occupants since it requires the removal of floor coverings and drilling through the foundation slab, thus clear communication with inhabitants and property owners about the sampling process is needed.

When sub-slab vapor sampling is conducted, an appropriate number of samples should be taken to characterize the sub-slab area. The number, type (time-integrated or grab samples), and locations of the sub-slab samples should be determined based on information collected during the building survey, an understanding of the building foundation(s), the COCs (*e.g.*, PHC versus chlorinated), the results from nearby soil gas, ground water, and/or soil sampling, and the site-specific DQOs. At residential properties, at least two sub-slab vapor samples should be taken with one sample taken in the center of the building's foundation. For foundations greater than 5,000 square feet, at a minimum sub-slab vapor samples should be collected approximately every 2,000 to 5,000 square feet from biased locations, such as locations directly over source areas, maximum ground water concentration areas or near preferential pathways, and one of the sample locations should be located near the center of the building foundation. If indoor air sampling is not performed concurrently, but is subsequently needed, the indoor air samples should be analyzed only for the chemicals detected in the sub-slab vapor (see Section 5.0). By selecting for the chemicals detected in the sub-slab samples, the chance of inadvertent inclusion of indoor sources of chemicals can be decreased or eliminated. However, analyzing indoor air samples for the method's full analyte list can be necessary when the full nature and extent of contamination has not yet been determined.

During sub-slab sampling care should be taken to not damage the integrity of the slab or underground utilities. Sub-slab utilities or tension cables need to be located prior to selecting sampling locations. Blueprints can assist in locating these features. A private utility locating service should be contracted to determine the presence of sub-slab utilities or tension cables if there is no information available from other sources. Since penetrating the slab creates a preferential pathway, proper sealing of the sampling port is essential to avoid leaks. Sub-slab sampling should be avoided in areas where ground water might intersect the slab. Figure 4 is a schematic of a sub-slab vapor probe made with Swagelok® parts. Another alternative is the Cox-Colvin vapor pin®.

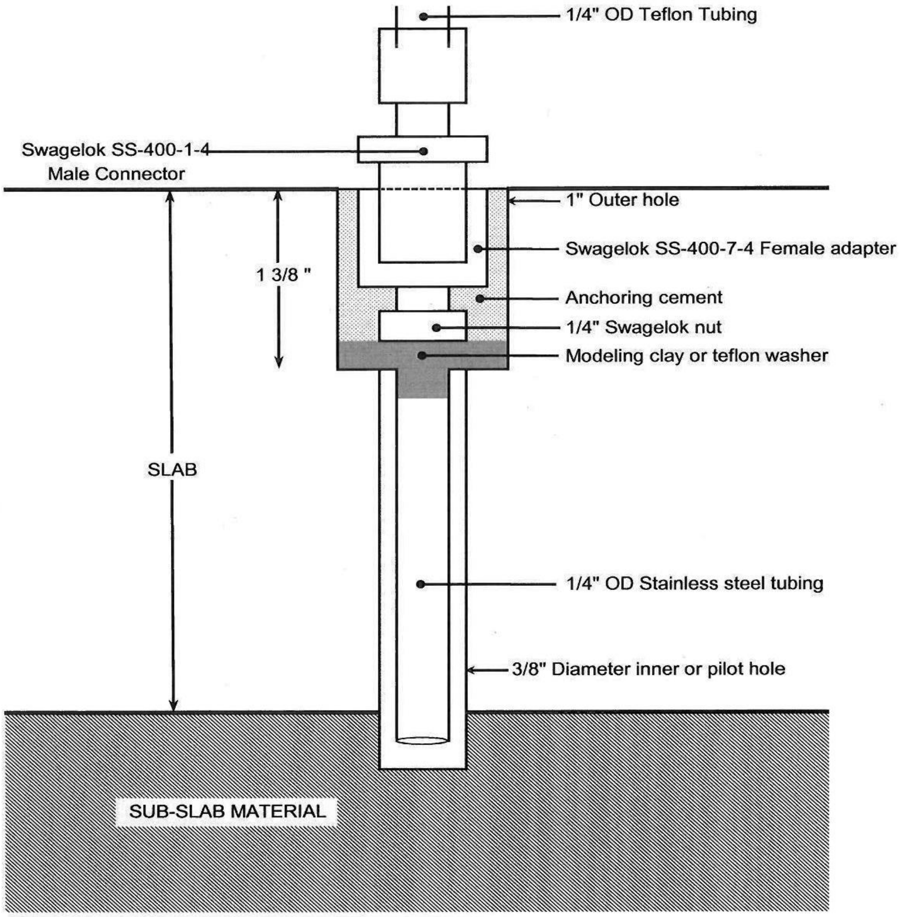


Figure 4. Example of a Sub-Slab Vapor Probe

Multiple sampling rounds may be needed to adequately account for temporal variability due to the “substantial spatial variability in sub-slab vapor concentrations” (U.S. EPA, 2015b). Generally, if both indoor air and sub-slab vapor samples are collected during the most desirable sampling conditions to evaluate reasonable maximum exposure and both are non-detect or below screening values, then one round of sampling may be sufficient. If, however, COCs are detected in both sub-slab vapor and indoor air, or if indoor air is non-detect, but COCs are elevated in sub-slab vapor, soil gas or other media, then multiple rounds of sampling (or preemptive mitigation) are typically required. The number of additional rounds depends on the chemical concentrations and other site-specific circumstances. For example, long-term quarterly, semi-annual, or annual sampling may be necessary in situations where vapor concentrations are variable, or to verify remedy effectiveness.

4.6 Sampling Basements with Dirt Floors and Crawl Spaces

If a basement or crawl space has a dirt floor, any sampling conducted should be with an evacuated air canister in the same manner as for sampling indoor air.

4.7 Leak Testing

Atmospheric air drawn into a soil gas or sub-slab vapor sample can result in dilution of the sample. Negatively biased samples, resulting from the inclusion of atmospheric air during soil gas or sub-slab vapor sampling, will be unusable to demonstrate that a vapor intrusion pathway is incomplete. To ensure that valid soil gas and sub-slab vapor samples are collected, leak tests on the probes should be conducted to demonstrate that dilution is not a concern. It is often desirable to conduct leak testing with utilization of tracer gases or a water dam. The water dam can consist of a secondary, larger hole surrounding the smaller hole that the vapor sampling point is installed through (such as the hole used for flush mount Vapor Pin® installation) or can be a ring temporarily sealed to the floor with VOC-free putty. The water dam is filled with water after connecting the tubing to the Summa canister. Changes in water level or appearance of bubbles during sampling are indicative of possible leaks.

Soil gas probes should be installed greater than five feet bgs and should be tested for integrity with a particular emphasis on the sampling train (*i.e.*, the tubing or the connectors). This testing is usually performed with compounds not found at the site that enshroud the sampling train. Atmospheric oxygen and CO_2 may also be considered for leak tests. As a general rule, shallow soil gas samples (*i.e.*, less than 5 feet bgs), are discouraged. However, if shallow soil gas sampling is the only option at a site, then leak testing should be utilized, and sampling must be discussed with Ohio EPA DERR personnel prior to collection of these samples. Temporary soil gas probes should be abandoned immediately after the investigation is concluded. Sub-slab vapor sample collection can also be affected by leaks from surface air and a sub-set of these samples should also have leak tests performed. In addition to tracer gas leak tests, a mechanical leakage test of the sampling train should be considered, such as Shut-in Test as proposed by McAlary et. al. (2009). This test involves pulling a vacuum on the tubing and valves used to construct the sampling train. Typically, a vacuum of 100 inches of water is applied to the “closed-off” sampling train and potential leaks are verified with an in-line vacuum gauge.

Depending on the contaminants of concern a number of different compounds can be used as a tracer, as shown in Table 1. Sulfur hexafluoride (SF_6), perfluorhydrocarbons and helium are commonly used as tracers because they are readily available, have low toxicity, and can be monitored with portable measurement devices. Isopropanol can also be used as a tracer but requires laboratory analysis for the tracer. In all cases the same tracer should be used for all sampling probes at any given site. The leak test should be conducted using a tracer that is not expected to be present in the soil gas or sub-slab vapor being tested. When choosing a liquid tracer, check with the laboratory to determine the reporting limit for the proposed tracer. Ideally, the reporting limit for the tracer should be similar to the constituents present in the soil gas or sub-slab vapor.

Infiltration of atmospheric air during sampling may also be indirectly evaluated through the measurement of oxygen and carbon dioxide concentration differences due to the presence or absence of petroleum hydrocarbon degradation. For example, if oxygen concentrations at a probe installed within a petroleum hydrocarbon source area are at atmospheric levels, the soil gas data should not be considered reliable and the probe seal should be modified and the probe re-sampled, because oxygen levels would be expected to have been depleted in the biological degradation process. Care should be exercised using this logic when investigating sub-slab vapor as the absence or presence of a robust microbial community may be questionable. The Soil Gas Probe Field Data Report Form in Appendix D is useful for recording data when conducting soil gas evaluations. Table 1 lists advantages and disadvantages of common tracer compounds.

Table 1. Common Tracers Advantages and Disadvantages

Tracer	Advantages	Disadvantages
Helium	Can check for leaks on site with handheld detector. Can quantify amount of leakage accurately. Does not interfere in TO-15 analysis.	Party-grade helium may have low VOC contamination. If used, send a QC sample to lab for analysis. Process is more cumbersome than some others. Cannot be analyzed by TO-15 Can be difficult to apply to sampling train connections.
Liquid Tracers	Easy to use in identifying leaks. Can be detected by VOC analytical methods. Easier to apply to sampling train connections.	Concentration introduced to assess leak is estimated. Large leak may lead to VOC analysis interferences. No simple field screening method. May leave residual contamination on sampling train. Qualitative.
Sulfur Hexafluoride	Can check for leaks with on-site instrument with very low detection limits.	Very expensive. Field instrument subject to interference with chlorinated solvents. Cannot be analyzed by TO-15. A greenhouse gas.
Ambient Air Oxygen	Cost effective, easy. Check for leaks with on-site multi-gas meter.	Cannot be used in an environment where oxygen is expected to be present at ambient levels. Qualitative.

If elevated levels of the tracer (greater than 10% in the shroud) are observed in a sample, the soil gas data should be evaluated for the significance of bias on the results. If the evaluation provides evidence that the results cannot be considered reliable, then re-testing should be attempted after determining the cause for the atmospheric or tracer break through. Portable, tracer gas-specific field monitoring devices with detection limits in the low part per million (ppm) range are available to screen samples for tracer leak testing.

4.8 Passive Soil Gas (Exterior or Sub-Slab) Sampling

Most methods for soil gas sampling involve the measurement of volatile constituents in soil gas after drawing soil gas into evacuated canisters, such as Summa canisters, with analysis by U.S. EPA method TO-15. Summa canister use is limited by flow regulators with sampling durations ranging from immediate grab up to 72-hour samples. Scientists and engineers concerned about impact of temporal variability on the representativeness of soil gas concentrations may consider longer sampling durations using passive soil gas sampling techniques. Passive sampling uses adsorbent materials which are placed in the subsurface and left for a period of time (up to weeks). The sampling devices are then retrieved and analyzed. Passive soil gas samples therefore may provide longer-term time-weighted average concentrations.

Passive samplers generally consist of a container with an opening to allow gas to permeate and be sorbed onto a sorbent. The opening is configured to allow vapors into the device with a steady uptake rate. The sorbent is selected for the chemicals of concern. The average concentration over the sampling period can be determined using the following equation.

$$\mathrm{C} = \mathrm{M}/(\mathrm{UR}\ \mathrm{x}\ \mathrm{t})$$

Where: C = Concentration
M = Mass of sorbed chemical (µg)
UR = Uptake Rate (mL/min)
t = time (min)

Conversion of these parameters into familiar units of µg/m^3 is usually performed by the laboratory. The analysis of the sorbent material can determine the mass (M) of the chemical adsorbed with high accuracy. The duration of sample acquisition (t) is also known, but the uptake rate (UR) can depend on a variety of factors. These factors include the geometry of the sampling device, the physical-chemical characteristics of the chemicals of concern (diffusion coefficient); the humidity of the soil atmosphere and the permittivity of the chemical through the soil.

Many of these factors for the uptake rate are not known without study, therefore Ohio EPA DERR considers passive soil sampling to be qualitative. Studies (McAlary et al., 2014a) suggest that quantitative passive soil gas sampling analysis is possible, but consultants should consult with Ohio EPA before site work begins to demonstrate the acceptability of passive soil gas sampling for quantitative purposes.

Passive soil gas sampling methods can be a useful tool for:

- Collecting soil gas from low-permeability and high moisture settings where conventional active soil gas sampling may be problematic;
- Detecting compounds present at very low concentrations;
- Assessing preferential vapor migration pathways such as utility corridors and foundation cracks to determine if these pathways are acting as significant VOC migration pathways into a structure; and
- Providing chemical vapor concentrations if the sampling method meets the project DQOs.

For additional information on passive sampling techniques, see:

- ITRC guidance, Vapor Intrusion Pathway: A Practical Guideline. January 2007, Appendix D, page D-16.
- NAVFAC Memorandum (July 2015), Navy Facilities Engineering Command: Passive Sampling for Vapor Intrusion Assessment. TM-NAVFAC EXWC-EV-1503. 14 pages.
- McAlary, T.A., H. Groenevelt, S. Seethapathy, P. Sacco, D. Crump, M. Tuday, B. Schumacher, H. Hayes, P. Johnson, and T. Górecki. 2014b. Quantitative passive soil vapor sampling for VOCs—Part 2: laboratory experiments. *Environ. Sci.: Processes Impacts* 16(3): 491–500.

5.0 INDOOR AIR SAMPLING

Indoor air sampling should be conducted when soil, ground water, soil gas, or sub-slab vapor data indicate the potential for unacceptable risk due to vapor intrusion, or an imminent hazard is suspected. Indoor air sampling in lieu of other media sampling may be necessary under circumstances where soil gas or sub-slab vapor sampling is not viable, such as: contaminated soil or ground water in close proximity to the foundation, during or after mitigation, or where preferential pathways may exist that would limit the usefulness of data from other environmental media. As previously noted, indoor air sampling in conjunction with sampling other media is recommended to prevent the potential for concentrations of chemicals from indoor sources (not related to vapor intrusion) inadvertently being included in the vapor intrusion risk evaluation.

Several steps should be considered when conducting indoor air sampling as part of a vapor intrusion assessment:

- Define the study goals and DQOs;
- Identify the vapor-forming chemicals, including parent and breakdown products;
- Inspect building interiors and product inventory;
- Select the number and location of indoor sample locations;
- Select the number and location of ambient air sample locations;
- Select the duration of samples based on DQOs and risk assessment or risk management needs;
- Select appropriate sampling methods with acceptable detection limit(s); and,
- Establish QA/QC requirements.

When assessing large plumes that have the potential to affect a significant number of structures, Ohio EPA DERR recommends a tiered approach to indoor air sampling. Highest priority for sampling should be given to structures at the greatest risk for indoor air contamination through an evaluation of nearby ground water concentrations, soil gas concentrations, sub-slab vapor concentrations, structural characteristics and sensitivity of receptors. Conduct sampling at the primary structures, *i.e.*, at the greatest risk of indoor air contamination, first. Conduct sampling at secondary structures if COC concentrations in or below primary structures are at unacceptable levels. This systematic "step-out process" should be implemented sequentially until a perimeter of structures with concentrations at acceptable levels is defined.

5.1 Site Inspection, Product Inventory and Field Screening

Prior to indoor air sampling, a site inspection and inventory of products containing volatile chemicals should be conducted in the building (see Appendix E). Activities that could influence indoor air concentration levels should be suspended a minimum of 24-48 hours prior to and during sampling. Activities that should be suspended include, but are not limited to, smoking, use of sprays and/or solvents, mowing, painting, and asphalting. Containers containing products that could confound indoor air vapor intrusion assessment results should be removed from the building if possible.

Field screening instruments used to assist with identifying indoor air sample locations should be capable of detecting vapors in the µg/m^3 range. However, field screening results are considered qualitative and often are not capable of measuring levels over time or at low enough concentrations to inform risk management decisions. Therefore, quantitatively collected indoor air samples are still needed to evaluate receptor exposure and quantify potential human health risks.

5.2 Indoor Air Sample Collection and Analysis

Ohio EPA DERR recommends that indoor air samples be paired with sub-slab vapor samples and an ambient air sample in order to compare the chemicals detected in these three distinct zones when interpreting data and making conclusions about the vapor intrusion pathway. When conducting paired indoor air and sub-slab vapor sampling, it is recommended that the samples be collected a minimum of 2 hours after the installation of sub-slab vapor ports to allow for equilibration of both the indoor air and sub-slab vapor sampling spaces (U.S. EPA, 2015b).

When collecting indoor air samples, it is preferable to collect samples under conditions that will result in the highest potential concentrations (see Table 2). Indoor air samples should not be collected when doors and windows are open frequently or for long periods of time. Special consideration should be given to areas where sewer lines may provide a preferential pathway, and it is often beneficial to sample in bathrooms, laundries, and mud rooms where dry traps or leaking plumbing are present and may be acting as a preferential pathway. Sampling in the lowest level of a residence or commercial/industrial building is often needed to evaluate the most likely highest concentrations in indoor air. If vapor-forming chemicals are detected in the lowest levels above applicable standards, then additional sampling may be needed from the next higher level of the building to further assess vapor intrusion exposures.

While sampling under the more conservative conditions specified in Table 2 is recommended, Ohio EPA DERR acknowledges that it may be difficult to time sampling to when these conditions are present. The sampling team must decide when to sample based on site-specific circumstances and each individual project’s DQOs.

Table 2. Comparison of Indoor Air and Sub-Slab Vapor Sampling Conditions to Bias Sampling to the Highest Potential Concentrations*

Parameter	More Conservative	Less Conservative
Temperature	Indoors 10°F greater than outdoors	Indoor temperature less than outdoor
Wind	Steady greater than 5 mph	Calm
Soil	Dry	Saturated with rain (1/2” of rain or more within 24 hours)
Doors/Windows	Closed	Open
Mechanical Heating System	Operating	Off

*Modified from Mass DEP Vapor Intrusion Guidance Document (2016)

Sampling duration should represent the exposure scenario(s) under consideration. Typical exposure scenarios include residential and commercial categories. A twenty-four (24) hour sampling duration is used to represent exposure for a residential setting and an eight (8) hour sample duration for a commercial or industrial setting. A 24-hour sample in a commercial or industrial setting is also acceptable.

The number and location of indoor air samples is site-specific and dependent upon the site conceptual model. Indoor air samples should, at a minimum, be collected from the lowest level of the structure where vapors are expected to enter such as basements or crawl spaces, and in areas where preferential pathways, including foundation penetrations and cracks, have been identified. In some circumstances, it may be beneficial to collect samples in first or second floor spaces, or necessary when a building is built slab on grade. However, subsequent risk management decisions based on these samples are site-specific and should be made in consultation with Ohio EPA DERR. Multiple indoor air sample locations are typically necessary in the following instances: when there is significant or unknown spatial variability in subsurface contamination, large buildings (>1,500 square feet), small rooms such as offices and break rooms present within larger buildings, buildings with additions, and areas subject to different HVAC systems. In larger buildings, samples should both be biased toward known or suspected subsurface contamination as well as collected from occupied areas of the building.

Multiple rounds of sampling may need to be collected to adequately account for temporal and seasonal variability. Generally, if both indoor air and sub-slab vapor samples are collected during more conservative sampling conditions (see Table 2) and both are non-detect or below screening values, one round of sampling may be sufficient. If, however, COCs are detected in both sub-slab vapor and indoor air, or if indoor air is non-detect but COCs are elevated in sub-slab vapor or subsurface media, then multiple rounds of sampling, or preemptive mitigation, are typically required. The number of additional rounds of sampling depends on the chemical concentrations and other site-specific circumstances. For example, long-term quarterly, semi-annual, or annual sampling may be necessary in situations where vapor concentrations are variable, or to verify remedy effectiveness.

For details on collecting indoor air, see Figure 5 and the appendices.

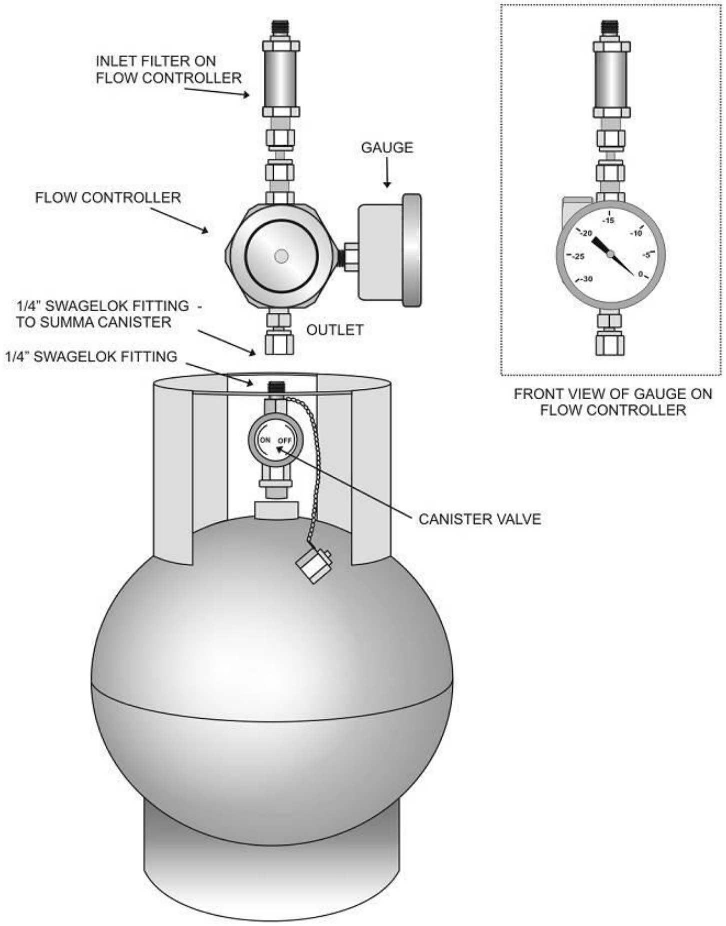


Figure 5. Schematic of a Summa Canister (*Eurofins Lancaster Laboratories Environmental, LLC 109)*

Indoor air samples are typically collected in Summa canisters. When requesting Summa canisters from a lab, it is recommended that you request canisters that are dedicated to indoor air sampling and are certified clean to appropriate levels for indoor air screening. The canisters from a lab can either be certified clean by "batch" certification or "individual" certification. Project DQOs as well as a discussion with the lab should help identify the need for "batch" or "individual" certification of the sample canisters. The analytical method chosen for the indoor air sample analysis must be able to identify and quantify the target volatile chemicals and be capable of detection below acceptable indoor air risk evaluation levels. Ohio EPA DERR recommends that laboratory analysis for VOCs be done using gas chromatography/mass spectrometry (GC/MS) and where appropriate, using the high-resolution selected ion monitoring (SIM) mode for low level detection.

Analyzing indoor air samples for the method's full analyte list is often necessary when the full nature and extent of contamination has not yet been determined, such as when indoor air samples are collected prior to or in lieu of sampling other media. However, if contaminant concentrations in ground water, soil, sub-slab vapor and/or soil gas have been sufficiently characterized, the analyte list may be limited to only those COCs known or suspected to be present and the degradation products of the primary VOC contaminants. By selecting for the chemicals detected in the release, the chance of inadvertent inclusion of indoor sources of chemicals can be decreased or eliminated.

6.0 GROUND WATER MONITORING AND EVALUATION

Vapor-forming chemical contamination in ground water can be a source of vapors that may impact an overlying structure. Ideally, soil gas or sub-slab vapor sampling should be conducted in addition to ground water sampling when a source of vapor-forming chemicals is present in or on the ground water. However, ground water data alone can sometimes be used to evaluate the potential for vapor intrusion from ground water contamination. Proper ground water monitoring well placement and construction, including screen placement, screen lengths, and sampling protocols, are important for gathering appropriate ground water data to evaluate the presence and concentrations of vapor-forming chemicals to assess vapor intrusion potential and the need for additional media samples. For technical guidance on installing and sampling ground water monitoring wells, please see the Ohio EPA Division of Drinking and Ground Waters Technical Guidance Manual in addition to the modifications for the VI assessment discussed below.

6.1 Well Placement

Sufficient sampling is needed to determine ground water contamination levels, contamination location, plume movement, and to assess and evaluate the potential vapor intrusion from ground water contamination. For the purposes of investigating vapor intrusion, wells should be placed in each area of anticipated maximum concentrations, or the core of the plume(s). Monitoring wells must also be properly located proximal to areas of known indoor air receptors to assess the potential impacts to those receptors. A conceptual site model and DQOs can help evaluate spatial and temporal variability in ground water concentrations and identify potential well locations.

6.2 Screen Placement

Ground water samples obtained from the uppermost portion of the aquifer are recommended to characterize representative vapor source concentrations for vapor intrusion assessments. Ground water samples from wells screened across the water table interface are preferred. Ohio EPA recommends that samples representing a flow-weighted average be collected as close as possible to the top of the water table using sampling methods designed to minimize loss of volatiles because VOCs volatilize from the top of the water table. Thus, monitoring wells used to make vapor intrusion evaluations should not have screens submerged below the top of the water table.

6.3 Screen Lengths

Monitoring wells with long well screens, regardless of screen placement, should not be used for VI evaluations. When sampling long well screens, clean water entering the well screen at depth may dilute the contaminated ground water near the top of the screen, biasing the sampling results and the associated risk determination. Therefore, short screen lengths are preferred for monitoring wells that will be used to make vapor intrusion evaluations. Ideally, the saturated thickness at a well screen should always be less than 10 feet.

A flow-weighted averaging of ground water concentrations happens when mixing of water from different stratigraphic units occurs while purging a well using low-flow methods, such as low-flow purge and sample. Areas of higher conductivity provide a proportionally higher volume of water than lower conductivity regions across the screened interval.

6.4 Ground Water Sampling

Ohio EPA recommends low-flow ground water sampling with bladder pumps or submersible pumps. These pumps minimize the loss of VOCs during sample collection and handling. Some submersible pumps can cause cavitation of the ground water and release of volatiles, so care should be taken in selection and operation of the pumps. For well-characterized sites where the contaminants are known, the appropriate diffusion bags may be used to sample ground water following the procedures in Interstate Technology and Regulatory Council (2004) guidance document *Technical and Regulatory Guidance for Using Polyethylene Diffusion Bag Samplers to Monitor Volatile Organic Compounds in Groundwater*. However, if levels of VOCs in ground water collected using diffusion bags are found to be near screening levels, samples may need to be verified using bladder or submersible pump sampling techniques.

This may require multiple sampling events conducted quarterly over several years to represent seasonal variations. The stability of the VOC plume must be demonstrated so that the risk to receptors would not be expected to increase due to contaminant migration or degradation to more toxic constituents, such as the degradation of tetrachloroethylene (PCE) and trichloroethylene (TCE) to vinyl chloride. Plume stability and migration may be affected by factors as simple as a change in the surface drainage and recharge patterns. Understanding these changes is important when characterizing the vapor intrusion potential of a ground water source.

6.5 Soil Gas Confirmation of Ground Water Concentration

Ground water chemical concentrations can be compared to VISLs to evaluate the potential of VI and the need for further sampling (see Section 8.3). Ohio EPA recommends applying the appropriate VISLs for any building with receptors within 100 feet of the plume boundary for non-PHC vapor-forming chemicals and 30 feet for PHC vapor-forming chemicals.

If ground water concentrations are less than VISL and a determination is made that additional sources in soil or preferential pathways are not present the investigation may be discontinued. If there is uncertainty as to whether a complete vapor intrusion pathway exists, soil gas, sub-slab vapor and/or indoor air data may be needed in addition to ground water data to determine vapor concentrations in vadose zone soils. Indoor air samples may be needed to establish whether the vapor intrusion exposure pathway from environmental media to indoor receptors is complete.

When collecting soil gas samples to measure concentrations of vapor-forming chemicals emanating from ground water, Ohio EPA recommends that seasonal ground water table elevation fluctuations be considered. Ground water elevation fluctuation can impact measured vapor concentrations in the vadose zone. Multiple sampling events may be needed to adequately address seasonal variations in concentrations from sources in ground water.

6.6 Other Factors

If the vapor-forming chemicals are present as Light Non-Aqueous Phase Liquid (LNAPL), then ground water sampling may underestimate soil gas concentrations in the vadose zone and a soil gas survey should be conducted. For further information on evaluating petroleum releases see Section 9.0.

7.0 BULK SOIL

Soil data are used to define the type, location and extent of soil contamination when investigating the potential for vapor intrusion. If a release of a vapor-forming chemical has been confirmed, a lack of detections in soil should not be interpreted to indicate the absence of a subsurface vapor source and soil data alone is not recommended to evaluate vapor intrusion risk or pathway completeness. Rather, a well-developed conceptual site model along with multiple lines of evidence should be used when evaluating the potential for vapor intrusion at a site. The uncertainty associated with soil partitioning equations and the potential for VOC contaminant loss during sample collection and analysis (Hewitt, 1994; Hewitt, 1999; Liikala et al., 1996; Vitale et al., 1999) makes using soil data alone unreliable for drawing risk assessment conclusions about a suspected or confirmed release at a site. Therefore, Ohio EPA DERR recommends soil vapor sampling when a suspected or known soil source of vapor-forming chemicals has a potential for vapor intrusion. VOC loss during sampling can be minimized using SW-846 Method 5035A (U.S. EPA, 2002). U.S. EPA SW-846 Method 5035A (2002) provides the minimum requirements and standards to prevent loss of VOCs during sample collection and handling. Specific soil collection requirements for SW-846 Method 5035A include chemical preservation in the field, using multi-functional sampling devices, or using empty, tared and labeled Volatile Organic Analysis (VOA) vials with Polytetrafluoroethylene (PTFE)-lined septum caps. Refer to the method for specific instructions.

Flowchart Step 5: Evaluate data and determine if data evaluation indicates the possibility of an imminent hazard

8.0 DATA EVALUATION AND ANALYSIS

For each site, multiple lines of evidence are used to assess the vapor intrusion pathway. Most of the lines of evidence will be based on empirical data from environmental media including soil, ground water, soil gas, sub-slab vapor and/or indoor air. Evaluating data from several environmental media, averaging among different collection times, and differing environmental conditions, poses a unique set of considerations when evaluating data for vapor intrusion. Generally, the multiple lines of evidence approach starts with evaluating soil and/or ground water data from the environmental release for the presence of volatile chemicals to assess the vapor intrusion pathway. If sufficiently volatile and toxic chemicals are detected in soil and/or ground water, additional sampling is usually warranted to further assess the vapor intrusion pathway.

Analytical methods, quantitation limits, qualified and coded data, and blanks should all be evaluated prior to relying on the data for decision making. Data are evaluated for several reasons which should be described in DQOs for the site. Generally, data are evaluated to determine the most logical and efficient next step in the investigation or remedial process. Initial comparisons to the appropriate risk-based screening levels or applicable standards may be appropriate and provide evidence for reacting to an imminent hazard or implementing early or interim response measures. For more information on comparisons to risk-based screening levels and appropriate responses to imminent hazards see Section 11.0 and flowchart Step 5.

8.1 Vapor Intrusion Screening Levels

U.S. EPA VISLs (https://www.epa.gov/vaporintrusion/vapor-intrusion-screening-levels-visls) are media-specific, risk-based screening level concentrations for ground water, sub-slab vapor and soil gas, and indoor air. VISLs are applied to identify site areas, building locations, exposure points, and/or concentrations of COCs that are either unlikely to present a human health concern and can be eliminated from further assessment or where further evaluation of the VI pathway is needed. Established DQOs should be met, and exposure assumptions should be consistent with the appropriate exposure scenario (*i.e.*, residential or commercial/industrial land use).

For Ohio EPA DERR RP sites, when considering concentrations measured in sub-slab vapor, soil gas, or ground water, the VISLs should be applied corresponding to an excess lifetime cancer risk (ELCR) of 1E-5 (*i.e.*, one increased cancer risk in 100,000 people) and a noncancer hazard quotient (HQ) of 1. Ohio EPA considers the generic application of the attenuation factor (AF) within the VISL calculation as an appropriate extension of safety to provide for applying these ELCR and HQ values. If the measured concentrations in the sampled media are less than the appropriate exposure scenario VISLs set at an ELCR of 1E-5 and a HQ of 1, Ohio EPA DERR considers the pathway to be 'incomplete' and additional investigation or risk estimation of this pathway is not warranted.

For Ohio EPA DERR VAP sites the VISLs should be applied corresponding to an ELCR of 1E-5 and a HQ of 1. If the measured concentrations in the sampled media are less than the appropriate VISLs set at an ELCR of 1E-5 and a HQ of 1 for the appropriate exposure scenario then additional investigation of this pathway is not warranted. However, the estimation of risk generated from the analysis of the media or indoor air must be included within the sitewide risk characterization in accordance with VAP rules OAC 3745-300-08 and OAC 3745-300-09. A sitewide risk characterization must meet the Ohio EPA cumulative risk goals of an ELCR of 1E-5 and a HQ of 1. In summary, the removal of detected COCs from the risk assessment using a risk-based approach is not permitted in the VAP, and the detected COCs must be multiple chemically adjusted and included in the summation of risk and hazards across the complete exposure pathways.

Ohio EPA considers concentrations in indoor air to be the exposure point concentration from which risk and hazard levels can be estimated and applicable standards can be demonstrated. When VISLs or U.S. EPA Regional Screening Levels (RSLs) are being used for risk and hazard assessment, care should be taken to use the appropriate land use scenario and an ECLR of 1E-5 and a HQ equal to 1. In some cases, it may be appropriate to evaluate multiple chemicals within indoor air to ensure Ohio statewide cumulative risk and hazard goals are met.

8.2 Bulk Soil Data

Soil data are less than ideal for evaluating vapor intrusion risk and the need for early or interim measures because of the uncertainty associated with using partitioning equations and the potential loss of VOCs during sample collection (see Section 7.0). In general, identification of elevated levels of VOCs in soil indicate the need for sub-slab vapor and indoor air sampling when buildings are present, or soil gas data in areas where buildings do not exist. Bulk soil detections of VOCs may be used to define the location of a VOC source and extent of soil contamination, to assess the risk from direct contact with soils, and to evaluate leaching to ground water.

8.3 Ground Water Data Screening

Ohio EPA recommends comparing ground water concentrations to U.S. EPA screening values calculated through the U.S. EPA VISL calculator (Section 8.1). Ground water sample data should be compared to screening values developed for the appropriate exposure scenario (*i.e.*, residential or commercial/industrial exposures), utilizing a default or site-specific attenuation factor (AF), and a default or site-specific ground water temperature.

The U.S. EPA VISL calculator uses AFs to calculate target ground water vapor intrusion screening levels from toxicity-based target indoor air concentrations. Ground water data should be compared with the appropriate VISL calculated with the recommended default ground water AF appropriate to the CSM for the site. A generic ground water AF of 0.001 can be applied for most site scenarios with the exception of shallow water tables less than five feet below the foundation of a building or when preferential vapor migration routes are present in vadose zone soils (U.S. EPA, June 2015b). A default ground water AF of 0.0005 can be applied at sites with fine-grained (low permeability) vadose zone soils when laterally extensive layers are present (U.S. EPA, June 2015b). Site-specific soil and geologic information are needed to support the use of non-default AFs.

In addition to adjusting the default AF, the ground water temperature in U.S. EPA's VISL calculator can be adjusted to Ohio EPA DERR's default ground water temperature of 11 degrees Celsius, or a verified property-specific value, to generate Ohio or site-specific target ground water vapor intrusion screening levels.

Areas with ground water COC concentrations exceeding the ground water VISLs warrant further evaluation of the VI pathway, including sampling of soil gas, sub-slab vapor and indoor air, depending on the presence and location of buildings. If buildings are not currently present at the site, it is recommended that a pre-emptive remedy requirement or future evaluation of potential VI pathway be recorded in an Environmental Covenant to avoid exposure to future receptors in the form of an institutional control (see Section 13.0, Remedy).

8.4 Soil Gas and Sub-Slab Vapor Data Screening

Soil gas and sub-slab vapor data for each area of concern should be compared individually to the VISLs. The recommended generic AF of 0.03 should be used to develop sub-slab vapor and soil gas VISLs. However, soil gas VISL values should not be used for VI source areas that are present less than five feet below the ground surface or if preferential vapor migration routes are present in vadose zone soils (U.S. EPA, 2015b). Soil gas and sub-slab vapor data that exceed VISLs warrant further VI assessment. If buildings are not currently present in the area(s), additional assessment is warranted in the future if buildings are constructed, and an Environmental Covenant with a building occupancy limitation may be needed depending on the site conditions and reasonably anticipated future use.

For evaluating the human health risk associated with crawl space air, an attenuation factor of 1.0 should be used for crawl spaces, consistent with U.S. EPA guidance (2015b). The use of an attenuation factor of 1.0 indicates the indoor air quality is assumed to be equal to the crawl space air quality for evaluation purposes.

8.5 Indoor Air Data Evaluation

The indoor air data collected (Section 5.2) provides a time-weighted (*e.g.*, 8 or 24 hours) average concentration representing the reasonable maximum exposure to a receptor to be evaluated in a human health risk assessment. The indoor air data is used to determine whether there is a potential risk to human health posed from vapor intrusion. Exceedances of indoor air applicable risk and hazard levels require implementation of remedial activities, and a confirmation of the effectiveness of the remedial activities.

8.6 Background Source Evaluation

Many VOCs are also present in common household and industrial products and may contribute to VOC detections in indoor air. Sources of background indoor air detections need to be evaluated and documented to help interpret data when VOCs are detected in indoor air (see Section 5.1). An inventory of potential background indoor air sources should be conducted prior to or during indoor air sampling. If background vapor sources are found to be primarily responsible for indoor air concentrations, then response actions for vapor intrusion would generally not be warranted. Information on “background” contributions of site-related VOCs in indoor air are part of the data evaluation because vapor intrusion mitigation will not address VOCs generated within the building or that are from natural or anthropogenic background levels. However, it is not appropriate to subtract background or ambient air concentrations from the quantitative evaluation of indoor air exposure determinations when it cannot be determined that the concentrations are not also from a vapor intrusion pathway. Sub-slab volatile chemical levels should be used to estimate the contribution of sub-slab VI sources to indoor air levels. Confirmation sampling (*i.e.*, an additional or additional rounds) may need to be conducted in order to estimate the contribution from the environmental release.

8.7 Occupational Exposure Limits

The Occupational Safety and Health Administration (OSHA) is the primary regulatory agency tasked with protecting workers while on the job. OSHA regulations and initiatives encompass many aspects of worker safety, including, among others, fall risks, workplace violence, heat illness, and chemical safety. Ohio EPA investigates and has jurisdiction over releases of hazardous chemicals to environmental media, including releases affecting receptors at OSHA-regulated sites.

When it has been demonstrated that OSHA has jurisdiction at a site or property, OSHA will regulate using its own indoor air regulatory thresholds. However, changes in processes or OSHA’s jurisdiction must be considered for future exposure scenarios.

OSHA's indoor air regulatory thresholds for workers are called Permissible Exposure Levels (PELs). OSHA also has indoor air regulatory standards called Short-Term Exposure Limits (STELs) for 15-minute exposures, and ceiling limits above which no worker should be exposed for any period of time.

9.0 VAPOR INTRUSION FROM PETROLEUM RELEASES

Petroleum Vapor Intrusion (PVI) is the intrusion of vapors from subsurface petroleum hydrocarbons (PHC) and non-PHC fuel additives into overlying or nearby buildings or structures. PVI can occur from PHC-contaminated soil or ground water contaminant plumes with high concentrations of dissolved PHC contaminants, or if the plume is in contact with a building foundation, basement, or slab. In contrast to chlorinated solvents that degrade slowly under anaerobic conditions, PHCs generally biodegrade rapidly under aerobic conditions. The biodegradation intermediates from PHC are also less toxic than chlorinated compounds. Some petroleum hydrocarbons may also degrade anaerobically and may produce methane, particularly if the source is from an ethanol-blended gasoline (U.S. EPA, 2015a).

Due to the effectiveness and speed of aerobic biodegradation in biologically active soils, Ohio EPA DERR recommends different lateral and vertical separation distances PVI sites with relatively small petroleum releases, such as underground storage tank (UST) sites, than VOC release sites to streamline the VI evaluation. Petroleum contamination at sites with a potential for larger petroleum releases, such as refineries, petrochemical plants, terminals, aboveground storage tank farms, bulk plants, pipelines, and large scale fueling and storage operations at federal facilities, sites where lead scavengers were used or stored, or sites with releases of non-petroleum chemicals including comingled plumes of petroleum and chlorinated solvents regardless of the source, should be addressed under more general vapor intrusion guidance such as other chapters of this guidance or U.S. EPA. (US EPA, 2015b) and should use the 100 feet lateral separation distance recommended for non-PHC VOCs.

A variety of petroleum products may be present at a site, such as gasoline, diesel, kerosene, jet fuels, and mineral oils, with varying potential for volatilization. Generally, less dense petroleum fractions such as benzene, toluene, ethylbenzene, and xylenes (also known as BTEX) will volatilize more easily than heavier fractions such as lubricating oils, waxes, asphalts and pitch and thus have a higher potential for vapor intrusion. Figure 6 shows petroleum fractions from light to heavy. Generally, lighter fractions are more volatile, and heavier fractions are less volatile. Sample analysis should correspond to the chemicals expected from the release.

Petroleum products are potentially flammable, and investigators should identify if there is a potential threat of explosion due to the presence of flammable PHCs, non-PHC fuel additive vapors, or methane. Methane cannot be detected based on odor, taste, or visible signs, so methane-detecting devices must be used if the presence of methane is suspected.

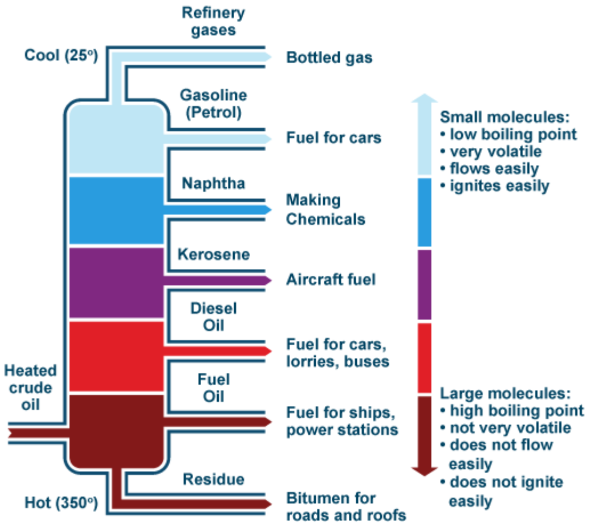


Figure 6. Petroleum Distillation (GlobalSpec.com)

9.1 Petroleum Release Characterization and Phase Partitioning

The PVI site characterization should consider the hydrologic and geologic characteristics of the site, identify potential receptors, and assess the potential for biodegradation of the PHCs and non-PHC fuel additives. A primary objective of site characterization is delineation of the lateral and vertical extent of contamination in the subsurface so that lateral and vertical separation distances can be accurately determined. It is also important to determine whether preferential transport pathways are present and, if so, delineate them to determine if they connect vapor sources directly to potential receptors. (U.S. EPA, 2015a)

The site characterization should address the potential for biodegradation of PHCs in soil. However, care should be taken if the vadose zone is not well-oxygenated as PHC degradation may be incomplete, thus posing a greater potential for PVI. Additionally, ethanol-blended gasoline (blends greater than E-20) may degrade anaerobically and may produce methane, which may result in methane buildup inside buildings and a risk of explosion (U.S. EPA, 2015a). See Section 11.2 if site conditions indicate the potential of an imminent explosive threat.

When petroleum fuels are released to soils from a leaking UST, PHCs partition into several phases: a light non-aqueous phase liquid (LNAPL), an accumulation of mobile LNAPL on and in the capillary fringe, an immobile residual phase, a phase dissolved in ground water, a phase dissolved in soil moisture, a phase adhered onto or absorbed into soil solids, and a phase of vapors in soil gas. While it is important to keep in mind the various PHC phases potentially present at the site, the vertical and lateral separation distance described in this document apply to the LNAPL and dissolved phase of PHCs.

The LNAPL phase floats at the water table. However, if a sufficient amount of LNAPL accumulates the LNAPL can become mobile and flow downgradient. Conversely, if it is a small release of LNAPL it can become immobile in the capillary fringe or smear zone as the elevation of the water table fluctuates due to seasonal changes. This is referred to as residual LNAPL. Residual LNAPL is not free-flowing and can represent a significant source of contaminants that may persist and generate PHC vapors, as well as a source of dissolved-phase contaminants, and thus should not be overlooked in a CSM or when developing DQOs.

Dissolved-phase sources in ground water consist primarily of BTEX, other aromatic hydrocarbons, and relatively water-soluble PHCs. Vapors emanating from LNAPL sources contain these petroleum fractions as well as aliphatic and relatively insoluble hydrocarbons, such as naphthalene, especially if the source is large or unweathered. (U.S. EPA, 2015a)

9.2 Lateral Inclusion Zone

The Lateral Inclusion Zone is the area surrounding a contaminant mass through which petroleum vapors may travel, move into buildings, and potentially pose a threat to human health and the environment. Buildings within 30 feet laterally of relatively small petroleum contaminated sources, whether as mobile LNAPL, residual LNAPL, or PHCs dissolved in ground water, are considered to be in the lateral inclusion zone. Buildings outside this zone generally may be excluded from further assessment unless site conditions change, preferential transport pathways are present connecting vapor sources to receptors, impermeable surface cover is so extensive that there is a concern whether sufficient oxygen is present to support biodegradation, or soil conditions are inhospitable to microorganisms (*i.e.*, dry soils with less than 2% soil moisture by dry weight).

9.3 Vertical Separation Distance

The vertical separation distance is the thickness of clean, biologically active soil between the highest vertical extent of a contaminant source and the lowest point of an overlying building (basement floor, foundation, or crawlspace surface). For a petroleum vapor intrusion investigation, clean soil does not necessarily mean that it is contaminant-free, but rather that the level of any contamination present is low enough that the biological activity of the soil is not diminished, and the subsurface environment will support sufficient populations of microorganisms to aerobically biodegrade PHC contamination. The highest vertical extent of contamination for dissolved sources is the historical high-water table elevation; for LNAPL sources this is the top of the smear zone or residual LNAPL in the source area.

LNAPL sources are capable of producing higher vapor concentrations than dissolved sources. Thus, the necessary vertical separation distance between PHC contamination and an overlying building foundation, basement, or slab is 6 feet for dissolved vapor sources and 15 feet for LNAPL sources beneath buildings that are less than 66 feet on the shortest side. Additional investigation, including sampling, is recommended if the vertical separation distance is less than this minimum. Where the vertical separation distance between a dissolved contaminant plume and the lowest point of a building is met or exceeded, no further investigation for PVI is necessary if there are no precluding factors present.

9.4 Ground Water Flow and Dissolved Plumes

Contaminants dissolved in ground water can migrate with flowing ground water and create three-dimensional distributions of contaminants called plumes. In aquifers where the direction and speed of ground water flow are stable, the plumes are usually long and narrow. Other plumes appear to spread in both the transverse as well as the longitudinal direction. This apparent transverse dispersion may be the result of changes in the direction of ground water flow. What may appear to be transverse dispersion is longitudinal dispersion occurring in different directions and the direction of flow changes. Plume movement and dispersion must be considered when applying lateral and vertical separation distances to a site. Figure 7 shows a typical PVI scenario with LNAPL, dissolved phase petroleum contamination in ground water, LNAPL smear zone, and vertical separation distances.

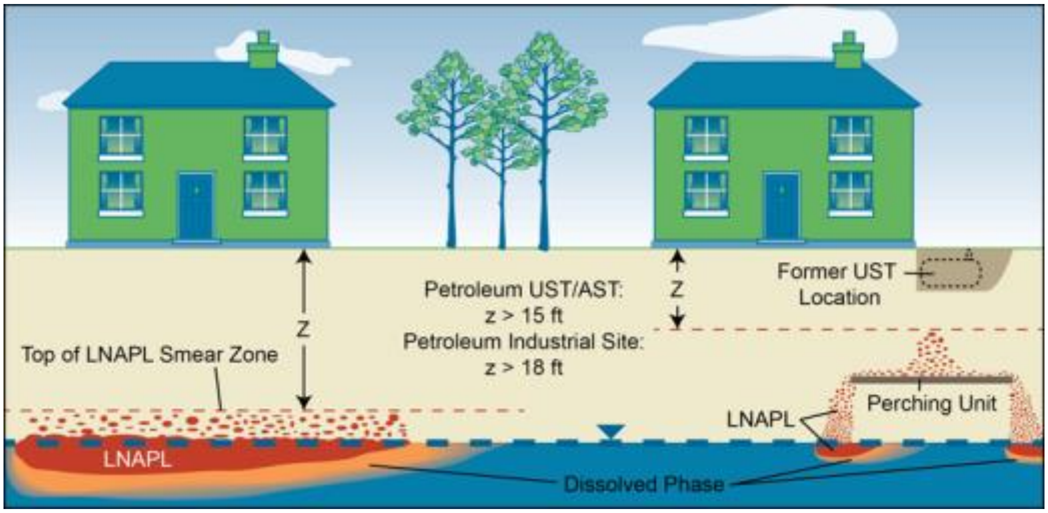


Figure 7. Schematic of PVI Scenario with LNAPL (ITRC-PVI, 2014)

9.5 Compliance with BUSTR

The State Fire Marshal, Bureau of Underground Storage Tank Regulations (BUSTR) program has regulatory primacy for UST petroleum cleanups. Entities undertaking PHC cleanup must consult with BUSTR in addition to, or instead of, Ohio EPA.

10.0 MODELING THE VAPOR INTRUSION PATHWAY

Predictive modeling has historically been extensively utilized by Ohio EPA DERR programs as a tool to predict contaminant concentrations and exposures at a site, often used to estimate the changes in concentrations and future movement of contaminants in ground water. Predictive models have also been developed to estimate the indoor air or soil vapor concentration of a contaminant in soil or ground water by using default and user-input chemical, soil, physical and building construction parameters, such as the U.S. EPA's Johnson and Ettinger Model (J&E). Recently, the U.S. EPA created and supports the Vapor Intrusion Screening Level (VISL) calculator, which uses exposure estimates, attenuation factors, volatility factors and inhalation toxicity in equations to develop screening levels below which vapor intrusion is not expected at a site. Lastly, due to the different nature of PHC vapor intrusion, the American Petroleum Institute created a model called BioVapor that estimates the potential for vapor intrusion of petroleum constituents in soil gas and ground water. While all three of these models are fundamentally different in nature, each is a predictive tool that can be used as part of a vapor intrusion evaluation and are discussed further in the subsections below.

Generally, Ohio EPA DERR requires that any use of modeling be confirmed with empirical data. Ohio EPA DERR RP sites can use VISL to make determinations of incomplete exposure pathways from subsurface contamination of volatile chemicals to indoor air, but this is a limited application. Ohio EPA DERR considers the use of models as one line of evidence when evaluating the vapor intrusion pathway, and generally requires that empirical data be provided at the point of exposure in order to determine that risk and hazard goals have been, and will continue to be met, and to eliminate the vapor intrusion pathway as a potentially complete exposure pathway.

10.1 U.S. EPA Vapor Intrusion Screening Level Calculator

Ohio EPA DERR recommends the use of U.S. EPA's VISL calculator to preliminarily evaluate the potential for vapor intrusion at remedial sites. While the VISL calculator may be used as a screening method to determine whether vapor intrusion is likely to occur at sites, in most situations, Ohio EPA requires empirical data to be used to eliminate vapor intrusion as a potentially complete exposure pathway. Please refer to Sections 3.0, 8.0 and 10.0 of this guidance for more information on data collection, data screening and general modelling.

The VISL calculator applies attenuation factors (AF) to toxicity-based indoor air concentrations to provide screening levels for soil gas and ground water. VISL can also be utilized to calculate risk and hazard estimates to receptors from chemical concentrations in ground water, soil vapor, and indoor air. These default attenuation factors were developed from measured vapor intrusion data. The default ground water to indoor air exposure pathway AF used by VISL calculator is 0.001, while the soil gas to indoor air exposure pathway default AF is 0.03. When the AFs are applied with the appropriate target risk and hazard levels and exposure scenarios, the resulting VISLs are levels below which soil gas or ground water concentrations are unlikely to provide the source strength to drive indoor air concentrations above health-based indoor air standards. While VISL uses default AFs, site-specific AFs may be developed and used to meet remediation goals at a site.

The VISL calculator allows the user to alter other select parameters in addition to the attenuation factors, including the target risk or hazard, exposure scenario, and ground water temperature. If any default VISL parameters are changed when determining site-specific VISLs for Ohio EPA DERR sites, the changes must be disclosed to Ohio EPA.

Specific factors may result in unattenuated or enhanced transport of vapors towards receptors and are likely to render the default assumptions of the VISL calculator, and thus its effectiveness as a predictive modeling tool, inappropriate. These factors include: 1) very shallow ground water sources, for example less than 5 feet below foundation level; and 2) buildings with significant openings to the subsurface, for example, sumps, unlined crawlspaces, earthen floors, or significant preferential pathways. In addition, certain vapor sources invalidate the recommended attenuation factors and screening levels used in the VISL: 1) sources originating in landfills where methane is generated in sufficient quantities to induce advective transport in the vadose zone; 2) sources originating in commercial or industrial settings where volatile chemicals can be released within an enclosed space and the density of the chemical's vapors may result in significant advective transport of the vapors downward through cracks and openings in floors and into the vadose zone; and 3) leaking vapors from pressurized gas transmission lines. In all of these scenarios the use of VISL calculator may not accurately predict movement of vapors from the subsurface to indoor air and indoor air sampling is recommended.

10.2 Overview of the Use of Fate and Transport Models in Ohio EPA

Fate and transport models can assist in evaluating the intrusion of subsurface volatile contaminants into enclosed spaces. However, models are not intended to serve as the exclusive approach for evaluating human health risk from vapor intrusion. When used in combination with site-specific empirical information, the results of modeling will add to the multiple lines of evidence for the exposure pathway, and to develop risk management decisions. As stated above, Ohio EPA DERR considers the use of models as one line of evidence when evaluating the vapor intrusion pathway, and generally requires that empirical data be provided at the point of exposure in order to determine that risk and hazard goals have been, and will continue to be, met, and to eliminate the vapor intrusion pathway as a potentially complete exposure pathway.

10.3 Overview of U.S. EPA's Johnson and Ettinger Model

The U.S. EPA's Johnson & Ettinger (J&E) model spreadsheets may be used as a predictive tool for evaluating subsurface vapor intrusion into buildings. However, the J&E model should not be used to estimate indoor air values for a demonstration that applicable standards or that risk and hazard goals have been met. The most current version should be used for predictive site-specific use only. As of the date of this guidance, the most current is Version 6.03.1, dated February 2017, updated September 2017.

The current version of the J&E model does not allow for vapor intrusion estimates to be made from bulk soil concentrations, which is a change from previous versions of the J&E

model. The current version of J&E may be used to predict vapor intrusion to indoor air from soil gas and ground water concentrations.

This guidance does not provide recommended J&E model input values and uses. Ohio EPA recommends appropriately applying the model recommendations provided in the U.S. EPA Johnson and Ettinger Model support documents and user's guide.

Again, given the uncertainty and variability in the VI pathway and the constraints to the J&E model, the model has limited use in the characterization of risk and should only be used as a tool to estimate or predict indoor air concentrations of hazardous constituents at sites where empirical data has not yet been gathered. Modeling results must be verified with empirical data.

10.4 BioVapor

The American Petroleum Institute's model BioVapor estimates the potential for vapor intrusion of petroleum constituents in soil gas and ground water. Petroleum constituents differ from chlorinated VOCs in that they degrade relatively rapidly in soil with the presence of oxygen. BioVapor is a steady-state 1-D analytical model designed to help the user understand the potential effect of aerobic biodegradation in the vadose zone on the vapor intrusion pathway. BioVapor does not directly account for spatial or temporal variations in parameter values.

BioVapor is an algebraic model that incorporates a steady-state vapor source, diffusion-dominated soil vapor transport in a homogeneous subsurface soil layer with vapor mixing in a building. The soil is divided into a shallow aerobic layer including first-order biodegradation and a deeper anaerobic layer where biodegradation does not occur. The user has three options for specifying the oxygen supply below the building foundation: 1) concentration below the building foundation; 2) constant oxygen concentration below the building foundation; or 3) constant flow of atmospheric air below the building foundation.

In the absence of aerobic biodegradation, the BioVapor model is essentially equivalent to the J&E Model. All model outputs should be verified with empirical data. BioVapor does not evaluate other potential exposure routes, migration pathways, or risks from fire or explosion. For more information on the BioVapor model, see the BioVapor User's Manual (GSI Environmental, 2012). For more information on other ways to address the potential for petroleum vapor intrusion, see Section 9.0 of this guidance.

11.0 EVALUATION OF IMMINENT HAZARD IN AN EXISTING BUILDING

For the purposes of this guidance, imminent hazard is defined as any condition which poses an immediate risk of harm to public health, safety, or the environment. Imminent hazards require an expeditious response to mitigate or end the exposure. Typically, prior to sampling, the potential threat level is unknown. There are situations where available historical sampling data or current conditions indicate that immediate actions are warranted.

11.1 Potential Imminent Hazard Conditions

Possible imminent hazards due to vapor intrusion include direct exposure to concentrations of vapors at risk of explosion or immediate danger to life and health, as well as exposure to chemical concentrations that may cause deleterious effects from short term exposures. If evaluation of data or current conditions indicate the possibility of an imminent hazard from a known or suspected nearby source, prompt action is necessary to verify or abate threats to human health.

The following conditions may indicate a potential imminent hazard and thus warrant prompt actions and early or interim measures for occupied structures:

- Known spill in a structure that may affect environmental media (*e.g.*, a release from a heating oil tank);
- Odors, particularly if described as “chemical,” “solvent,” or “gasoline”;
- Reports of physiological effects (*e.g.*, dizziness, nausea, vomiting, confusion);
- Wet basement or sump in areas with known contaminated ground water;
- Free product at the water table under or immediately adjacent to a structure;
- Exceedance of one-tenth (10%) of a lower explosive limit; or,
- Vapor intrusion-caused indoor air concentrations of a chemical with an unacceptable human health risk for an acute or short-term exposure scenario.

Professional judgment should be applied to these criteria and the timeframe appropriate to evaluate whether an imminent hazard is present. Please note that spills not affecting environmental media may pose an imminent hazard or unacceptable human health risk and, as a result, may be under the jurisdiction of regulatory agencies other than Ohio EPA (*i.e.*, OSHA or ODH).

Where vapor intrusion is of concern and indoor sources of volatile chemicals are present (for either occupational use or any other identifiable indoor source), sub-slab vapor or soil gas data may be utilized to evaluate the relative contribution to the indoor concentrations from environmental media. The presence of identifiable indoor air sources may alter the need for or type of early or interim response action taken.

11.2 Explosive Hazard

Commonly encountered chemicals that can exhibit explosive hazard are generally petroleum hydrocarbons (PHCs) and the landfill gas methane. Prompt action is required when the concentration of a combustible chemical exceeds 10% of its lower explosive limit (LEL). If data collected from inside buildings, below buildings, or utility conduits indicate an exceedance of 10% of the LEL, immediate action may be needed whether the building is inhabited or not. If concentrations in indoor air indicate the potential for explosion or imminent danger to life or health, building occupants should be evacuated and building owners and the fire department should be notified immediately. Also notify, Ohio EPA DERR immediately via Ohio EPA’s Spill Hotline at 1-800-282-9378. For

BUSTR-regulated releases, notify BUSTR immediately via the BUSTR hotline at 1-800-589-2728.

Flowchart Step 6: Evaluate the potential risk and hazard from the vapor intrusion pathway

12.0 RISK CHARACTERIZATION

Risk characterization for the vapor intrusion pathway compares measured indoor air concentrations to chemical-specific target cancer and noncancer concentrations considered protective for the anticipated land use exposure. The primary scenarios evaluated are residential and worker/commercial exposures. Additionally, in the VAP, a characterization of the vapor intrusion risk may be developed by a proportional estimation of a VISL from media other than indoor air. For example, if carbon tetrachloride is the only COC that has been measured in sub-slab vapor, and the concentration is half of the VISL based on a hazard quotient of 1, the VAP volunteer can assume a HQ contribution to the site-wide non-carcinogenic risk characterization of 0.5 from the vapor intrusion to indoor air pathway. Please refer to Section 8.1 for further information on vapor intrusion screening levels. Risk characterization serves to bridge risk assessment and risk management and therefore assist in the decision-making process. The appropriate media target concentrations and risk and hazard goals must be utilized. Please refer to Section 8.0 concerning data evaluation.

The investigator should be aware of imminent hazards involving explosive gasses, unacceptable human health risk from an acute or short-term exposure scenario, and gasses that may collect and create a deadly environment. Please refer to both Sections 11.0 and 13.0, for more information on evaluation of imminent hazards in an existing building and remedies, respectively.

12.1 Determining Applicable Risk Goals and the Need for Further Evaluation

For Ohio EPA DERR sites, the excess lifetime cancer risk (ELCR) goal is 1E-5 and the noncancer hazard quotient or index is 1, accounting for exposure to multiple contaminants, as appropriate. For all Ohio EPA DERR sites, if the complete pathways, including direct contact, ingestion and vapor intrusion, from soil and ground water releases are well-characterized, and meet a cumulative ELCR of 1E-5 and a hazard index of 1, then no further evaluation of the vapor intrusion pathway may be warranted. If media other than indoor air are not well characterized or exceed an ELCR of 1E-5 or a hazard index of 1 on a multiple chemical and multiple pathway (if applicable) basis, then further sampling or preemptive remediation may be necessary.

In the VAP, all site-related COCs must undergo a multiple chemical adjustment and the resulting ELCR and hazard values are carried through as a contribution to site-wide risk and must meet Ohio EPA risk and hazard goals of an ELCR of 1E-5 and a Hazard Index of 1. Thus, risk and hazard contributions from vapor-forming chemical detections in indoor air due to vapor intrusion should be calculated in a multiple chemical adjustment and pathway summation for a complete exposure pathway. If indoor air data was not collected, the risk and hazard contributions from the vapor-forming chemicals detected in an alternative media sampled to evaluate vapor intrusion (*i.e.*, either soil gas, sub-slab vapor or ground water) should be included in a multiple chemical adjustment and pathway summation. This is because the VAP requires the incremental risk and hazard from all COCs be aggregated within each complete exposure pathway and then summed across all complete exposure pathways.

12.2 Use of Maximum Contaminant Levels (MCLs)

Screening and cleanup levels for other exposure pathways are not necessarily protective of the vapor intrusion pathway. Since the MCLs and VAP risk-based unrestricted potable use standards (UPUS) address the potable ground water pathway, additional sampling may be necessary even if ground water concentrations meet MCLs or VAP risk-based UPUS values.

12.3 Use of BUSTR Petroleum Standards

At VAP sites, a volunteer may use BUSTR action levels, including action levels for soil and ground water to indoor air contained in look-up tables found in OAC 1301:7-9-13(J)(3), as the generic numerical standards for petroleum at residential, commercial, and industrial properties in the VAP. For more information on applying BUSTR action levels as VAP applicable generic standards, please see VAP Technical Guidance Compendium Applying Generic Petroleum Standards under the VAP.

At RP sites the potential for using BUSTR action levels for addressing the VI pathway for petroleum and petroleum constituents is something the responsible party may contemplate, however coordination with Ohio EPA is recommended.

Flowchart Step 7: If data evaluation indicates risk or hazard goals are or may be exceeded, then additional data may be collected, or a remedy may be implemented

If data from environmental media other than indoor air exceed risk or hazard goals, then additional data may need to be collected and/or a remedy may need to be implemented. If indoor air exceeds risk or hazard goals, then mitigation must be implemented and maintained to reduce the concentrations of COCs in indoor air to acceptable levels until the final remedy has rendered the VI pathway incomplete. If indoor air concentrations meet risk or hazard goals for commercial/industrial land use but not residential land use, then a land use restriction may be necessary to ensure the site remains protective of future receptors. Communication with Ohio EPA DERR is recommended when a site does not contain buildings, but a potential future VI problem is identified, and for sites with current vapor intrusion problems.

Flowchart Step 8: Remediation, mitigating indoor air exposure and/or conducting long-term monitoring

13.0 REMEDY

This chapter provides an overview of considerations when selecting and implementing a remedy to mitigate or eliminate risk from the VI pathway.

Remedies may be short-term interim actions meant to mitigate acute exposures to receptors over the near term, and long-term actions meant to provide ongoing mitigation by rendering the VI pathway incomplete until a remedy addressing the source of contamination is completed. These remedies can be to prevent a potentially complete VI pathway. A combination of the remedies discussed in the following sub-sections can be implemented to mitigate or eliminate risks from VI. Please note, additional remedial actions may be required on a site-specific basis. Confirmatory sampling is often required to determine if further remedial actions are necessary to protect human health.

13.1 Remedy Selection and Implementation Considerations

Remedy selection should consider the type of risk present at the site, site-specific building conditions, and the proximity and nature of current and future receptors. The following site conditions should be considered:

- Sensitivity of receptor;
- Type of contaminant – total petroleum hydrocarbons (TPH) vs. chlorinated solvents;
- Type of exposure risk (acute vs. chronic);
- Cumulative risk from multiple chemical exposures;
- Time frame or length of exposure (current or future exposure);
- Temporary, interim or permanent mitigation measures;
- Source strength;
- Media contaminated (soil vs. groundwater);
- Foundation type;
- Building age;
- Preferential pathways;
- Agency jurisdiction (U.S. EPA, Ohio EPA, OSHA, health department); and,
- Potential future receptors.

When implementing a remedy several items should be considered such as:

- Immediate response requirements;
- Interim response;
- Short-term mitigation until a more permanent fix is completed;
- Long-term response;
- On-going sampling;

- System installation;
- System monitoring; and,
- Confirmatory sampling after disturbance.

Some examples of available mitigation technologies are provided in Table 3, along with typical applications and challenges of each (ITRC, 2007).

Table 3. Comparison of Mitigation Technologies

Technology	Typical Applications	Challenges
Passive barrier	New construction. Crawl spaces (existing homes). Often combined with passive or active venting, sealing openings in the slab, drains, etc.	Preventing tears, holes. May not suffice as a stand-alone technology. Ensuring caulking seals cracks in floors and preferential pathways. On-going monitoring and maintenance.
Passive venting	New construction. Low soil gas flux sites. Should be convertible to active system if necessary.	Relies on advective flow of air due to wind and heat stack effects. Air flows and suctions typically far less than achieved by fans (active venting).
Passive aerated floor	New construction or extensive remodeling. May be useful for large commercial structures.	Not yet widely used. May not be suited for all soil types.
Active sub-slab depressurization (ADS)	New and existing structures. Sumps, drain tiles, and block wall foundations may also be depressurized if present.	Low permeability and wet soils may limit performance. Incurs operating cost. Requires monitoring and fan upkeep.
Passive sub-membrane	Existing structures. Crawl spaces.	Sealing to foundation wall, pipe penetrations. Membranes may be damaged by occupants or trades people accessing crawl space.
Active sub-slab pressurization	Same as ADS. Most applicable to highly permeable soils.	Higher energy costs and less effective than ADS. Potential for short-circuiting through cracks.
Active building pressurization	Large commercial structures, new or existing. Specialized cases only.	Requires regular air balancing and maintenance. May not maintain positive pressure when building is unoccupied. Incurs cost to operate.
Active indoor air treatment	Indoor air spaces. Special cases where other remedies cannot be applied.	May generate waste disposal stream. May not effectively capture all air contaminants. May be subject to tampering.
Sealing the building envelope	Cracks and holes in existing building.	Access to perforations. Lack of permanence.
Active heat recovery ventilator	Useful in crawl spaces or basements that cannot be sealed or depressurized.	Incurs higher energy loss. Higher costs to operate.

13.2 Remediation of Environmental Media

An environmental media source of VI can be addressed through application of a soil or ground water remedy. Remediation of soil and ground water contamination may include source removal, technologies to reduce contaminant concentrations in soil and soil gas, such as soil vapor extraction (SVE), or technologies to reduce concentrations in ground water such as in-situ bioremediation (chemical oxidation or reductive de-chlorination), thermal desorption, or air-sparging. In general, source removal and SVE remedies are likely to be the most successful to reduce or eliminate soil gas migration and this may prevent the need for institutional or engineering control remedies.

Environmental media should be monitored during the remedial process to assess breakdown products that may form as a result of natural attenuation or chemical treatment processes and may pose risks to receptors, and to determine when remediation efforts can be terminated.

13.3 Institutional Controls

Institutional controls are activity and use limitations that are recorded in an environmental covenant within the property deed that restricts how a site can be used or what activities can occur at the site. Examples of institutional controls include:

- Restriction of a property to commercial or industrial uses only;
- Prohibition against constructing habitable structures in areas with VI risk;
- Prohibition of building occupancy unless indoor air concentrations are below screening levels; and,
- Building-specific conditions, such as prohibitions of basements.

Generally, two rounds of indoor air sampling collected at least 30 days apart are needed prior to occupancy of a building located within a vapor intrusion activity and use limitation area.

13.4 Engineering Controls

Engineering controls, also known as building controls for vapor intrusion, can be considered interim remedial measures as they usually do not address the reduction of the source contamination. They can be implemented in both new and existing buildings. Engineering controls can be separated into two groups: active or passive. An active engineering control usually involves a mechanical system, such as a sub-slab depressurization system. Engineering controls that do not involve mechanical systems, such as a floor slab, are known as passive controls. Future conditions must be considered when choosing an appropriate engineering control. Maintenance, repair, failure monitoring, and termination criteria should be considered when selecting an engineering control. These considerations are contained within an operating and maintenance (O&M) plan and an O&M agreement between Ohio EPA and the property owner. This agreement identifies and ensures that the responsibility for the engineering control and liability for the contamination is maintained while vapor intrusion remedial goals are exceeded in the subsurface.

13.5 Active Sub-Slab Depressurization Systems

Active Sub-Slab Depressurization Systems (ADS) are defined as systems that rely on motor-driven fans to maintain a negative pressure below the building floor, evacuating contaminated vapors before they enter the building. ADS can have a variety of configurations, both designed as standalone systems or as components in a mitigation engineering system.

There are generally two types of active sub-slab depressurization systems, those for newly constructed buildings and those installed in existing buildings. Systems for newly constructed buildings usually consist of a sub-slab layer of granular fill coupled with a network of slotted pipes that vent to the roof with the aid of a fan. The granular layer is overlain by an impermeable barrier layer. The motorized fans are used to draw a vacuum on the sub-slab granular layer, assuring the necessary vacuum differential. The number, size and spacing of the slotted pipes are building-specific with the performance standard being an adequate pressure differential generally across the floor of the entire building. The exhaust points of the discharge pipes should be positioned to avoid ingress to the surrounding buildings through windows, vents, or HVAC system intakes. Generally, the granular bed and barrier layers should cover the entire footprint of the building unless the owner can demonstrate that less coverage is needed.

For existing buildings, the sub-slab system generally consists of pits under the floor, filled with granular material and connected to the extraction system. The major obstacle to performance of these systems is low permeability soil, since installation of a granular layer under the entirety of an existing building is usually impossible. Again, the number and placement of the suction points is site-specific and performance driven. A lower permeability soil may require more extraction points. Another concern with preexisting buildings is the presence of subsurface barriers, such as building footers, that might impede airflow. The placement of suction points must consider such barriers.

ADS are most effective if the building is isolated from the environmental media. This condition increases the efficacy of the sub-slab depressurization and removal of vapors beneath the slab. Therefore, Ohio EPA recommends that sealing of foundation crack and other conduits into the building be included with the construction of an ADS. The building floor should be examined for competency and building construction diagrams should be evaluated for utility and plumbing penetration points. These seals should be identified and maintained throughout the active life of the ADS. Seals that are a component of an ADS should be labeled to identify that these seals should be maintained in any operation and maintenance plan.

In regard to sealing, the following should be considered when reviewing work and design plans for ADS systems:

- Caulks and sealants should be reviewed thoroughly prior to use for volatile content. Sealants that are selected should be durable and designed for minimal maintenance over the expected lifespan of the ADS (ASTM C1193-16).
- Sumps, other pit openings in the slab, and utility corridors that need to maintain their accessibility should use sealants such as silicone caulks that may easily be re-applied. Sump covers should remain accessible by utilizing gasket or non-permanent sealants. Piping emanating from sumps should also be sealed to prevent vapor migration.
- Cracks less than 1/16-inch in width may be sealed using selected sealants or caulks.
- Cracks greater that 1/16-inch in width may require special backing material or expandable foam sealants.
- Expansion joints.
- Wall/floor junctions.
- Utility lines, drains, and other plumbing features that penetrate the building slab offer a direct conduit to soil gas. To seal these penetrations, practitioners may have to wrap these features with membrane material and seal these to competent flooring. Specialty spray on products, such as Liquid Boot™, may have to be applied if the penetration points are too difficult to seal via normal means.
- Drains may provide a vapor intrusion pathway that can be prevented using one-way flow valves that retard or prevent vapor entering buildings. Drains used to draw water from basement areas to sumps need to be covered, sealed and tied into the ADS to draw vapors to the outside air.

In some cases, a competent floor is not present or may only cover a portion of the building footprint. An example of this condition is a home that has an open crawl space. Conditions such as these require special consideration as an ADS may not be capable of providing adequate mitigation unless the building floor and walls are sufficiently sealed.

Dug basements with open areas or crawl spaces will require covering to prevent soil gas migration and to provide a seal for the ADS to depressurize the lower area of the building. A soil gas barrier can be installed over open soil in a crawl space or dug basement to prevent vapor migration and provide a plenum that will be evacuated using the ASD. The membrane should be sealed to competent walls. Seams between membrane sheets should be overlapped at least 12 inches and sealed with sealant or caulk. Membrane material should be designed to prevent vapor migration. Common moisture barriers used in construction may not be adequate as a vapor intrusion membrane. This is especially true if the space may be used to store heavy objects. Ohio EPA recommends that membranes be at least 10-mil thick and may range up to 60-mil depending on the occupancy requirements for the area being covered. Vapor barriers should have a permeance of at least 0.1 perms as defined by ASTM E96/96M. Pipe penetrations or drains penetrating the membrane should be sealed as described previously in this section.

If the floor is generally soil and without rubble, concrete can be poured to provide adequate cover. This option may be desirable if the floor space is used to store heavy materials or heavy use would puncture membrane materials.

Ohio EPA has encountered rubble-filled or dug basements that are inaccessible that prevent the use of membrane or cementitious coverings. In these cases, the open space itself may need to be ventilated and have fresh air brought in from the outside and stale air vented (see Section 13.6 for more information).

Water tables that seasonally intersect the building slab, wet basements, or contaminated pore water infiltrating directly into buildings requires an additional engineering control before the installation of an ADS. These conditions can be mitigated by foundation drainage systems and treating surfaces to prevent water infiltration. Consideration of these conditions should be made before an ADS is installed.

Back drafting from indoor heating sources may be problematic in some basements where furnaces or water heating equipment is used. The ADS should be checked by local HVAC personnel and local fire marshals before the initial system demonstration. There may be some situations where an ADS cannot be installed due to homeowner requirements. Any site where back drafting could be a problem should have CO_2 monitors installed as part of the ADS.

13.6 Heating, Ventilation, Filtration Units and Air Conditioning (HVAC) Measures

Ventilation system modifications can be made in a variety of ways, but the general approach is to increase the intake of make-up (fresh ambient) air. In commercial buildings, HVAC systems can be modified to increase the amount of make-up air. These modifications should be made by experienced HVAC professionals. Systems in residential properties may be limited in the degree of modification for make-up air. In these cases, the addition of a Heat Recovery Ventilation (HRV) unit may be necessary to increase the intake of fresh air. HRV systems can be installed independently of existing HVAC systems and may be beneficial to residential properties that need to vent crawlspaces or basements that can’t be incorporated into an ADS. HRVs are designed with two fans. One fan brings in fresh air from outside the building, the second fan vents stale air from inside the structure. A heat exchanger equalizes the temperature between these two independent air streams which are not allowed to physically mix. The net result in an increased air exchange rate that can significantly reduce concentrations of contaminants. HRVs can be costly to install and must be powered which can increase the average cost for heating a home or small business.

Filtering of air can be an option for vapor mitigation. These systems are designed to pass contaminated air through filtering media, usually granular activated carbon, thereby removing VOCs from the air. Industrial-sized units can be designed, but generally these filters are used on a temporary basis before permanent systems can be installed. Filter use requires regular monitoring to ensure breakthrough of contaminants from the filter has not occurred. Costs for units vary by size, electrical costs, costs for the filter media and monitoring.

HVAC systems can sometimes be modified to create a positive pressure within a building or room to resist vapor ingress from the sub-slab, or to maintain sufficient air flow through the building to dilute indoor air concentrations to acceptable levels.

The ultimate standard of performance must be the measured indoor air concentrations rather than analyses based on flow calculations. Indoor air samples should be collected several times during the year to assess the effects of heating and air conditioning on the system's performance. Caution should be exercised choosing these types of methods as the high air flow rates needed to achieve remedial goals may greatly increase heating and cooling costs and have the potential to decrease occupant comfort.

13.7 Passive Engineering Controls

Passive Depressurization Systems (PDS) are similar to active systems except the extraction fans are not motorized. Rather, PDS use wind-driven turbines or venturi systems to maintain a vacuum on the extraction pipes. The major issue for PDS is maintenance of an adequate sub-slab vacuum. Passive systems are best used in new construction with highly permeable granular layers. PDS are not as effective for existing structures with low permeability soils. The performance standard for passive systems is consistent maintenance of adequate pressure differentials under the building.

Barrier systems are typically installed during new building construction and consist of an impermeable barrier between the granular collection bed and the floor of the building. The barrier can either be laid out in overlapping sheets or sprayed in-place. Some sheet systems consist of multiple layer laminates to achieve both strength and vapor resistance. A critical requirement for any vapor barrier is resistance to the chemical contaminants in the underlying soil. Installation should strictly follow the manufacturer's directions with particular attention to adequate joining and sealing of sheet materials and adequate thickness of sprayed materials. Any penetrations through the barrier, such as plumbing or utility conduits, must be properly sealed. Typically, the finished system is subject to smoke testing to locate any breaches in the barrier. Long-term operation and maintenance plans must require proper sealing of any future breaches through the barrier layer.

Barrier systems can also include building slabs. Proper sealing of cracks in floors or around the bases of walls to break ingress routes should be conducted as necessary for preferential pathways to improve the effectiveness of the passive slab engineering control. This approach is more applicable for older existing buildings. Such repairs will require long-term monitoring and maintenance to assure their reliability (Section 14.3), which may need to be recorded in an operation and maintenance plan. Low permeability flooring materials have sometimes been installed in existing buildings to reduce vapor ingress. Such coatings should be durable enough to withstand expected industrial activities including chemical spills and would also require careful installation and sealing.

13.8 Monitoring Requirements for Engineering Controls

For ADS, Ohio EPA recommends that the depressurization field be mapped to demonstrate that depressurization is occurring across the building footprint for residential structures and commercial buildings or is of sufficient aerial extent under a large building to effectively remove sub-slab vapors. Any sub-slab depressurization systems should be equipped with sampling ports in the floor to allow measurement of the pressure differential between the building and the sub-slab space. Differential pressure gauges should be capable of reading to 1/1000-inch water column or 0.25 pascals with + 25% accuracy. There should be adequate sample ports to cover the entire floor space of the building. If it is proposed that only a small portion of the structure needs to be covered by the sub-slab system, then the owner/operator will have the burden of proving that only limited coverage is needed. Based on a review of the available guidance and state standards, a presumptive minimum pressure differential across the slab should be 5 pascals or 0.02 inches of water. That standard should be applied if there is no granular backfill under the slab or if the soil composition under the slab is unknown. If the slab has been underlain with a permeable, granular backfill then a lower pressure differential could be considered based on a demonstration that the flow through the backfill is sufficient to capture vapors emanating from the underlying soil.

Depressurization field monitoring should be followed with indoor air measurements to complete the demonstration that the remedy is effective. A sufficient number of indoor air samples should be taken to demonstrate that indoor air quality meets the standards for a residential or commercial/industrial setting. The number of indoor air samples will be dependent on the building size or footprint, the presence of a basement or crawlspace or occupancy conditions. The typical approach is to sample at the same locations as used to determine that the vapor intrusion pathway was complete. Ohio EPA DERR recommends that the number of samples and locations be reviewed and discussed with agency personnel prior to implementation.

The collection lines for a sub-slab system should be equipped with sampling ports to analyze the sub-slab vapors. The initial performance evaluation of a sub-slab system should include indoor air sampling. If the performance evaluation is not being met, sampling must be repeated until corrective actions have met remedial goals.

13.9 Post-Mitigation and Seasonal Monitoring

Once indoor air sampling shows acceptable COC concentrations and, if applicable, vacuum ports show adequate depressurization, then the remedy monitoring program may be reduced to periodic pressure differential measurements at the vacuum sampling ports and/or indoor air samples to demonstrate system effectiveness through seasonal variations in temperature, pressure, humidity and building occupancy conditions. Prior to sampling frequency reduction, vacuum differentials should be measured several times a year to account for variations caused by seasonal heating and air conditioning.

The effect of seasonal variations should be considered in both the heating and cooling seasons. This evaluation is especially important if modifications to the HVAC system were made as a mitigation measure. In addition, in cases where seasonal high-water tables are present, sub-slab differential pressure measurement should be made to determine if the sub-slab conditions are present to maintain the depressurization requirements.

The results of these seasonal post-mitigation tests should be carefully evaluated to determine the degree of variability in results. If the system is functioning adequately to mitigate vapor intrusion issues, it is possible that only periodic checks will be needed in the future. If HVAC modifications are not protective in all seasons, additional engineering measures will need to be installed. Ohio EPA should be consulted if results show break-through of vapors into indoor air. In these cases, additional indoor air sampling on a frequent basis may be needed in the post-mitigation period.

13.10 Termination of Engineering Controls

Termination of mitigation systems should only be considered if the contamination source has been remediated to the point where vapor intrusion is not an on-going concern. Any request to terminate monitoring should contain a demonstration that sub-slab vapor concentrations are below VISLs during several sampling events.

Any site with methane should include combustible gas monitors. The combustible gas monitors should have alarms if safe levels are exceeded.

The precise details of sampling and maintenance of the system should be specified in an O&M plan whose requirements are included in an environmental covenant.

13.11 Owner Documentation/Notification of Engineering Controls

The building owner should be provided with information on the mitigation system, which should be passed on to future owners during property transfers. This information should include, at a minimum:

- The pre-mitigation concentrations of constituents of concern;
- The post-mitigation concentrations of constituent of concern; and,
- The regulatory standards used for each constituent.

The mitigation system installation should be described. This should include:

- System diagram showing the individual components of the system (*e.g.*, slab, SSDS, vapor barrier);
- As built diagrams, if available; and,
- The operational requirements, such as inches of water vacuum, slab competency, fan or filter life.

The schedule for replacing system components, such as filters, should be described, including:

- The schedule for monitoring the system, such as review of manometer readings; and,
- Any warranty information should be included with the system documentation package.

The owner, either through O&M agreements or self-initiated investigation, should describe and document any system disruption and subsequent corrective actions taken and provide the documentation to Ohio EPA DERR, if required. Information on the mitigation system (*e.g.*, environmental covenants, remedial design/remedial action judicial consent decrees, O&M plans and agreements) should be disclosed to future property owners as required by the RP or VAP (see Section 14.4 for more information).

14.0 LONG-TERM MANAGEMENT AND EXIT STRATEGY AT VAPOR INTRUSION SITES

Remediation of a vapor intrusion source can take a long time, often months or years. Therefore, when vapor intrusion has been determined to be a significant risk pathway at sites, mitigation measures such as ADS systems or institutional controls are needed to prevent exposure to current occupants and to make sure that future occupants are protected. Many sites have the long-term goal or requirement to eliminate the source of the vapor intrusion and termination of the mitigation systems. Therefore, the need to address long-term management and pathway mitigation should be understood, discussed with Ohio EPA, and plans formulated to make sure that occupants remain protected.

14.1 Long-Term Management

Long-term management at vapor intrusion sites may consist of the one or more of the following:

- Ground water or soil gas monitoring;
- Sub-slab vapor or indoor air monitoring;
- Contingency plans if monitoring shows exceedance of indoor air standards;
- Land use restrictions recorded in an environmental covenant;
- Inspections or audits of environmental setting and slab competency if used as an engineering control;
- Periodic review of the protectiveness and/or efficiency of the remedy or mitigation system;
- Inspection and corrective action of mitigation systems;
- Notification plan to inform new occupants/potential purchasers of need to maintain mitigation systems; or,
- Development of an exit strategy for turning off active mitigation.

Ohio EPA DERR does not have a single approach for long-term management because there are many site-specific variables and unique requirements for each administrative program, Ohio EPA DERR will work with responsible parties through orders, permits and the VAP to develop appropriate controls and monitoring strategies and to develop administrative requirements. Several of the above referenced items will be discussed in the following sections.

14.2 Ground Water, Soil Gas, Sub-Slab Vapor and Differential Pressure Monitoring/Sampling

Sites that are undergoing an environmental response for vapor intrusion may require long-term ground water or soil gas monitoring to verify that new or un-mitigated buildings within the area of influence of contamination are protected and that mitigation or remedial systems are functioning properly. In these cases, the type of monitoring (*e.g.*, soil gas or ground water), frequency of monitoring, applicable screening levels and appropriate secondary actions if data is above screening levels will need to be recorded in an O&M Plan and O&M Agreement. Demonstrations of ongoing remediation may also include statistical analysis for trend monitoring which can help in determining if the contaminated area is increasing or decreasing.

Where appropriate, sub-slab monitoring ports may be installed and used for routine monitoring of vapor concentrations and differential pressure. For example, where the slab of the building has been designated as an engineering control, sub-slab samples can establish the need for continued maintenance of the slab or indicate when indoor air sampling should be conducted to determine if risk and hazard goals continue to be met. Differential pressure monitoring may be considered when facilities have increased the intake of air to create positive pressure conditions. The monitoring ports can also be used to monitor differential pressure between the sub-slab and indoors with the use of a manometer to help determine whether a differential pressure remedy is being maintained.

Once the efficacy of the engineering system is verified by a qualified professional, system maintenance should be recorded in an O&M plan that details the system’s components, operation and maintenance schedule and system performance standards. Sub-slab vapor and/or periodic indoor air monitoring should be considered to demonstrate continued system efficacy. The plan should also include the corrective measures to be taken if the system unexpectedly fails and the interim measures to be used to protect human health while the system is not functional.

14.3 Passive Mitigation System Efficacy Verification

If the mitigation system involves vapor barriers, seals or passive venting, the building conditions must be carefully checked periodically to determine that these passive components remain in place and are effective. Building operations change through time and altering structural components can provide less of a barrier to vapor migration. In addition, sealants also degrade through time. On-going review of these components must be made, and it is highly recommended that periodic indoor air monitoring be considered while volatile chemicals remain above screening levels in the sub-surface.

Data generated during the monitoring period may also provide evidence of favorable conditions for termination of monitoring and any associated mitigation systems once sources have been remediated or risk and hazard goals have been met.

14.4 Environmental Covenants and Deed Restrictions

Environmental covenants (EC) and deed restrictions compliment engineering and institutional controls for addressing vapor intrusion exposure. Ohio’s Environmental Covenant Law is found in Ohio Revised Code (ORC) 5301.80 - 5301.92. The law states that an owner of a real property may enter an EC with the State of Ohio if an environmental response project has occurred on that property. In many cases, vapor intrusion investigations can be considered an environmental response project. The EC may contain restrictions for land use or occupancy status, such as restricting a property to commercial/industrial land use or prohibiting building occupancy until certain conditions are met. Environmental covenants require the property owner to report compliance with the restrictions to Ohio EPA once a year. Ohio EPA also reviews sites with ECs at least every three years to verify compliance. ECs provide information to future occupants that vapor intrusion is a concern at the site. Deed restrictions are not reviewed or enforced by Ohio EPA; therefore, even if a site has a deed restriction Ohio EPA requires an EC.

Ohio EPA legal and technical staff can provide more information on how ECs can be utilized to address vapor intrusion exposure.

14.5 Exit Strategy

The time period for remedial efforts can vary and actions taken to mitigate exposure from vapor intrusion may continue for some time. Nevertheless, an exit strategy to terminate active mitigation should be contemplated by site managers. The Ohio EPA expects that RP sites continue to work on decontamination until sources for vapor intrusion are abated. RP sites can build exit strategies into orders, records of decision or permits so that responsible parties can approach the agency to terminate vapor intrusion mitigation when the source(s) has been reduced to appropriate levels. VAP sites need to plan for how to determine when remedial activities can be terminated as well; however, the remedial goals for VAP sites may not include source removal. In these cases, the on-going mitigation of the vapor intrusion pathway is tied to an operation and maintenance plan. Specific requirements for termination outlined in the O&M Plan are then followed and Ohio EPA is notified and provided a demonstration when applicable standards are met and will continue to be met at the time termination is requested.

The exit strategy should clearly identify what criteria will be used to determine that the site no longer poses an unacceptable vapor intrusion risk. The exit strategy should be developed early in a vapor intrusion project so as to provide defined criteria for when risks at a site have been adequately mitigated or controlled. Factors such as mitigation or remediation techniques, final cleanup goals, land use, and future building construction, should be considered when developing the exit strategy. The exit strategy should be recorded in a decision document with specific, reasonable and achievable outcomes defined.

15.0 CITATIONS AND REFERENCES

American Society for Testing and Materials (ASTM). 2013. *E1527-13: Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process.* ASTM International, West Conshohocken, PA.

American Society for Testing and Materials (ASTM). 2014. *E1689-95: Standard Guide for Developing Conceptual Site Models for Contaminated Sites.* ASTM International, West Conshohocken, PA.

American Society for Testing and Materials (ASTM). 2016a. *C1193016: Standard Guide for Use of Joint Sealants*. *ASTM International,* West Conshohocken, PA.

American Society for Testing and Materials (ASTM). 2016b. E96/*E96M-16: Standard Test methods for Water Vapor Transmission of Materials. ASTM International,* West Conshohocken, PA.

California Environmental Protection Agency. December 2004. *Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air.* Department of Toxic Substance Control.

GSI Environmental, Inc. November 2012. *BioVapor: A 1-D Vapor Intrusion Model with Oxygen-Limited Aerobic Biodegradation.* Version 2.1. Currently available online: https://www.api.org/~/media/Files/EHS/Clean_Water/Ground_Water_Quality/biovapor/BioVapor-Users-Guide.pdf

Hartman, B. March 2008. *Results from EPA Research Programs on Sample Flow Rate, Purge Volume, Tubing Type, Tedlar Bags & Temporal Variations On Soil Gas Concentrations*. Cal EPA Soil Gas Forum, Los Angeles, CA.

Hayes, H., N. Khan, and D. Benton. 2006. *Impact of Sampling Media on Soil Gas Measurements*. In Proceedings; Air and Waste Management Association's Vapor Intrusion Symposium: The Next Great Environmental Challenge – An Update, Los Angeles, CA, p. 69-83. September 13-15, 2006.

Hewitt, A.D. 1994. *Concentration Stability of Four Volatile Organic Compounds in Soil Subsamples*. US Army Cold Regions Research and Engineering Laboratory, Special Report 946.

Hewitt, A. D. 1994*. Losses of Trichloroethylene From Soil During Sample Collection, Storage and Laboratory Handling*. U. S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory. Special Report 94-8.

Hewitt, A. D. 1999. *Storage and Preservation of Soil Samples for Volatile Compound Analysis*. U. S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory. Special Report 99-5.

Indiana Department of Environmental Management (IDEM). August 2015. *Investigation of Manmade of Preferential Pathways.* Office of Land Quality. Currently available online: https://www.in.gov/idem/cleanups/files/remediation_tech_guidance_investigation_mpp.pdf

Interstate Technology & Regulatory Council (ITRC). February 2004. *Technical and Regulatory Guidance for Using Polyethylene Diffusion Bag Samplers to Monitor Volatile Organic Compounds in Groundwater.* Currently available online: https://www.itrcweb.org/GuidanceDocuments/DSP-3.pdf

Interstate Technology & Regulatory Council (ITRC). January 2007. *Vapor Intrusion Pathway: A Practical Guideline.* ITRC Vapor Intrusion Team, Washington, D.C. VI-1. January. Currently available online: https://www.itrcweb.org/Documents/VI-1.pdf

Liikala, T. L., K. B. Olsen, S. S. Teel, and D. C. Logan. 1996. *Volatile Organic Compounds: Comparison of Two Sample Collection and Preservation Methods*. Environmental Science and Technology, v. 30, n. 12, p. 3441 – 3447.

Massachusetts Department of Environmental Protection (MADEP). April 2002. *Indoor Air Sampling and Evaluation Guide*. Office of Research and Standards.

Massachusetts Department of Environmental Protection (MassDEP). October 2016. Vapor Intrusion Guidance, Site Investigation, Mitigation and Closure. Currently available online: https://www.mass.gov/files/documents/2016/10/nu/vapor-intrusion-guidance-10-14-2016.pdf

McAlary, T.A., H. Groenevelt, S. Seethapathy, P. Sacco, D. Crump, M. Tuday, B. Schumacher, H. Hayes, P. Johnson, and T. Górecki. 2014b. Quantitative passive soil vapor sampling for VOCs—Part 2: laboratory experiments. Environ. Sci.: Processes Impacts 16(3): 491–500.

McAlary, T.A., P. Nicholson, H. Groenevelt, and D. Bertrand. 2009. *A Case Study of Soil-Gas Sampling in Silt and Clay-Rich (Low-Permeability) Soils.* Ground Water Monitoring & Remediation, v. 29, n.1, p 144-153.

McHugh, T., L. Beckley, T. Sullivan, C. Lutes, R. Truesdale, R. Uppencamp, B. Cosky, J. Zimmerman, and B. Schumacher. 2017. Evidence of a sewer vapor transport pathway at the USEPA vapor intrusion research duplex. Journal Science of the Total Environment 598. Currently available online: https://www.bnl.gov/envsci/pubs/pdf/2017/BNL-113837-2017-JA.pdf

Minnesota Pollution Control Agency. August 2010. *Vapor Intrusion Technical Support Document.* Remediation Division. Currently available online: https://www.pca.state.mn.us/sites/default/files/c-rem3-01.pdf

NAVFAC Memorandum (July 2015), Navy Facilities Engineering Command: Passive Sampling for Vapor Intrusion Assessment. TM-NAVFAC EXWC-EV-1503. 14 pages.

New Jersey Department of Environmental Protection (NJDEP). August 2005. Field Sampling Procedures Manual. Currently available online: https://www.nj.gov/dep/srp/guidance/fspm/pdf/fsmp2005.pdf

New Jersey Department of Environmental Protection (NJDEP). January 2018. *Vapor Intrusion Technical Guidance.* Version 4.1. Site Remediation and Waste Management Program. Currently available online: https://www.nj.gov/dep/srp/guidance/vaporintrusion/vig_main.pdf?version_4.1

Nicholson, P., D. Bertrand, and T. McClary. 2007. *Soil Gas Sampling in Low-Permeability Soils.* In Proceedings; Air and Waste Management Association's Vapor Intrusion; Learning for the Challenges, Providence, RI. P. 299-310. September 26-28, 2007.

Ohio Department of Commerce, Bureau of Underground Storage Tank Regulations. Ohio Administrative Code 1301:7-9-13 Petroleum UST Corrective Action.

Ohio Environmental Protection Agency (EPA). January 2002. *Data Quality Objectives Process Summary* [DERR-00-DI-32]. Division of Environmental Response and Revitalization. Currently available online: https://www.epa.ohio.gov/portals/30/rules/Data%20Quality%20Objectives%20Process%20Summary.pdf

Ohio Environmental Protection Agency (EPA). April 2013. Technical Guidance Compendium VA30008.14.001: Applying Generic Petroleum Standards Under the Voluntary Action Program. Currently available online: https://www.epa.ohio.gov/portals/30/vap/tgc/VA30008-14-001.pdf

Ohio Environmental Protection Agency (EPA). April 2015. Conceptual Site Models. Division of Environmental Response and Revitalization. Currently available online: https://epa.ohio.gov/portals/30/rules/CSM%20Guidance%204-27-15%20Final.pdf

Ohio Environmental Protection Agency (EPA). October 2017. *Closure Plan Review Guidance for RCRA Facilities.* Division of Hazardous Waste Management. Currently available online: https://epa.ohio.gov/Portals/30/RCRA/docs/Closure%20Plan%20Review%20Guidance.pdf

Ohio Environmental Protection Agency (EPA). Various Dates. *Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring*. Division of Drinking and Ground Waters. Currently available online: https://www.epa.state.oh.us/ddagw/gw_support#126937182-chapters

Ouellette, G. 2004. *Soil Vapor Sampling and Analysis – Lessons Learned*. Presented at the Department of Energy / Petroleum Environmental Research Forum Soil Vapor.

U.S. Environmental Protection Agency (EPA). December 1989. *Risk Assessment Guidance for Superfund; Volume I: Human Health Evaluation Manual (Part A)* [EPA 540/1-89/002]. Office of Emergency and Remedial Response. Currently available online: https://www.epa.gov/sites/production/files/2015-09/documents/rags_a.pdf

U.S. Environmental Protection Agency (EPA). November 2002. *OSWER Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Ground water and Soils (Subsurface Vapor Intrusion Guidance)* [EPA530-D-02-004]. Draft. Currently available online: https://semspub.epa.gov/work/06/9351183.pdf

U.S. Environmental Protection Agency (EPA). February 2006. *Guidance on Systematic Planning Using the Data Quality Objectives Process* [EPA/240/B-06/011]. Office of Environmental Information. Currently available online: https://www.epa.gov/sites/production/files/documents/guidance_systematic_planning_dqo_process.pdf

U.S. Environmental Protection Agency (EPA). September 2011. *Toxicological Revise of Trichloroethylene: In Support of Summary Information on the Integrated Risk Information System (IRIS). Currently available online: https://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/0199tr/0199tr.pdf*

U.S. Environmental Protection Agency (EPA). August 2014. *Compilation of Information Relating to Early/Interim Actions at Superfund Sites and the TCE IRIS Assessment.* Office of Solid Waste and Emergency Response. Currently available online: https://clu-in.org/download/contaminantfocus/tce/TCE-compilation-final-2014.pdf

U.S. Environmental Protection Agency (EPA). June 2015a. *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* [EPA 510-R-15-001]. Office of Solid Waste and Emergency Response, Office of Underground Storage Tanks. Currently available online: https://www.epa.gov/sites/production/files/2015-06/documents/pvi-guide-final-6-10-15.pdf

U.S. Environmental Protection Agency (EPA). June 2015b. *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air [*OSWER Publication 9200.2-154]. Office of Solid Waste and Emergency Response, Office of Underground Storage Tanks. Currently available online: https://www.epa.gov/sites/production/files/2015-09/documents/oswer-vapor-intrusion-technical-guide-final.pdf

Vitale, R. J., R. Forman, and L. Dupes. 1999. *Comparison of VOC Results Between Methods 5030 and 5035 on a Large Multi-State Hydrocarbon Investigation*. Environmental Testing and Analysis, January 1999, p. 18 – 39.

Wisconsin Department of Health and Family Services (DHFS). February 2003. *Chemical Vapor Intrusion and Residential Indoor Air Guidance for Environmental Consultants and Contractors.* Division of Public Health. Currently available online: https://www.dhs.wisconsin.gov/publications/p4/p45037.pdf

APPENDIX A. Vapor Intrusion Conceptual Site Model Checklist

Utilities and Process Piping

☐ Identify on a site plan all underground utilities near the soil or ground water impacts; pay particular attention to utilities that connect impacted areas to occupied buildings.

☐ Identify on a site plan all underground process piping near the soil or ground water impacts.

Buildings

☐ Identify on a site plan all existing and future buildings under investigation.

☐ Identify the occupancy and use of each building (*e.g.,* residential, commercial)

☐ Describe building construction materials (*e.g.*, wood frame, block,), openings (*e.g.,* windows, doors), and height (*e.g.*, one-story, two-story, multiple-story); identify if there is an elevator shaft in the building.

☐ Describe building foundation construction including:
Type (*e.g.,* basement, crawl space, slab on grade)

Floor construction (*e.g.,* concrete, dirt)

Depth below grade.

☐ Describe the building HVAC system including:

Furnace/air conditioning type (*e.g.*, forced air, radiant)
Furnace/air conditioning location (*e.g.*, basement, crawl space, utility closet, attic, roof)
Source of return air (*e.g.,* inside air, outside air, combination)
System design considerations relating to indoor air pressure (*e.g.*, positive pressure is often the case for commercial buildings).

☐ Identify sub-slab ventilation systems or moisture barriers present on existing buildings.

Source Area

☐ Identify the COC’s related to the vapor intrusion pathway.

☐ Describe the distribution and composition of any NAPL at the site.

☐ Identify on a site plan all source areas for the COC's related to the vapor intrusion pathway.

☐ Identify on a site plan soil and ground water results for the COC's, between the source area and the buildings under investigation.

☐ Identify on a geologic cross section soil and ground water results including depth.

☐ Describe the potential migration characteristics (*e.g.,* stable, increasing, decreasing) for the distribution of COC's.

Geology/Hydrogeology

☐ Review all boring logs and soil sampling data to understand the locations of:
Sources: NAPL, soil, ground water, suspected vapor leaks.
Soil types:
Finer-grained soil layers
Higher-permeability layers that may facilitate vapor migration.

☐ Identify on a geologic cross section distinct strata (soil type and moisture content, *e.g.*, "moist," "wet," "dry") and the depth intervals between the vapor source and ground surface, and include the depth to ground water.

☐ Describe ground water characteristics (*e.g.*, seasonal fluctuation, hydraulic gradient).

Site Characteristics

☐ Estimate the distance from the ground water concentration contour interval for each COC to buildings under investigation.

☐ Estimate the distance from vadose zone source area to buildings under investigation.

☐ Describe the surface cover between the vapor source and buildings under investigation.

APPENDIX B. Special Considerations for Evaluating Residential Properties

Ohio EPA generally recommends evaluating the vapor intrusion pathway using the prescribed stepwise approach listed in Figure 1. Sub-slab vapor and indoor air samples should be collected to assess the vapor intrusion pathway if site ground water or soil gas data indicates hazard and risk goals may be exceeded. If available data indicates there may currently be unacceptable risk to residential receptors, Ohio EPA should be contacted promptly and potential exposures to residential receptors evaluated in an expedited manner. If it is determined that no current unacceptable risk exists to residential receptors, the stepwise approach shown in Figure 1 may resume.

Prior to conducting residential sampling, the person undertaking the vapor intrusion investigation should consider how the potentially impacted community and local government should be notified. Proper community involvement efforts are critical to the effective implementation of sample collection, evaluation, and risk communication. Ohio EPA should be involved early in the risk communication planning process to ensure proper interagency notification and coordination with the U.S. EPA, Ohio Department of Health, and local health departments, as appropriate.

Public meetings may be necessary, including a pre-sampling meeting to explain results from previous sampling and the vapor intrusion sampling workplan, and a post-sampling meeting to explain any findings. Meetings may also be necessary to discuss additional and/or follow-up air sampling or the determined remedy. Please contact Ohio EPA DERR for assistance or additional guidance on informing property owners and/or tenants about sampling results and possible next steps.

The quality of outdoor air is important to consider in the CSM and remedy selection. Thus, collecting outdoor ambient vapor samples concurrently with indoor air sampling is required. Additionally, the indoor air/sub-slab sampling form found in Appendix E should be completed prior to indoor air or sub-slab vapor sampling at residential properties. Ohio EPA DERR's FSOP for indoor air sampling also includes instructions for building occupants prior to indoor air sampling.

For further guidance on community outreach, please see Appendix A (Community Stakeholder Concerns) of ITRC's Vapor Intrusion Pathway: A Practical Guide 2007, and Chapter 9 (Planning for Community Involvement) in U.S. EPA's June 2015 VI Guidance.

Procedure for Active Soil Gas Sampling Using Direct Push Systems

FSOP 2.4.1 (March 9, 2017)
Ohio EPA Division of Environmental Response and Revitalization

1.0 Scope and Applicability

1.1 Vapor intrusion (VI) is defined as vapor phase migration of volatile organic compounds (VOCs) into occupied buildings from underlying contaminated ground water and/or soil. Soil gas surveys provide information on the soil atmosphere in the vadose zone that can aid in assessing the presence, composition, source, and distribution of contaminants. The purpose of this document is to provide guidance for conducting soil gas sampling, and shall pertain to active soil gas surveys, whereby a volume of soil gas is pumped out of the vadose zone into a sample collection device for analysis.

1.2 U.S. EPA's OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air (U.S. EPA June 2015) states that the chemicals in the subsurface must be both sufficiently volatile and toxic to present a vapor intrusion risk. A chemical is considered volatile if its vapor pressure is greater than 1 millimeter of mercury (mmHg) or if its Henry's Law constant is greater than 10^{-5} atmosphere-meter cubed per mole (atm M^3 mol^{-1}). Please refer to the Vapor Intrusion Screening Level (VISL) calculator to determine whether to include a chemical in a vapor intrusion investigation. For additional information refer to Chapter 3 of U.S. EPA June 2015. A volatile organic chemical may present a vapor intrusion risk if:

- The vapor concentration of the pure compound exceeds the target indoor air concentration when the subsurface vapor is in soil, or
- The maximum ground water vapor concentration (*i.e.*, the vapor concentration above the ground water from the Henry's Law constant and water solubility) exceeds the target indoor air concentration for a ground water vapor source.

1.3 Results from soil gas surveys are used in both qualitative and quantitative evaluations. The quality and application of the data is dependent upon many factors, including but not limited to: the DQO's used to develop the sampling plan, the number of sample locations and data points, the selection of the sample locations, the soil characteristics of the site, the distribution of the contaminants in both the vadose and saturated zones, the equipment and personnel used to gather the data, etc. The work plan should be finalized before any sampling is conducted. The work plan will provide specific information on the type and quality of data gathered during the soil gas sampling event. Any questions regarding data needs and usage should be resolved prior to sampling.

1.4 The evaluation of the indoor inhalation pathway at contaminated sites is a significant concern at sites/properties where contamination is known or expected to exist. As a result, procedures and technology related to evaluating the pathway continue to evolve. This procedure pertains to the active collection of soil gas using direct-push techniques (*i.e.*, driven probe rods/tooling). With respect to the use of other appropriate methods, procedures, and equipment for measuring concentrations of chemicals of concern in soil gas, please refer to Appendix D, Section 4 of the Vapor Intrusion Guidance: A Practical Guide (ITRC, January 2007).

2.0 Definitions

Terms specific to soil gas sampling using direct-push systems are defined throughout this FSOP.

3.0 Health and Safety Considerations

3.1 Follow the site-specific health and safety plan (HASP). If a site-specific HASP is not available, follow the health and safety procedures in FSOP 1.1, Initial Site Entry.

3.2 The use of direct push systems on a site within the vicinity of electrical power lines and other utilities requires that special precautions be taken by the operators. Underground electrical utilities are as dangerous as overhead electricity. Be aware and always suspect the existence of underground utilities (water, natural gas, cable and phone lines, fiber optic cables, storm water and sewer lines, etc.).

REMEMBER....Call B-4-U Dig:
Ohio Utilities Protection Service (OUPS): 800-362-2764
&
Oil & Gas Producers Underground Protection Service (OGPUPS):
800-925-0988

4.0 Procedure Cautions

A soil gas survey is only applicable to volatile contaminants. Geological barriers may exist that interfere with vapor migration such as perched water, clay or man-made structures. Interference from these geological barriers can lead to non-representative sampling with low or false negative readings or may produce localized areas of high concentrations. In addition, heavy precipitation, 24 to 48 hours prior to sampling can result in a significant reduction in volatile concentrations.

5.0 Personnel Qualifications

Ohio EPA personnel working at sites that fall under the scope of OSHA's hazardous waste operations and emergency response standard (29 CFR 1910.120) must meet the training requirements described in that standard.

6.0 Equipment and Supplies

Personal Protective Equipment (PPE):

6.1 Hearing protection
6.2 Safety glasses
6.3 Nitrile (or similar) disposable gloves
6.4 Steel-toed boots

Equipment/Tooling/Supplies for Probe Installation:

6.5 Direct push rig
6.6 4-foot probe rods
6.7 2-foot probe rods
6.8 Inner Extension Rods (48")
6.8 Rod Grip Pull System
6.10 Drive Cap
6.11 Miscellaneous tools
6.12 Log book/Data sheets
6.13 Bentonite granules

Soil Gas Sampling:

6.14 Expendable Point Holder
6.15 Implant Expendable Point Holder
6.16 Expendable Drive Points (w/ O-ring)
6.17 6.25 Expendable Point Popper
6.18 PRT Adapter for ¼" tubing w/ O-ring
6.19 ¼" OD x 3/16" ID tubing (Teflon™ or Nylon)
6.20 20/40 grade sand (#5 quartz silica sand, or equivalent)
6.21 1L Evacuated canisters (*i.e.*, Summa canisters), with grab flow-choke regulators
6.22 Implants (stainless steel, aluminum, ceramic, or plastic)
6.23 Funnel
6.24 Tubing cutter
6.25 Polycarbonate 2- & 3-way valves
6.26 Disposable 60cc Syringe
6.27 Photoionization detector (FSOP 3.1.1, Photoionization Detector), ppb capable
6.28 Multi-gas meter (FSOP 3.1.2, Multiple Gas Detection Meters)
6.29 Field documentation equipment and supplies, including pens, markers, field logbook and data sheets, chain-of-custody forms, camera, etc.

7.0 Procedures: Summary of Probe Installation Methods

7.1 Using the Post-Run Tubing System for Grab Sample Collection

This is a temporary, single use application for collecting a soil gas grab sample. Using the post-run tubing system (PRT), probe rods are driven to the desired depth, and then internal tubing, with PRT fitting attached, is inserted and seated for soil gas sampling. Using the inner tubing for soil gas collection has many advantages - potential for leakage is reduced, dead air volume that must be purged is reduced, and decontamination problems are reduced as the sample does not contact the rod bore.

7.1.1 Clean all parts prior to use. Inspect all probe rods and clear them of obstructions. Install O-ring on the PRT expendable point holder and the PRT adapter.

7.1.2 Test fit the adapter with the PRT fitting on the expendable point holder to assure that the threads are compatible and fit together smoothly. Ensure the threads are clean of debris.
NOTE: PRT fittings are left-hand threaded and must be rotated counter-clockwise to engage the point holder threads.

7.1.3 Push the PRT adapter into the end of the selected tubing. Tape may be used on the outside of the adapter and tubing to prevent the tubing from spinning freely around the adapter during connection - especially when using Teflon^{TM} tubing.

NOTE: The sample will not come into contact with the outside of the tubing or adapter.

7.1.4 Attach the PRT expendable point holder (with O-ring) to the female end of the leading probe rod.

7.1.5 Attach an O-ring to an expendable soil vapor drive point and insert into the expendable point holder. Attach the drive cap to the male end of the drive rod and position rod under probe.

7.1.6 Drive the PRT rod configuration into the ground, connecting probe rods as necessary to reach the desired depth.

7.1.7 After desired depth has been achieved, disengage the expendable drive point. Using the inner extension rods, insert the expendable point popper to the bottom of the rod string and then slowly pull up on the probe rods using the rod grip pull system. Retract the rods approximately 4"- 6" up to create a void from which to sample the soil gas. Position the probe unit to allow room to work around the sample location.

7.1.8 Insert the PRT adapter end of the tubing down the inside diameter of the probe rods.

7.1.9 Feed the tubing down the rod bore until it hits bottom on the expendable point holder. Allow approximately 4-6 ft. of tubing to extend out of the hole before cutting it. Grasp the excess tubing end and lightly apply downward pressure while turning it in a counter-clockwise motion to engage the adapter threads with the expendable point holder. Continue turning until the PRT adapter O-ring bottoms out in the expendable point holder.

7.1.10 Pull up lightly on the tubing to test the engagement of the threads. Failure of the PRT adapter to thread could mean that intrusion of soil may have occurred during driving of the rods or disengagement of the expendable drive point. Once tubing has been connected, finish the surface end with a 2-way valve in the closed position.

7.1.11 Sampling at the location can commence following an equilibrium period (minimum of 15 minutes). Connect the sampling tubing and follow appropriate purging and sampling procedures. Refer to “Procedures for Collection of Indoor Air, FSOP 2.4.3” for reference for use of evacuated canisters for sample collection; and refer to Section 7.3.1 below, for sampling procedures using the bag sampler (*e.g.*, Lung Box).

7.1.12 Prior to sample collection and screening, ensure that the implant is in a porous soil zone that will freely give up soil gas. Connect a 60 cc syringe to the implant tubing, open the 2-way tubing valve, and gently pull the plunger out to fill the syringe with gas. Let go of the plunger and observe whether it holds position where released, or if it can be observed moving back due to an induced vacuum. Should a vacuum be present, the soil zone at the end of the probe rods may be too tight to get a representative soil gas sample. Should this occur, the probe rods can be pulled up 1 to 2 feet at a time, retesting each interval until soil gas can be freely obtained. If not, abandon the location, seal the borehole with bentonite, and reposition the probe; or relocate to another position.

7.2 Installation of Soil Gas Implants

For long-term soil gas monitoring applications (multiple sampling events from the same location), a stainless steel, aluminum, polycarbonate or ceramic implant can be installed at any depth by direct push. Implants are inserted down inside the probe rods when the appropriate sampling depth has been achieved. When installing soil gas implants, knowledge of the local geology and soil types is paramount to the success of any soil gas survey. For sites where geology or soil characteristic information is not available, the collection of soil borings to target depth may be helpful in identifying zones or soil horizons in which to set soil gas implants.

7.2.1 Drive probe rods to the desired depth using the implant expendable point holder and an expendable drive point. Disengage the drive point using the point popper. Using the inner extension rods, insert the expendable point popper to the bottom of the rod string and then slowly pull up on the probe rods using the rod grip pull system. Retract the rods approximately 1”- 2” to push the expendable point out with the point popper. Remove all extension rods and point popper. Check end of last inner rod or point popper for evidence of moisture. Implants should not be installed in moist zones as these can inhibit vapor migration as well as, given enough time for water to accumulate, may result in water being drawn up and into sample containers (evacuated canister or Tedlar® bag).

7.2.2 Attach implant to one end of appropriate sample tubing (Teflon™, or nylon). Depending on implant type and diameter of sample tubing, a very short length of silicone tubing of appropriate size may be used to securely connect the implant to the sample tubing.

7.2.3 Lower the implant and tubing down the inside of the probe rods until the implant hits the top of the anchor/drive point. Note the length of the tubing to assure that proper depth has been reached. Cut the tubing flush with the top of the probe rod.

7.2.4 Using an inner extension rod, place one end of the rod on top of the fresh cut tubing. While holding the rod in place, slowly retract the rods, 4 feet at a time, and remove the drive rod. Continue this action of using the extension rod to hold the tubing in place until all the drive rods have been removed from the borehole.

7.2.5 Slowly pour sand (20/40 grade or #5) down the borehole around the outside of the tubing so that the sand extends several inches above the implant. Use the tubing to “stir” the sands into place around the implant. Do not lift up on the tubing. It should take less than 250 mL of sand to fill the space around the implant. The sand therefore will act as a grout barrier, inhibiting the grout from impacting the implant. Slowly pouring sand and bentonite will lessen the chance for the materials to bridge in the borehole.

NOTE: Implants come in various sizes and the drive rods can vary in diameter, so it is best to calculate the necessary volume of sand for each implant installation. Placement of the grout barrier by backfilling the borehole can only be performed in the vadose zone, not below the water table.

7.2.6 Once the sand is in place, slowly add the bentonite granules on top of the sand. After approximately 0.5 L of bentonite has been added, hydrate the bentonite in the hole. Hydration can be accomplished using a pump sprayer, or by using a section of tubing connected to the 60 cc syringe filled with water. Depending on borehole depth, the bentonite should be hydrated at a minimum of 3-5 intervals. Allow bentonite to come to ground surface, saturate the bentonite with water to create a bentonite “mud” and, using a finger, push this mix around the tube and back down the hole to enhance the closure. This results in a tight seal preventing gas migration down the column.

NOTE: Use caution not to over hydrate, as the water may flow out into the soil formation and travel down to the implant, causing it to become wet and potentially loose diffusivity

7.2.7 After sealing the borehole, cut the tubing to a manageable length (~12” - 18”), attach a 2-way valve connector (in the OFF position) or air tight (e.g., Swagelok®) plug, and mark the location with a pin flag or stake. Attach a label or tag to the tubing indicating the sample location identifier and depth at which the implant was set for future reference when sampling. Example: SG-3-18, meaning a soil gas point at location #3 with an implant set at 18 feet bgs.

7.2.8 Check the viability of the sample point just installed following the procedures outlined in Section 7.1.12 using a 60 cc syringe. A multi-gas meter with a PID is also a very good way to purge and check the sample point’s viability and usefulness. Stable field screening measurements for VOC’s, oxygen, and hydrogen sulfide can be good indicators on a well-sealed and sampling-ready implant. Should the meter’s pump motor labor, or if the syringe plunger recedes back into syringe after pulling, a vacuum has been induced and the point is not viable for sample collection. The induced vacuum would be too much to overcome to obtain a gas sample using either an evacuated canister or a bag sampler.

7.2.9 A minimum equilibrium time should be established prior to sampling the implant (preferably stated in the work plan). While a 24-hour equilibrium period will ensure adequate equilibration, four to eight hours is generally sufficient. After equilibration, the implant is ready for sampling. Refer to Section 7.3 for sampling procedures using a vacuum canister (*e.g.,* Summa or Silco).

7.2.10 To provide long term security to the sampling port, the installation of a flush mount or above ground protective casing with a cap can be installed and finished with a concrete pad. For temporary, short-term finishing of a sampling port, 4-6" (ID) PVC pipe sections with associated caps can be installed.

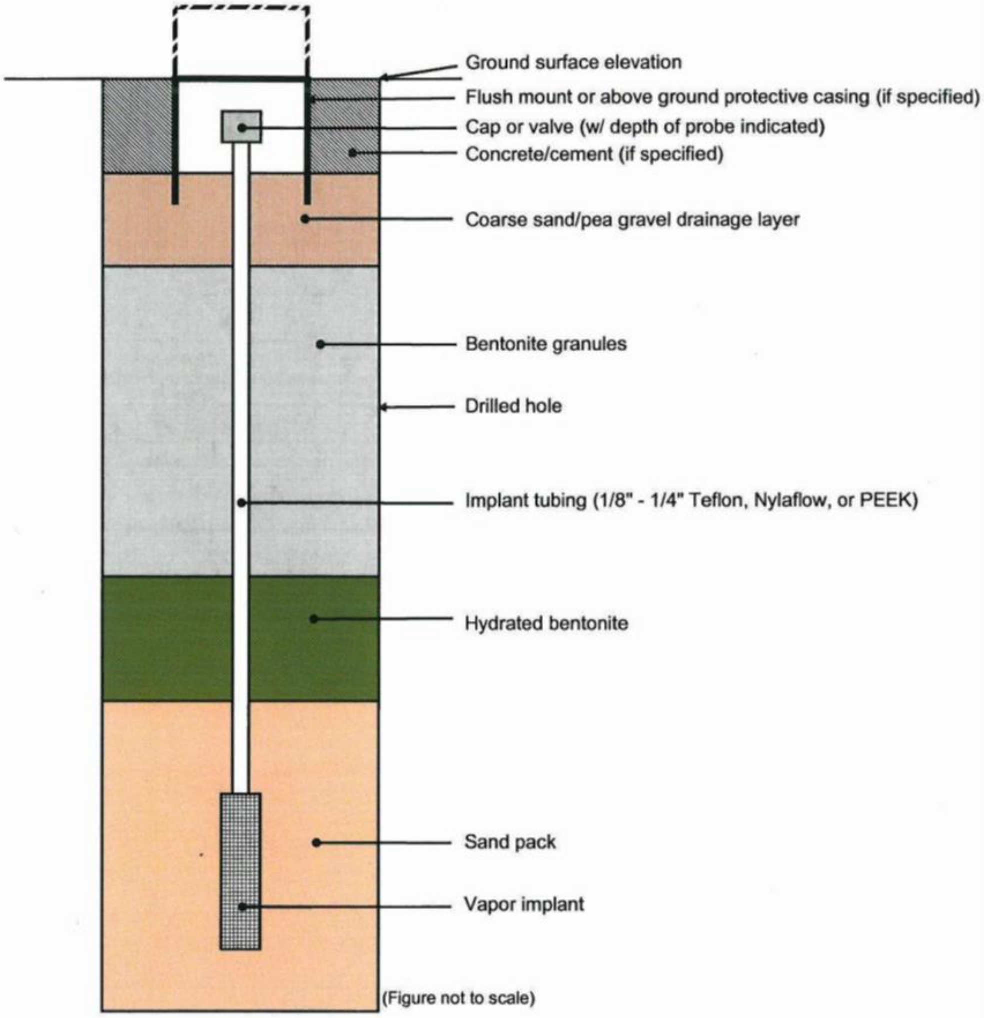


Figure 3: Permanent Soil Gas Probe Schematic

7.3 Sample Collection Methods

Two common methods of sample collection for vapor intrusion contaminants of concern (COCs) are discussed in this FSOP. The lung box sampler uses Tedlar® bags as sample containers. Collection of samples on adsorbents is performed by using a small external pump to pull air through adsorbent media cartridges and/or tubes. Data Quality Objectives (DQOs) for the project will determine which sample collection method to use. Field data should be recorded on the Soil Gas Sampling Data Sheet (attached) or in a field notebook.

7.3.1 The Lung Box Sampler (Bag Samplers)

The Lung Box allows direct filling of a Tedlar® air sample bag using negative pressure without passing gas through the pump. This eliminates the risk of contaminating the pump or the sample. The Lung Box, pictured below, includes an in-line pump. Other types of bag samplers may require the use of a separate air pump or hand pump.

The recommended holding time for samples collected into Tedlar® bags is 24 to 48 hours. Therefore, soil gas samples collected in Tedlar® bags should be analyzed as quickly as practical or samples can be transferred to another container with longer holding times (*i.e.*, Summa canister). If this method of sampling is performed, ensure that the laboratory can accept Tedlar® bags, and can meet the holding time requirements.

Semi-permanent soil gas probe location with multi-depth implants. The lung box sampler is used to collect soil gas samples using 1-liter Tedlar bags. Note that each tube is labeled with the sampling depth; the PVC pipe is used to protect the soil gas tubing.

7.3.1.1 Prior to sampling, and after an appropriate equilibrium period (typically 8 – 24 hrs. depending on DQOs), ambient air needs to be removed from the sample train by purging. Purging of the filter pack is required if sampling occurs within 24 hours of installation. At least three volumes should be removed. For example, the sample tubing can be purged using a 60 cc syringe with an attached 3-way valve (~4 cc/ft for ¼” ID tubing/volume). Other methods may be used as long as a minimum of 3 volumes are purged from the tubing. Once purging is complete, the sample may be collected.

Field screening may be performed using a direct reading instrument after sample collection.

7.3.1.2 Install new tubing in the bag sampler before collecting each sample. Place a new Tedlar® sample bag (already labeled) inside the bag sampler. Attach the inside portion of the tubing to the inlet valve on the sample bag. Open the sample valve on the sample bag following the manufacturer's instructions. Close sampler lid and secure. (DO NOT use any type of permanent marker, *i.e.*, "*Sharpie"* pens)

7.3.1.3 Attach external part of the inlet tubing to the sample tubing. Make sure that the purge valve on the side of the box is closed (closed for fastest fill rate, open for slower fill rate).

7.3.1.4 Turn on the sample pump or initiate hand pumping. While filling, watch through the observation window of the Bag sampler as the Tedlar® bag fills with gas. Avoid filling bag more than 80% of its maximum volume. Turn the pump off when the bag has filled to the desired volume. Do not over fill sample bags. The vacuum pump may be strong enough to break a sample bag.

NOTE: Be sure to watch the sample line for the first sign of water coming up the line. Pulling water up the line is not uncommon, especially in cases where the position of the water table is unknown. This is a good reason why ample lengths of tubing should be used for the sample line. If water is drawn up the tubing, the tubing can be cut before the water reaches the sampling equipment.

NOTE: Exercise extreme caution if filling sample bags with explosive gases.

7.3.1.5 Once filling of the sample bag is complete, turn off the pump, open the purge valve to equalize the pressures, unlatch the bag sampler lid and open. Close the sample bag inlet valve by holding the side stem and turning the entire upper portion of the fitting clockwise until snug. Remove the filled sample bag from the internal inlet tubing.

NOTE: In an effort avoid any photochemical reactions, keep filled Tedlar® bags out of sunlight. Store and ship bag samples in a protective box at room temperature. Do not chill to avoid condensation.

7.3.1.6 If measurements with a portable meter are to be made (*e.g.,* oxygen), conduct measurements after collecting the soil gas sample(s).

7.3.2 Collection of Samples on Adsorbents

7.3.2.1 An alternative approach to collecting soil gas in a sample container is to concentrate the soil gas on an adsorbent media. This type of method is required for SVOCs and is often used for mercury (generally compounds heavier than naphthalene). Typically, a pump is used to draw soil gas through the adsorbent matrix, and the adsorbent is then analyzed by a laboratory.

7.3.2.2 A variety of adsorbent cartridges and pumping systems are available from commercial vendors. In addition, it is essential that the soil gas be drawn through the adsorbent by the pump, not pumped through the adsorbent to eliminate the chance for cross-contamination by the pump. It is often recommended that two tubes be used in series to avoid breakthrough losses in areas of suspected higher concentrations. The adsorbent, purge rate, and sample volume must be determined by discussion with the analytical laboratory.

7.4 Soil Gas Sample Field Screening

7.4.1 Following sample collection, field-screen the borehole or soil gas probe atmosphere with a PID in accordance with FSOP 3.1.1, Photoionization Detector, to estimate the bulk concentration of VOCs present in the soil gas sample. The PID field screening data should be recorded with the sample information on the chain-of-custody form. The analytical laboratory needs to be aware of any samples potentially containing high concentrations of VOCs that may need to be diluted prior to analysis.

7.4.2 If desired, to perform the field-screening, attach an appropriate length of tubing to the PID sampling tip with a small piece of silicon tubing and extend it at least halfway into the boring or attach PID directly to tubing on a soil gas probe to obtain readings.

7.4.3 The PID field screening data may also be collected for sampler health and safety concerns or to use as real-time screening information to help evaluate the need for additional sampling or other site assessment activities while in the field.

7.4.4 In addition to a PID, a multi-gas meter (FSOP 3.1.2, Multiple Gas Detection Meters) may be used to field screen the borehole or soil gas probe atmosphere to collect gas concentration field screening data. This information may be provided to the analytical laboratory, used to monitor health and safety concerns, or used as real-time screening information to help evaluate the need for additional sampling or other site assessment activities while in the field. Parameters often include VOCs (ppb), Oxygen (% O_2), Lower Explosive Level (% LEL), Carbon monoxide (ppm CO), and Hydrogen sulfide (ppm H_2S)

8.0 Data and Records Management

Refer to FSOP 1.3, Field Documentation.

9.0 Quality Assurance and Quality Control

Refer to the Site-Specific Work Plan

10.0 Attachments

Soil Gas Sampling Data Sheet

11.0 References

FSOP 1.1, Initial Site Entry

FSOP 1.3, Field Documentation

FSOP 3.1.1, Photoionization Detector

FSOP 3.1.2, Multiple Gas Detection Meters

Interstate Technology & Regulatory Council (ITRC) Vapor Intrusion Team, January 2007, Vapor Intrusion Pathway: A Practical Guideline

U.S. EPA, 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

SOIL GAS SAMPLING DATA SHEET

GENERAL INFORMATION

Site Name:________________________________

Site Address:_____________________________

City:____________________________________

County/District___________________________

Contact Name:____________________________

Phone #:_________________________________

Sampling Address:__________________________
(if other than site address)

Grab Sample:________ **Canister Sample:**_________

Sample ID #: ______________________________

If canister used, complete info below:

Canister ID #:_____________________________

Regulator ID #:____________________________

SAMPLING INFORMATION

(mm/dd/yy) ***(military)***

Soil Gas port installed: Date:_______**Time:**_______
Depth :_______

If canister used for sample collection, complete following info:

Sample Collection Start: Date:_______**Time:**_______

Sample Collection End: Date:________ **Time:**_______

Regulator Calibrated for:

_____ **8-hr** _____ **12-hr** _____ **24-hr** _____ **grab (no regulator)**

Laboratory & Analytical Method: _________________

Sample Delivered: Date_________ **Time:**__________

Method of Delivery: _____________________________
(ex. Lab courier, UPS, delivered by sampler, etc.)

Canister Info:

Initial canister vacuum:

______ **"Hg or mm Hg**

Final canister vacuum:

_______**"Hg or mm Hg**

Temperature:

__________ **°F**

Field Screening Info:

PID (ppm):__________

% O_2 :______________

CH_4 (%LEL):_________

CO_2:_______________

CO:________________

H_2S:_______________

List instrument (and ID#) used to collect parameters:

____

NOTES: (include any information on the installation of the soil gas port, or problems with sampling/canister etc.)

Signature of Sampler: ______________________________________ **Date:**________________

Note: If a diagram of the sample location(s) is sketched on the back of this data sheet, check here ☐

Construction, Installation and Decommissioning of Sub-Slab Vapor Ports

FSOP 2.4.2 (May 2, 2018)

Ohio EPA Division of Environmental Response and Revitalization

1.0 Scope and Applicability

Sub-slab vapor ports are used to sample the vapor contained in the interstitial spaces beneath the floor slab of dwellings and other structures for volatile organic compounds (VOCs) and other volatile chemicals. Sub-Slab vapor ports may be constructed using a custom fit stainless steel implant with Swagelok® fittings or a custom pre-manufactured Vapor Pin®.

2.0 Definitions

Summa Canister: Genericized trademark that refers to electro-polished, passivated stainless steel vacuum sampling devices (*i.e.*, evacuated canister). Sizes of canisters will vary with the most commonly used sizes being 6L and 1L. Canister size will depend on the pre-determined time-frame for sampling (*e.g.*, 24-hour vs. “grab”). A “Silco” canister is another name for a Summa canister.

3.0 Health and Safety Considerations

3.1 This activity involves accessing private residences and spaces in commercial buildings. Follow Ohio EPA Standard Safety Operating Procedure Number SP11-19 (Working Alone) to determine if working alone is appropriate given the site conditions and circumstances.

3.2 Never enter an OSHA-defined confined space for any reason. Only Ohio EPA Office of Special Investigation (OSI) staff or other appropriately trained staff are qualified to enter confined spaces for reconnaissance or sampling activities and will perform such work as necessary in accordance with Ohio EPA Standard Safety Operating Procedure Number SP14-4 (Confined Space Entry).

3.3 Follow the site-specific health and safety plan (HASP), which should identify the potential presence of asbestos-containing materials and other building-specific health and safety concerns. If a site-specific HASP is not available, follow the health and safety procedures in FSOP 1.1, Initial Site Entry.

3.4 This activity may result in the creation of silica dust when drilling through concrete. To prevent exposure to silica, a HEPA vacuum with an associated dust containment system must be used when drilling through concrete. Staff must be trained in the proper use of the silica dust collection equipment before installing sub-slab vapor probes.

3.5 When using electricity, be cautious of wet areas or areas with standing water, *e.g.*, wet basement floors, sump pumps, etc.

3.6 Be aware of potential vermin (fleas, rats, etc.)

3.7 Hearing protection should be worn while using a hammer drill.

3.8 A dust mask may be worn during drilling if desired.

3.9 Use a photoionization detector (PID) to evaluate VOC concentrations during vapor port installation in accordance with FSOP 3.1.1, Photoionization Detector.

3.10 Review available plans or documents before selecting sampling locations. Ensure that all sub-slab utilities (public and private or building specific) have been located and marked prior to installation.

3.11 Do not attempt to drill through steel-reinforcement (e.g., rebar) within a concrete slab.

4.0 Procedure Cautions

4.1 Review the site-specific work plan (SSWP), which should include a description of the building's size and use. In certain emergency circumstances a SSWP may not be available, and all necessary information for sub-slab vapor port installation and sampling will need to be obtained during the pre-sampling visit as described below. If a pre-sampling meeting cannot be held due to time constraints, please collect as much of the information as possible as listed below. This information can be obtained during a telephone call or in person.

4.2 A pre-sampling site visit should be conducted to meet with the building's owner and/or tenant and inspect the proposed vapor port sampling locations. During the pre-sampling visit, discuss sample location access and associated logistical concerns, including, but not limited to, lighting and electrical power, the need to temporarily move furnishings, the need to remove floor coverings (e.g., carpet or tile), the location of floor drains and/or other sub-slab utilities, and whether or not the sampling areas are occupied or unoccupied spaces.

4.3 The thickness of concrete slabs varies from structure to structure. A single structure may also have a slab with variable thickness. Drill bits of various sizes and cutting ability may be required to penetrate slabs of variable thicknesses. If a slab contains steel reinforcement (e.g., rebar), a sub-slab vapor port can only be installed if SIFU can find a location where steel reinforcement is not present. SIFU cannot drill through the steel reinforcement within a concrete slab.

4.4 There is a potential for high concentrations of VOC vapors to exist under the slab. Perform work quickly to ensure minimal exposure to VOCs.

4.5 When installing sub-slab vapor ports in commercial or industrial buildings, there is the potential to encounter sub-slab utility conduits (e.g., floor drains or electric, gas or water lines). Follow the procedures provided in Section 7.1 for sub-slab utility clearance before installing vapor ports.

4.6 Unless approved by Ohio EPA management and the building owner, sub-slab vapor ports should never be installed in the floor of a building with an existing sub-slab vapor barrier that is a component of a vapor mitigation system because vapor port installation could penetrate the barrier. However, sub-slab vapor ports may be installed through sub-slab moisture barriers that are typically not components of vapor mitigation systems, providing that the vapor port is decommissioned when it is no longer needed for sampling purposes.

4.7 When using the drill and HEPA vacuum, you will exceed 15 amps which is the standard for most household outlets. Therefore, be prepared to connect the drill and the HEPA vacuum to separate outlets.

5.0 Personnel Qualifications

Ohio EPA personnel working at sites that fall under the scope of OSHA's hazardous waste operations and emergency response standard (29 CFR 1910.120) must meet the training requirements described in that standard. Prior knowledge, training and experience with this sampling technique is strongly recommended before collecting samples.

6.0 Equipment and Supplies

General

6.1 Hammer drill or rotary hammer drill
6.2 Alternating current (AC) extension cord
6.3 AC generator, if AC power is not available on site
6.4 Hammer or rotary hammer drill bit, ⅜" diameter
6.5 Hammer or rotary hammer drill bit, 1" diameter
6.6 1 – ¾" open end wrench or 1 – medium adjustable wrench
6.7 2 – $^{9}/_{16}$" open end wrench or 2 – small adjustable wrenches
6.8 Disposable cups, 5 ounces (oz.)
6.9 Disposable mixing implement (*i.e.*, popsicle stick, tongue depressor, etc.)
6.10 Vapor Sampling Data Sheet, Sub-Slab and Indoor Air (attached) or log book
6.11 Pens and markers
6.12 Flashlight or equivalent head lamp
6.13 Utility knife
6.14 Disposable syringe (60 cc)
6.15 Personal protective equipment appropriate for site-specific work activities\
6.16 Disposable mixing implement (*i.e.*, popsicle stick, tongue depressor, etc.)
6.17 Tap water, for mixing anchoring cement/grout
6.18 Hand broom and dust pan
6.19 Small bottle brush to remove loose debris clean side walls of borehole
6.20 Portable HEPA vacuum
6.21 Dust collector

Swagelok® Equipment and Supplies

6.22 Hex head wrench, ¼"
6.23 Tubing cutter and pipe cutter
6.24 Swagelok® SS-400-7-4 female connector, ¼" national pipe thread (NPT) to ¼" Swagelok® connector
6.25 Swagelok® SS-400-1-4 male connector, ¼" NPT to ¼" Swagelok® connector
6.26 Hose barb adapter, brass, 3/16" barb x ¼" male iron pipe (MIP)
6.27 ¼" NPT flush mount hex socket plug
6.28 ¼" outer diameter (OD) stainless steel tubing, pre-cleaned, instrument grade

6.29 ¼” OD Teflon™ or nylon tubing
6.30 Teflon™ or nylon washer ID ¼”, OD ¾”
6.31 ¼” OD stainless welded tubing, 12” to 24” length
6.32 Swagelok® tee, optional (SS-400-3-4TMT or SS-400-3-4TTM)
6.33 Appropriate size tubing

Vapor Pin® Equipment and Supplies

6.34 Cox-Colvin Vapor Pin® Kit
6.35 Dead blow hammer
6.36 Appropriate silicon tubing
6.37 Vapor Pin® protective cap to prevent vapor loss prior to sampling
6.38 Standard Operating Procedure Installation and Extraction of the Vapor Pin® https://www.vaporpin.com/resources/#SOP

7.0 Procedures

7.1 Review the SSWP, which should include a description of the building’s size and use. In certain emergency circumstances a SSWP may not be available, and all necessary information for sub-slab vapor port installation and sampling will need to be obtained during the pre-sampling visit as described below. If a pre- sampling visit is not feasible, call the owner and/or tenant prior to sampling to obtain the information.

7.2 A pre-sampling site visit should be conducted to meet with the building’s owner and/or tenant and inspect the proposed vapor port sampling locations. During the pre-sampling visit, discuss sample location access and associated logistical concerns, including but not limited to lighting and electrical power, the need to temporarily move furnishings, the need to remove floor coverings (e.g., carpet or tile), the location of floor drains and/or other sub-slab utilities and whether or not the sampling areas are occupied or unoccupied spaces.

7.3 Before installing sub-slab vapor ports in a commercial or industrial building, use the following procedures for sub-slab utility clearance:

7.3.1 Perform a visual inspection of the area(s) of the building where vapor ports are to be located for potential sub-slab utility lines.

7.3.2 Discuss the presence and location(s) of sub-slab utility lines with the building owner and/or operator and review any available building construction plans that may show the location of sub-slab utility lines.

7.3.3 If the presence or location(s) of sub-slab utility lines cannot be verified following the procedures in Sections 7. 1 and 7. 2, contract a private utility locating company to locate potential sub-slab utility lines before installing vapor ports.

7.4 Preparation and Drilling of the Vapor Port

7.4.1 Connect the dust collector to the HEPA vacuum. Ensure that all connections are tight.

7.4.2 Plug the HEPA vacuum into the outlet and place the dust collector on the floor. Turn on the HEPA vacuum and ensure that the dust collector has created a tight seal with the floor. If a tight seal is not present, turn off the vacuum and check to ensure that all of the connections between the vacuum and the dust collector are tight. If the connections are tight, check the filter. It may be full, and need replaced. Also make sure the rubber gasket on the dust collector is in good condition. Finally, reposition the dust collector to a smoother floor surface. Retest the seal between the dust collector and the floor.

7.4.3 After ensuring that there is a good seal between the floor and the dust collector, set-up the drill and make sure the dust collector is positioned over the location selected for the vapor port. Turn on the vacuum and then the drill.

7.5 Swagelok® Probe Assembly and Installation for Multiple Sampling Events

7.5.1 Drill a ⅜" diameter pilot hole to a depth of approximately 2" (Figure 1).

7.5.2 Using the ⅜" pilot hole as your center, drill a 1" diameter outer hole to a depth of approximately 1 ⅜" (Figure 1). Vacuum cuttings out of the hole.

Figure 1: Assembled sub-slab port ready for installation

7.5.3 Continue drilling the ⅜" inner or pilot hole through the slab and a few inches into the sub-slab material.

7.5.4 Determine the length of stainless steel tubing required to reach from the bottom of the outer hole, through the slab and into the open cavity below the slab. To avoid obstruction of the probe tube, ensure that it does not contact the sub-slab material. Using a tube cutter, cut the tubing to the desired length.

7.5.5 Attach a measured length (typically 3"-4") of ¼" OD stainless tubing to the female connector (SS-400-7-4) with the Swagelok® nut. Make sure that the tubing rests firmly in the fitting body and that the nut is finger tight. While holding the fitting body firmly, tighten the nut 1¼ turns.

7.5.6 Insert the ¼" hex socket plug into the female connector. If using a stainless steel socket plug, wrap one layer of Teflon™ thread tape around the threads to prevent binding. If using a brass socket plug, Teflon™ tape is not needed. Tighten the plug slightly. Do not over tighten. If excessive force is required to remove the plug during the sample set up phase, the probe may break loose from the anchoring cement.

7.5.7 Place the completed probe into the outer hole to check fit and to ensure that stainless steel tubing is not in contact with the sub-slab material. Make necessary adjustments to the hole or probe assembly.

7.5.8 In a disposable cup or other container, mix a small amount of the anchoring cement or grout. Add water sparingly to create a mixture that is fairly stiff and moldable. Place a spoonful or two of the cement/grout around the stainless steel tubing adjacent to the female connector nut. Mold the cement/grout into a mass around the connector nut and up around the main body of the probe assembly. Slide the Teflon™ washer onto the stainless steel tube so that it rests next to the cement/grout mixture. The washer will prevent any anchoring cement/grout from flowing into the inner hole during the final step of probe installation.

7.5.9 Carefully place the probe assembly into the drilled hole, applying light pressure to seat the assembly. While inserting the probe assembly, work the concrete/grout mixture to fill voids. Clean up cement/grout that discharged out of the hole during placement; avoid getting any of the concrete/grout into fittings or on fitting threads. Allow the cement/grout to cure according to manufacturer's instructions before sampling (typically 24 hours). This elapsed time also allows for subsurface conditions to equilibrate prior to sampling.

7.6 Swagelok® Sample Set-Up and Collection

7.6.1 Conduct a leak test prior to sampling. Follow project-specific DQO's and/or the SSWP to determine which of the following method(s) are appropriate:

7.6.1.1 The water dam that is included in the Cox-Colvin Vapor Pin® kit is a simple means of determining if there are any leaks (see Cox-Colvin instructions, Figure 6). To use the water dam, simply attach the water dam to the floor using putty ensuring that there are no holes between the putty and the floor. Then add water to the dam and observe whether there are any air bubbles. If there are no air bubbles, the seal is tight. If there are air bubbles, refer to Section 7.7.

7.6.1.2 Another option is to evaluate the oxygen concentration by attaching an oxygen sensor (Multi-RAE Pro meter) to the vapor pin®. If the percent oxygen drops, it can be inferred that there is a tight seal. However, since this method draws in sub-slab vapor, a longer waiting period may be required before collecting the sample to allow for the sub-slab air to re-equilibrate.

7.6.1.3 A tracer gas can be used during sample collection to evaluate whether the connections between the vapor pin® and the sample container have any leaks. A tracer gas is very lightly sprayed on a paper towel and the paper towel is briefly laid around the fittings. As an alternative, the tracer gas can be lightly sprayed into the atmosphere near the sample train. Do NOT spray directly on the fittings. **Note**: you will not know if there were any leaks until after the sample has been analyzed. The recommended tracer gas is 1,1-Difluoroethane, which is present in some brands of dust cleaner for electronics.

7.6.2 Wrap one layer of Teflon™ thread tape onto the NPT end of the male connector OR wrap one layer of Teflon™ tape onto the threaded end of the hose barb adapter (3/16” barb x ¼” MIP).

7.6.3 Carefully remove the ¼” hex socket plug from the female connector. Refer to Section 7.7 if the probe breaks loose from the anchoring cement/grout during this step.

7.6.4 To ensure that the sub-slab port has not been blocked by the collapse of the inner hole below the end of the stainless steel tubing, a stainless steel rod, ⅛” diameter, may be passed through the female connector and the stainless steel tubing. The rod should pass freely to a depth greater than the length of the stainless steel tubing, indicating an open space or loosely packed soil below the end of the stainless steel tubing. Either condition should allow a soil gas sample to be collected. If the port appears blocked, the stainless steel rod may be used as a ramrod to open the port. If the port cannot be cleared, the probe should be reinstalled, or a new probe installed in an alternate location.

7.6.5 Screw and tighten the Teflon™ taped male connector into the female connector, or screw and tighten the hose barb adapter (3/16” barb x ¼” MIP) into the female connector. Do not over tighten. This may cause the probe assembly to break loose from the anchoring cement/grout during this step or when the male connector/hose barb adapter is removed upon completion of the sampling event. Refer to Section 7.7 if the probe breaks loose from the anchoring compound during this step.

7.6.6 If a co-located sub-slab sample or split sample is desired, a stainless steel Swagelok® T, may be used in place of the male connector.

7.6.7 Using a short piece of silicon tubing, attach a length of ¼" tubing (Teflon™ or nylon) to the sampling container (e.g., Summa canister) or system (e.g., lung box for Tedlar® bag) to be used for sample collection. Connect the other end of the tubing to the male connector with a Swagelok® nut or connect directly to the barbed hose adapter.

7.6.8 Refer to site-specific work plan for canister size and type of sample required (e.g., 6-liter canister with regulator for either 8-hour or 24-hour sample collection or a 1-liter evacuated canister for a grab sample). After sampling, use a PID to measure the VOC concentrations to provide the laboratory with an indication of how concentrated the VOCs may be in the sample. Provide this information to the laboratory. **Note**: PID readings are not contaminant-specific quantifications. Do not assume that the PID reading equates (or approximates) the concentration of the contaminant of concern.

7.6.9 After sample collection, remove the male connector or barbed hose adapter from the probe assembly and reinstall the ¼" hex socket plug. Make sure the plug threads are wrapped with Teflon tape. Do not over tighten the hex socket plug. If excessive force is required to remove the plug during the next sampling event, the probe may break loose from the anchoring compound. Refer to Section 7.7 if the probe breaks loose from the anchoring compound during this step.

7.7 Repairing a Loose Swagelok® Probe Assembly

7.7.1 If the probe assembly breaks loose from the anchoring compound while removing or installing the hex socket plug, the Swagelok® male connector, or the barbed hose adapter, lift the probe assembly slightly above the surface of the concrete slab.

7.7.2 Hold the female connector with the ¾"open-ended wrench.

7.7.3 Complete the step being taken during which the probe broke loose, following the instructions contained in this SOP (*i.e.*, do not over tighten the hex socket plug, the male connector, or the barbed hose adapter).

7.7.4 Push the probe assembly back down into place and reapply the anchoring cement/grout.

Figure 2: Swagelok® port connected to canister and ready for sampling

7.8 Vapor Pin® Probe Installation

7.8.1 Refer to attached Cox-Colvin Vapor Pin® Standard Operating Procedure for proper vapor pin installation and removal.

7.8.2 After installing a Vapor Pin® place the small rubber cap over the barbed inlet to prevent and gas from escaping.

7.8.3 Conduct a leak test. The project specific DQO's or SSWP may dictate which of the following method(s) may be followed. **Note**: There are other techniques beyond those listed that may be used.

7.8.3.1 The water dam that is included in the Cox-Colvin Vapor Pin® kit is a simple means of determining if there are any leaks (see Cox-Colvin instructions, Fig 6). To use the water dam, attach the water dam to the floor using putty ensuring that there are no holes between the putty and the floor. Then add water to the dam and observe whether there are any air bubbles. If there are no bubbles, the seal is tight. If there are air bubbles, remove the water and reset the vapor point. Test with the water dam again to see if the seal is now tight. Remove the water and dam once test is complete.

7.8.3.2 Another option is to attach an oxygen sensor (Multi-RAE Pro meter) to the vapor pin® and evaluate the oxygen concentration. If the percent oxygen drops, it can be inferred that there is a tight seal. However, since this method draws in sub-slab vapor, a longer waiting period may be required before collecting the sample to allow for the sub-slab air to re-equilibrate.

7.8.3.3 A tracer gas can be used during sample collection to evaluate whether the connections between the vapor pin® and the sample container have any leaks. A tracer gas is very lightly sprayed on a paper towel and the paper towel is briefly laid around the fittings. As an alternative, the tracer gas can be lightly sprayed into the atmosphere near the sample train. Do NOT spray directly on the fittings. **Note**: you will not know if there were any leaks until after the sample has been analyzed. The recommended tracer gas is 1,1-Difluoroethane, which is present in some brands of dust cleaner for electronics.

7.8.3.4 Allow 2 hours for the sub-slab vapor conditions to re-equilibrate prior to sample collection unless site-specific work plan requires a different equilibration time.

Figure 3: Vapor Pin® installed and ready for sampling

7.9 Vapor Pin® Sample Collection

7.9.1 Remove the rubber cap and attach a piece of ¼” tubing (Teflon™ or nylon) to the barbed hose adapter. The tubing must be long enough to span from the sample port to the sample container (e.g., Summa canister) or system (e.g., lung box for Tedlar® bag).

7.9.2 Refer to site-specific work plan for canister size and type of sample required (e.g., 6-liter canister with regulator for either 8-hour or 24-hour sample collection or a 1-liter evacuated canister for a grab sample). After sampling, use a PID to measure the VOC concentrations to provide the laboratory with an indication of how concentrated the VOCs may be in the sample. Provide this information to the laboratory. **Note:** this number is not contaminant specific. Do not assume that your contaminant of concern equates to the reading from the PID.

7.10 Vapor Port Decommissioning

Remove the vapor pin® according to the attached Cox-Colvin Vapor Pin® Standard Operating Procedure for proper vapor pin® installation and removal.

7.10.1 Prior to filling the vapor port hole, measure the slab thickness. One method is to use a “hole hook”, a section of rigid wire (such as a stiff-wire coat hanger) with a small (0.25-inch) 90-degree crimp at one end. Insert the hole hook inside the drilled hole and catch the hooked end on the underside of the concrete slab. Mark the wire where it meets the top of the slab, remove the hole hook, and measure the distance between the hooked end and marked end of the wire to determine the slab thickness. Record the measured slab thickness on the log sheet or in a field note book. This information is necessary if a sub-slab treatment system is ever installed.

7.10.2 Gently pour dry granular bentonite into the hole to fill any void space in the gravel or soil below the underside of the slab that may have been created during the drilling of the slab or installation of the vapor port. Continue adding bentonite until the level is approximately one inch below the top of the slab.

7.10.3 Slowly add a small amount of water to hydrate the bentonite without creating a column of standing water in the hole. Use of a flashlight when adding water helps to visually determine when the bentonite stops absorbing water. If too much water is added, use a syringe or absorbent material (e.g., paper towels) to remove the standing water. While adding water, try to wet the hole side walls to help create good contact with the floor tile grout that will be used to fill and seal the hole as described below.

7.10.4 Mix approximately ¼ cup of floor tile grout with a small amount of water using a disposable spoon. Add water until the consistency of the grout mixture is a little stiffer than drywall or spackling compound.

7.10.5 Use a plastic knife, putty knife, tongue depressor or similar tool to add the tile grout mixture to the hole until it is completely full. Use a concrete trowel or similar tool to remove any excess grout and finish the top of the seal so that it is smooth and even with the surrounding floor.

7.10.6 Clean up the area around the sealed hole and complete any needed field documentation, including photographs if required.

8.0 Data and Records Management

Refer to FSOP 1.3, Field Documentation.

9.0 Quality Assurance and Quality Control

9.1 Clean Vapor Pins® and sampling ports prior to installation by washing in warm water with laboratory-grade detergent, followed by rinsing with hot water and then rinsing with deionized water. Always inspect equipment before use.

9.2 Leak testing should be conducted to document the quality of the sample.

9.3 Photographs of the sampling location and equipment may be required for project documentation.

9.4 Refer to the data quality objectives (DQOs) provided in the work plan.

10.0 Attachments

Cox-Colvin Standard Operating Procedure, Installation and Extraction of the Vapor Pin®

Vapor Sampling Data Sheet, Sub-Slab and Indoor Air (revised May 2018)

11.0 References

FSOP 1.1, Initial Site Entry

FSOP 1.3, Field Documentation

FSOP 3.1.1, Photoionization Detector

Ohio EPA Standard Safety Operating Procedure SP11-19 (Working Alone)

Ohio EPA Standard Safety Operating Procedure SP14-4 (Confined Space Entry)

Standard Operating Procedure
Installation and Extraction of the Vapor Pin™

Updated February 27, 2015

Scope:

This standard operating procedure describes the installation and extraction of the Vapor Pin™ for use in sub-slab soil-gas sampling.

Purpose:

The purpose of this procedure is to assure good quality control in field operations and uniformity between field personnel in the use of the Vapor Pin™ for the collection of sub- slab soil-gas samples or pressure readings.

Equipment Needed:

- Assembled Vapor Pin™ [Vapor Pin™ and silicone sleeve(Figure 1)]; Because of sharp edges, gloves are recommended for sleeve installation;
- Hammer drill;
- 5/8-inch (16mm) diameter hammer bit (Hilti™ TE-YX 5/8" x 22" (400 mm) #00206514 or equivalent);
- 1½-inch (38mm) diameter hammer bit (Hilti™ TE-YX 1½" x 23" #00293032 or equivalent) for flush mount applications;
- ¾-inch (19mm) diameter bottle brush;
- Wet/Dry vacuum with HEPA filter (optional);
- Vapor Pin™ installation/extraction tool;
- Dead blow hammer;
- Vapor Pin™ flush mount cover, if desired;
- Vapor Pin™ drilling guide, if desired;
- Vapor Pin™ protective cap; and
- VOC-free hole patching material (hydraulic cement) and putty knife or trowel for repairing the hole following the extraction of the Vapor Pin™.

Figure 1. Assembled Vapor Pin^{TM}

Installation Procedure:

1) Check for buried obstacles (pipes, electrical lines, etc.) prior to proceeding.

2) Set up wet/dry vacuum to collect drill cuttings.

3) If a flush mount installation is required, drill a 1½-inch (38mm) diameter hole at least 1¾-inches (45mm) into the slab. Use of a Vapor Pin™ drilling guide is recommended.

4) Drill a 5/8-inch (16mm) diameter hole through the slab and approximately 1-inch (25mm) into the underlying soil to form a void.

5) Remove the drill bit, brush the hole with the bottle brush, and remove the loose cuttings with the vacuum.

Vapor Pin^{TM} protected under US Patent # 8,220,347 B2

6) Place the lower end of Vapor Pin™ assembly into the drilled hole. Place the small hole located in the handle of the installation/extraction tool over the Vapor Pin™ to protect the barb fitting, and tap the Vapor Pin™ into place using a dead blow hammer (Figure 2). Make sure the installation/extraction tool is aligned parallel to the Vapor Pin™ to avoid damaging the barb fitting.

Figure 2. Installing the Vapor Pin™.

During installation, the silicone sleeve will form a slight bulge between the slab and the Vapor Pin™ shoulder. Place the protective cap on Vapor Pin™ to prevent vapor loss prior to sampling (Figure 3).

Figure 3. Installed Vapor Pin™

7) For flush mount installations, cover the Vapor Pin™ with a flush mount cover, using either the plastic cover or the optional stainless-steel Secure Cover (Figure 4).

Figure 4. Secure Cover Installed

8) Allow 20 minutes or more (consult applicable guidance for your situation) for the sub-slab soil-gas conditions to re-equilibrate prior to sampling.

9) Remove protective cap and connect sample tubing to the barb fitting of the Vapor Pin™. This connection can be made using a short piece of Tygon™ tubing to join the Vapor Pin™ with the Nylaflow tubing (Figure 5). Put the Nylaflow tubing as close to the Vapor Pin as possible to minimize contact between soil gas and Tygon™ tubing.

Figure 5. Vapor Pin™ sample connection.

10) Conduct leak tests in accordance with applicable guidance. If the method of leak testing is not specified, an alternative can be the use of a water dam and vacuum pump, as described in SOP Leak Testing the Vapor Pin™ via Mechanical Means (Figure 6). For flush-mount installations, distilled water can be poured directly into the 1 1/2 inch (38mm) hole.

Figure 6. Water dam used for leak detection

11) Collect sub-slab soil gas sample or pressure reading. When finished, replace the protective cap and flush mount cover until the next event. If the sampling is complete, extract the Vapor Pin™.

<u>Extraction Procedure:</u>

1) Remove the protective cap, and thread the installation/extraction tool onto the barrel of the Vapor Pin™ (Figure 7). Continue turning the tool clockwise to pull the Vapor Pin™ from the hole into the installation/extraction tool.

2) Fill the void with hydraulic cement and smooth with a trowel or putty knife.

Figure 7. Removing the Vapor Pin™.

3) Prior to reuse, remove the silicone sleeve and protective cap and discard. Decontaminate the Vapor Pin™ in a hot water and Alconox® wash, then heat in an oven to a temperature of 265° F (130° C) for 15 to 30 minutes.

The Vapor Pin™ to designed be used repeatedly, however, replacement parts and supplies will be required periodically. These parts are available on-line at VaporPin.CoxColvin.com.

VAPOR SAMPLING DATA SHEET: SUB-SLAB AND INDOOR AIR

General Information

Site Name / Address: ______________________________

Sampling Location / Address: ______________________________
(if other than site address)

Contact Name:______________________________**Phone:** ______________________________

Laboratory & Analytical Method:__________________ **Method of Delivery:** __________
(Courier, UPS, delivered by sampler, etc.)

Sampling Team Members: ______________________________

Met with resident/business on (date)____________**to provide information on VOC inventory and sampling cross-contamination concerns. If not, explain why:**______________________________

____

Indoor Air Samples

Sample ID #:__________________ **Canister ID #:**__________________**Regulator ID #**__________________

Start: Date:__________________**Time:**__________ **Initial canister vacuum:**________**mm Hg**

End: Date:__________________**Time:**_ **Final canister vacuum:**__________**mm Hg**

Regulator Calibrated for: 8 hr______ **24 hr**______ **grab (no regulator)**______

Canister/ Regulator Leak Checked: Yes______**No**_______

Sub-Slab Samples

Sample ID #:________________ **Canister ID #:**________________**Regulator ID #**______________ **Size of canister:**________________ **Thickness of sub-slab (inches)**_________**Port install time:** ___________

Sampling Start: Date:________________**Time:**___________ **Initial canister vacuum:**________**mm Hg**

Sampling End: Date:________________**Time:**___________ **Final canister vacuum:**_________**mm Hg**

Regulator Calibrated for: 8 hr______ **24 hr**______ **grab (no regulator)** ______

Canister/ Regulator Leak Checked: Yes No **Sub-Slab Port Leak Checked: Yes No**

Type of sub-slab port: Swagelok__________ **Vapor Pin®:** _________

Sub-Slab Port Installed by: _________________________**Sub-Slab Port Sealed: Yes No**

PID Reading: VOC ppb **% 02**_______________**PID ID#:**

NOTES: (sampler/canister problems, other significant sampling details, or FSOP deviations)

Note: If a diagram of the sample location(s) is sketched on the back of this data sheet, check here ☐

Procedures for Collection of Indoor Air FSOP 2.4.3
(March 9, 2017)
Ohio EPA Division of Environmental Response and Revitalization

1.0 Scope and Applicability

Indoor air samples investigate air quality within buildings for possible vapor intrusion of volatile organic compounds (VOCs) and other volatile chemicals. Samples are collected from locations within buildings and structures that are occupied on a regular and on- going basis to evaluate potential exposure to VOCs. Analysis of the air samples are typically performed using U.S. EPA Method TO-15.

2.0 Definitions

"Summa® Canister", a genericized trademark that refers to electropolished, passivated stainless steel vacuum sampling devices (*i.e.*, evacuated canister). Sizes of canisters will vary with the most commonly used sizes being 6L and 1L. Canister size will depend on the predetermined time-frame for sampling (*e.g.*, 24-hour v. "grab" sampling). A "Silco" canister is another name for a Summa canister.

3.0 Health and Safety Considerations

3.1 This activity involves accessing private residences and spaces in commercial buildings. Follow Ohio EPA Standard Safety Operating Procedure Number SP11-19 (Working Alone) to determine if working alone is appropriate given the site conditions and circumstances.

3.2 Never enter an OSHA-defined confined space for any reason. Only Ohio EPA Office of Special Investigation (OSI) staff or other appropriately trained staff are qualified to enter confined spaces for reconnaissance or sampling activities, and will perform such work as necessary in accordance with Ohio EPA Standard Safety Operating Procedure Number SP14-4 (Confined Space Entry).

3.3 Follow the site-specific health and safety plan (HASP), which should identify the potential presence of asbestos-containing materials and other building-specific health and safety concerns. If a site-specific HASP is not available, follow the health and safety procedures in FSOP 1.1, Initial Site Entry.

3.4 Be aware of potential vermin (fleas, rats, etc.)

3.5 Review available plans or documents before selecting sampling locations.

4.0 Procedure Cautions

4.1 Review the site-specific work plan (SSWP), which should include a description of the building's size and use. In certain emergency circumstances a SSWP may not be available, and all necessary information for indoor air sampling will need to be obtained during the pre-sampling visit as described below.

4.2 A pre-sampling site visit should be conducted to meet with the building's owner and/or tenant and inspect the proposed indoor air sampling locations. During the pre-sampling visit, address arrangements for sampling location access and associated logistical concerns. Also, determine if the sampling areas are occupied or unoccupied spaces. Obtain property access agreements prior to sampling.

4.3 Sampling personnel should not handle hazardous substances (such as gasoline), permanent marking pens, wear/apply fragrances, or smoke before and/or during the sampling event.

4.4 Care should be taken to ensure that the flow regulator is pre-calibrated to the appropriate sample collection time (8 hours, 24 hours, etc.). Eight (8) hour sample collection is utilized for commercial/industrial settings. Twenty-four (24) hour sample collection is used for residential and/or sensitive receptor settings (*e.g.*, day care facilities).

4.5 The flow regulator must be correctly connected to the sample canister to eliminate the potential for leaks.

4.6 The regulator should be closed shortly before the actual sampling time is completed so that a small amount of vacuum remains. If it isn't closed and no vacuum remains in the canister, extracting a sample for analysis may be very difficult. In addition, sample integrity may be compromised if the canister reaches atmospheric pressure.

4.7 An interview of the building occupants should be conducted before sampling to determine if there are any potential chemicals present that could cause false positives during sample collection. For example, paints, woodworking products, household solvents and various chemicals used in hobbies may all contain VOCs that could be detected. If possible, the building occupants should remove such products several days before sampling takes place. A copy of Instructions for Building Occupants Prior to Indoor Air Sampling Form (attached) should be provided to the resident during the interview.

4.8 If sub-slab samples are to be collected from the same building that indoor air samples are being collected, it is preferable to complete the indoor air sampling prior to installing a sub-slab vapor port (FSOP 2.4.2, Construction, Installation and Decommissioning of Sub-Slab Vapor Ports). However, if site-specific reasons (*e.g.*, access or emergency conditions, etc.) dictate the need to collect both samples at the same time, care needs to be taken to install the sub-slab vapor port before beginning the indoor air sampling. In addition, the indoor air sample should be taken as far as possible from the location where the sub-slab vapor point is installed.

4.9 Indoor air samples should only be collected from the first floor/ground-level floor of the structure.

5.0 Personnel Qualifications

Ohio EPA personnel working at sites that fall under the scope of OSHA's hazardous waste operations and emergency response standard (29 CFR 1910.120) must meet the training requirements described in that standard. Prior knowledge, training and experience with this sampling technique is strongly recommended before collecting samples.

6.0 Equipment and Supplies

6.1 Stainless steel canister(s) (request at least one additional canister as a backup). A 6L canister will be required for this sampling activity. A 1L "grab sample" canister will not provide enough volume to sample for a timed (8 hr. or 24 hr.) sample period, refer to Section 2.0 (Definitions).

6.2 Flow regulator(s) properly calibrated for the specific sample collection duration – 8 hr. or 24 hr. (request at least one extra regulator as a back-up)

6.3 In-line filters, if needed (*e.g.*, for SVOC volatile compounds)

6.4 Open-end wrenches, typically 9/16" (two wrenches are recommended to tighten the fitting in two directions at the same time)

6.5 PID (refer to FSOP 3.1.1, Photoionization Detector)

6.6 Indoor Air Building Survey and Sampling Form (attached)

6.7 Instructions for Building Occupants Prior to Indoor Air Sampling Form (attached)

6.8 Vapor Sampling Data Sheet (attached)

6.9 Field documentation supplies and equipment, including pens, markers, field log book and additional data sheets, chain-of-custody forms, camera

7.0 Procedures

7.1 Sample Location Determination

7.1.1 Conduct a building/structure survey using the Indoor Air Building Survey and Sampling Form to determine potential target receptors and identify potential interferences to sample collection. PID screening may also help to identify VOC sampling interferences. In addition, provide the Instructions for Building Occupants Prior to Indoor Air Sampling Form to the building residents or worker for completion at this time. Potential sampling interferences need to be recognized and eliminated before sample collection begins. This should be completed at least 48 to 72 hours prior to sample collection.

7.1.2 Select indoor air sampling locations that are in inhabited or frequently used.

7.1.3 Do not place sample canisters in locations near primary-use doors or open windows.

7.1.4 Do not place sample canisters in the pathway of indoor fans.

7.1.5 If ceiling fans are in use, request that they be turned off for the duration of the sample period.

7.1.6 Note any obvious odors from scented candles, mothballs, cleaning products, gas or oils.

7.1.7 If the building has a dirt basement or crawl space, evaluate whether or not an indoor air canister should be placed in this area.

7.2 Sample Set-up

7.2.1 Place the sampling canisters at breathing-zone height.

7.2.2 Remove the brass plug from the canister and connect the flow regulator (with in-line particulate filter and vacuum gauge, if needed) to the canister.

7.2.3 Gently tighten the connection between the flow regulator and the canister using the open-end 9/16” wrenches. Do not over-tighten this connection. Before continuing, record the canister number and the associated flow regulator number on the “Vapor Sampling Data Sheet”. The canister number can be used for sample identification on the COC form.

7.2.4 Open the canister/regulator valve. Record the sample start time and the canister pressure.

7.2.5 Photograph the canister and the surrounding area.

Example of a canister with a regulator attached and placed in the breathing zone.

7.3 Termination of Sample Collection

7.3.1 Return to the sample collection site a minimum of 15 minutes before the end of the sample collection interval. Examine the flow regulator to ensure that some vacuum is left on the gauge (preferably 2” to 10” of mercury on the regulator flow dial).

7.3.2 Record the vacuum pressure and stop sample collection by closing the flow regulator.

7.3.3 Remove the flow regulator from the canister using the 9/16” open-end wrenches. Re-install the brass plug on the canister fitting, and tighten it with an open-ended wrench.

7.3.4 Package the canister and the flow regulator into the shipping container provided by the lab. **Note**: the canister does not require preservation.

7.3.5 Complete the appropriate forms and sample labels as directed by the laboratory. Use the sample start time when completing the laboratory chain of custody and double check canister identification numbers for accuracy.

7.3.6 Ship the canisters to the laboratory for analysis.

8.0 Data and Records Management

Refer to FSOP 1.3, Field Documentation.

9.0 Quality Assurance and Quality Control

Usually, an ambient air sample is collected outside of the building where the indoor air is being sampled. The ambient air sample is collected at the same time as the indoor air sample and provides quality assurance/quality control (QA/QC) to help evaluate outdoor air quality. In addition, the work plan may specify co-located indoor air samples. Typically, the co-located QA/QC samples are collected at a frequency of 10 percent of the total samples collected.

10.0 Attachments

Indoor Air Building Survey and Sampling Form

Instructions for Building Occupants Prior to Indoor Air Sampling Vapor

Sampling Data Sheet

11.0 References

FSOP 1.1, Initial Site Entry

FSOP 1.3, Field Documentation

FSOP 2.4.2, Construction, Installation and Decommissioning of Sub-Slab Vapor Ports

FSOP 3.1.1, Photoionization Detector

Ohio EPA Standard Safety Operating Procedure SP11-19 (Working Alone)

Ohio EPA Standard Safety Operating Procedure SP14-4 (Confined Space Entry)

Ohio Environmental
Protection Agency

INDOOR AIR BUILDING SURVEY and SAMPLING FORM

Preparer's name: ______________________________________ Date:____________________________

Preparer's affiliation: __________________________________ Phone #: ________________________

Site Name: ____ Case #: _________________________

Part I - Occupants

Building Address: ____

Property Contact:__________________________Owner / Renter / other: _________________________

Contact's Phone: home ( )___________ work ( )_______________ cell ( )_____________

# of Building occupants: Children under age 13 ______ Children age 13-18 _______ Adults ______

Part II – Building Characteristics

Building type: residential / multi-family residential / office / strip mall / commercial / industrial

Describe building:____ Year constructed: __________

Sensitive population: day care / nursing home / hospital / school / other (specify): ________________

Number of floors below grade:_______(full basement / crawl space / slab on grade)

Number of floors at or above grade: _______

Depth of basement below grade surface:________ft. Basement size:________ft^2

Basement floor construction: concrete / dirt / floating / stone / other (specify): _____________________

Foundation walls: poured concrete / cinder blocks / stone / other (specify) _________________

Basement sump present? *Yes / No* Sump pump? *Yes / No* Water in sump? *Yes / No*

Type of heating system (circle all that apply):

hot air circulation
heat pump
hot air radiation
hot water radiation
wood
kerosene heater
steam radiation
electric baseboard
other (specify): __________________________

Type of ventilation system (circle all that apply):

central air conditioning mechanical fans bathroom ventilation fans individual air
conditioning units kitchen range hood fan outside air intake
other (specify): ___________________

Type of fuel utilized (circle all that apply):
Natural gas / electric / fuel oil / wood / coal / solar / kerosene

Are the basement walls or floor sealed with waterproof paint or epoxy coatings? *Yes / No*

Is there a whole house fan? *Yes / No*

Septic system? *Yes / Yes (but not used) / No*

Irrigation/private well? *Yes / Yes (but not used) / No*

Type of ground cover outside of building: grass / concrete / asphalt / other (specify) __________________

Existing subsurface depressurization (radon) system in place? *Yes / No* *active / passive*

Sub-slab vapor/moisture barrier in place? *Yes / No*
Type of barrier: ______________________________

Part III - Outside Contaminant Sources

Potential contaminated site (1000-ft. radius): ____

Other stationary sources nearby (gas stations, emission stacks, etc.): ______________________________

Heavy vehicular traffic nearby (or other mobile sources): ____

Part IV – Indoor Contaminant Sources

Identify all potential indoor sources found in the building (including attached garages), the location of the source (floor and room), and whether the item was removed from the building 48 hours prior to indoor air sampling event. 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.

Potential Sources	**Location(s)**	**Removed** **(Yes / No / NA)**
Gasoline storage cans		
Gas-powered equipment		
Kerosene storage cans		
Paints / thinners / strippers		
Cleaning solvents		
Oven cleaners		
Carpet / upholstery cleaners		
Other house cleaning products		
Moth balls		
Polishes / waxes		
Insecticides		
Furniture / floor polish		
Nail polish / polish remover		
Hairspray		
Cologne / perfume		
Air fresheners		
Fuel tank (inside building)		NA

Wood stove or fireplace		NA
New furniture / upholstery		
New carpeting / flooring		NA
Hobbies - glues, paints, etc.		

Part V – Miscellaneous Items

Do any occupants of the building smoke? *Yes / No* How often? _______________

Last time someone smoked in the building? _____________hours */ days ago*

Does the building have an attached garage directly connected to living space? *Yes / No*

If so, is a car usually parked in the garage? *Yes / No*

Are gas-powered equipment or cans of gasoline/fuels stored in the garage? *Yes / No*

Do the occupants of the building have their clothes dry cleaned? *Yes / No*

If yes, how often? weekly / monthly / 3-4 times a year

Do any of the occupants use solvents in work? *Yes / No*

If yes, what types of solvents are used? ____

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

Have any pesticides/herbicides been applied around the building or in the yard? *Yes* / No

If so, when and which chemicals? ____

Has there ever been a fire in the building? *Yes / No* If yes, when? ______________

Has painting or staining been done in the building in the last 6 months? *Yes / No*

If yes, when___________________ and where? _____________________________

Has there been any remodeling done (flooring/carpeting) in the building in the last 6 months? *Yes / No*

If yes, when ___________________ and where? _____________________________

Part VI – Sampling Information

Sample Technician:______________________________Phone number: ( )________- ___________

Sample Source: Indoor Air / Sub-Slab / Soil Gas

Sampler Type: Tedlar bag / Sorbent / Stainless Steel Canister / Other (specify): __________________

Analytical Method: TO-15 / TO-17 / other:___________ Cert. Laboratory: __________________

Sample locations (floor, room):

Field ID #______- __________________________ Field ID #______- ____________________________

Field ID #______-__________________________ Field ID #______- ___________________________

Were "Instructions for Occupants" followed? Y*es / No*

If not, describe modifications: ____

Additional Comments:

Provide Drawing of Sample Location(s) in Building

Part VII - Meteorological Conditions

Was there significant precipitation within 12 hours prior to (or during) the sampling event? *Yes / No*

Describe the general weather conditions: ____

____

Part VIII – General Observations

Provide any information that may be pertinent to the sampling event and may assist in the data interpretation process.

(NJDEP 1997; NHDES 1998; VDOH 1993; MassDEP 2002; NYSDOH 2005; CalEPA 2005; Ohio EPA 2015)

Instructions for Building Occupants Prior to Indoor Air Sampling

Representatives from the Ohio EPA – Division of Environmental Response and Revitalization (DERR) - will be collecting one or more indoor air samples from your building on_____- beginning @______and ending @______. Your assistance is requested during the sampling program in order to collect an indoor air sample that is both representative of indoor conditions and avoids the common background indoor air sources associated with occupant activities and consumer products.

<u>Please follow the instructions below starting at least 48 hours (2 days) prior to and during the indoor air sampling event:</u>

- ☐ Do operate your furnace and whole house air conditioner as appropriate for the current weather conditions
- ☐ Do not use wood stoves, fireplaces or auxiliary heating equipment
- ☐ Do not use window air conditioners, fans vents
- ☐ Do not use paints or varnishes (up to a week advance, if possible)
- ☐ Do not use cleaning products (*e.g.*, bathroom cleaners, furniture polish, appliance cleaners, all-purpose cleaners, floor cleaners)
- ☐ Do not use hair spray, nail polish remover, perfume, etc.
- ☐ Do not store containers of gasoline, oil or solvents within an attached garage.
- ☐ Do not operate or store automobiles within an attached garage
- ☐ Do not open windows or keep doors open
- ☐ Do not smoke in the building
- ☐ Do not apply pesticides
- ☐ Do not use air fresheners or odor or eliminators
- ☐ Do not engage in indoor hobbies that in use solvents (*e.g.* gun cleaning)
- ☐ Do not operate gasoline powered equipment within the building, attached garage or around the immediate perimeter of the building
- ☐ Do not bring freshly dry cleaned clothes into the building

You will be asked a series of questions about the structure, consumer products you store in your building, and occupant activities typically occurring in the building. These questions are designed to identify “background” sources of indoor air contamination. While this investigation is looking for a select number of chemicals related to the known or suspected subsurface contamination, the laboratory will be analyzing the indoor air samples for a wide variety of chemicals. As a result, chemicals such as tetrachloroethene that is commonly used in dry cleaning or acetone, which is found in nail polish remover might be detected in your sample results.

<u>Your cooperation is greatly appreciated</u>. If you have any questions about these instructions, please feel free to

contact_______________at___________________.

SUB-SLAB VAPOR SAMPLING AND INDOOR AIR DATA SHEET

General Information

Site Name / Address: ____________________

Sampling Location / Address: ____________________
(if other than site address)

Contact Name:____________________ **Phone:**____________________

Laboratory & Analytical Method:____________________ **Method of Delivery:** __________
(Courier, UPS, delivered by sampler, etc.)

Sampling Team Members: ____________________

Met with resident/business on (date)__________**to provide information on VOC inventory and sampling cross-contamination concerns. If not, explain why:**_

____

Indoor Air Samples

Sample ID #:____________________ **Canister ID #:**__________________**Regulator ID #**__________________

Start: Date:__________________**Time:**__________ **Initial canister vacuum:**________**mm Hg**

End: Date:__________________**Time:**_ **Final canister vacuum:**__________**mm Hg**

Regulator Calibrated for: 8 hr______ **24 hr**______ **grab (no regulator)**______

Canister/ Regulator Leak Checked: Yes_______**No**_______

Sub-Slab Samples

Sample ID #:__________________ **Canister ID #:**________________**Regulator ID #**______________ **Size of canister:**________ **Thickness of sub-slab (inches)**_________**Port install time:** ___________

Sampling Start: Date:_________________**Time:**___________ **Initial canister vacuum:**________**mm Hg**

Sampling End: Date:________________**Time:**___________ **Final canister vacuum:**_________**mm Hg**

Regulator Calibrated for: 8 hr_______ **24 hr**______ **grab (no regulator)** ______

Canister/ Regulator Leak Checked: Yes No **Sub-Slab Port Leak Checked: Yes No**

Type of sub-slab port: Swagelok___________ **Vapor Pin®:** _________

Sub-Slab Port Installed by:__________________________**Sub-Slab Port Sealed: Yes No**

PID Reading: VOC ppb___________**% 02**______________**PID ID#:** ____________________

NOTES: (sampler/canister problems, other significant sampling details, or FSOP deviations)

Note: If a diagram of the sample location(s) is sketched on the back of this data sheet, check here ☐

APPENDIX D. Soil Gas Probe Field Data Report Form

Ohio Environmental Protection Agency
Division of Emergency and Remedial Response
Soil Gas Probe Field Data Report Form

Soil Gas Probe Field Data Report								
Site:								
Date:								
Instrument(s) used:								
Tracer used:								
Weather:								
Technician:								
Soil Gas Probe Number	Probe Depth (ft.)	Probe Volume (l)	Purge Rate (lpm)	Volume Purged (l)	Tracer Field Analysis (ppmv or ppbv)	%CO$_2$	%O$_2$	Other indicators

ND=Non-Detect
NM=Not Measured

APPENDIX E. Indoor Air/Sub-Slab Sampling Form

Ohio Environmental Protection Agency
Division of Emergency and Remedial Response
Indoor Air/Sub-slab Sampling Form

OHIO EPA DERR Site #____

Site Name____

Address____

____

Occupant Information

Name____

Address____

____

Telephone No:

(H) (_____)____

(W) (_____)____

Number and Age(s) of Occupant(s)

____

____

Does anyone smoke inside the building?

Building Characteristics

Type of building (circle):

Residential / Industrial / School / Commercial / Multi-use / Other?

If residential, what type (circle):

Single family / Condo / Multi-family / Other?

If commercial, what is the business?

How many floors does the building have?

Does the building have a (circle):

Basement / Crawl space / Slab-on-grade / Other?

Is the basement used as a living / workspace area?

What type of foundation does the building have (circle):

Field stone / Poured concrete / Concrete block / Other?_____________

Describe the heating system and type of fuel used.

Is there an attached garage?

Spill / Contaminant Source Information

Type of petroleum / VOC release?

When did the release occur?

What areas of the building have been impacted by the release?

Are there any odors? ___________ If so, describe the odors:

Where are the release odors found?

Sampling Information

Sampling Date

Sampler Type (circle):

Sorbent Canister Tedlar® Other__________

Analysis Method ____________________

Consulting Firm ____

Contact Person Name____

Contact Person Telephone No (____)__________________________________

Laboratory Name ____

Laboratory Telephone No (____)_____________________________________

Table 1: Sorbent Tube Sample Information

Sample ID#	Floor	Room	Tube ID #	Pump ID #	Volume (liters)	Duration (minutes)	Comments

Table 2: Canister Sample Information

Sample ID #	Floor	Room	Canister ID #	Initial On-site Pressure*	Pressure* On-site Following Sample Collection	Pressure Received at the Laboratory

* Indicate pressure in units of inches of mercury.

Please provide a sketch of area and location of sampler unit(s), include all pertinent structures.

Pre-Sampling Inspection and Product Inventory

List products or items which may be considered potential sources of VOCs such as paint cans, gasoline cans, gasoline powered equipment, cleaning solvents, furniture polish, moth balls, fuel tank, woodstove, fireplace, etc.

Date and time of pre-sampling inspection

Table 3: Pre-sampling Inspection Product Inventory

Potential VOC Source	Present (Y / N)	Location	Field screening Results (ppm)	Product Condition
Paints or paint thinners				
Gas powered equipment				
Gasoline storage cans				
Furniture polish				
Moth balls				
Fuel tank				
Wood stove				
Fireplace				
Perfumes/colognes				
Other:				
Other:				
Other:				

Table 4: Potential vapor migration entry point information

Potential Vapor entry points	Present (Yes/No)	Field screening results (ppm)	Comments
Foundation penetrations in floor or walls			
Cracks in foundation floor or walls			
Sump			
Floor drain			
Other			
Other			

Was the building aired out prior to sample collection?

How long was the airing out process?

Were vapor control methods in effect while the samples were being collected?

Windows open? Yes / No Ventilation fans? Yes / No
Vapor barriers? Yes / No
Vapor phase carbon treatment system? Yes / No
Other site control measures________________________________

Weather Conditions during Sampling

Outside temperature (°F) __________ Inside temperature (°F)_____________

Prevailing wind speed and direction

Describe the general weather conditions (*e.g.*, sunny, cloudy, rainy)

Significant precipitation (0.1 inches or more) within 12 hours of the sampling event?

General Comments

Is there any information you feel is important related to this site and the samples collected which would facilitate an accurate interpretation of the indoor air quality?

APPENDIX F. Soil Gas and Sub-Slab Vapor Analytical Methods and Reporting Limit Ranges

A list of several analytical methods and reporting limit ranges for soil gas and sub-slab vapor samples.

NOTE: The laboratory should be consulted prior to choosing the analytical method. The laboratory can advise sampler on holding times and any method specific requirements.

Method No.	Examples of Collection Device and Methodology#	Type of Compounds	Reporting Limit Range**
TO-1	Tenax solid sorbent GC/MS or GC/FID	VOC	0.02 – 200 µg/m^3 (0.01-100 ppbv)
TO-2	Molecular sieve sorbent GC/MS	VOC	0.2 – 400 µg/m^3 (0.1-200 ppbv)
TO-3	Tedlar® bag or canister GC/FID	BTEX, MTBE, TPH	1-3 µg/m^3
TO-4A*	Filter media$ GC/ECD	Pesticides PCBs	Pesticides (0.5 - 1 µg/sample) PCBs (1 – 2 µg/sample)
TO9A	Filters designed for PCB collection High resolution GC/MS	Mono/Di-PCBs	Contact lab
TO-10A*	Filter media$ GC/ECD	Pesticides PCBs	Pesticides (0.5 - 1 µg/sample) PCBs (1 – 2 µg/sample)
TO-13A*	Polyurethane foam (PUF)$ GC/MS	SVOCs	5-10 µg/ sample
TO-13A SIM*	PUF or XAD-2 resin media$ GC/MS	Low Level SVOCs	0.5-1 µg/sample
TO-14A	Canister / Tedlar® bag GC/ECD/FID or GC/MS	Non-polar VOCs	1-3 µg/m^3
TO14A	Silica lined canisters/Tedlar® bag/sorbent media	H_2S	Contact lab

A list of several analytical methods and reporting limit ranges for soil gas and sub-slab vapor samples.

NOTE: The laboratory should be consulted prior to choosing the analytical method. The laboratory can advise sampler on holding times and any method specific requirements.

Method No.	Examples of Collection Device and Methodology[#]	Type of Compounds	Reporting Limit Range**
TO-15	Canister / Tedlar® Bags GC/MS	VOC (polar/nonpolar)	0.4 – 20 µg/m^3 (0.2-2.5 ppbv)
TO-15	Silica lined canisters/Tedlar® bag/sorbent media	H_2S	Contact lab
TO-15	Canister / Tedlar® bag GC/FID	TPH – Alkanes (C4-C12)	0.1 ppmv
TO-15 SIM	Canister / Tedlar® bag GC/MS	Low level VOCs	0.011-0.5 µg/m^3
TO-17*	Sorbent tube (chilled) GC/MS	VOCs	1-3 µg/m^3
8021B modified	Syringe / Tedlar® bag / Canister/ glass vial GC/PID	VOC	1 – 60 µg/m^3
8260D modified	Syringe / Tedlar® bag / Canister / glass vial GC/MS	VOC	50 – 100 µg/m^3
8270E	Tedlar® bag / Canister GC/MS	SVOC	1000 µg/m^3 (20,000 ppbv to 100,000 ppbv)
8015 modified	Tedlar bag / canister GC/FID	TPH – alkanes (C4-C24)	10 ppmv
Air Toxics IO-5	Gold trap Dual amalgamation cold vapor atomic fluorescence spectrometry (CVAFS)	Hg	Contact lab
NIOSH 6009	Hopcalite cold vapor / Atomic Absorption (CV/AA)	Hg	Contact lab
9056	Silica lined canisters / Tedlar® Bag / sorbent media	H_2S	Contact lab

A list of several analytical methods and reporting limit ranges for soil gas and sub-slab vapor samples.

NOTE: The laboratory should be consulted prior to choosing the analytical method. The laboratory can advise sampler on holding times and any method specific requirements.

Method No.	Examples of Collection Device and Methodology[#]	Type of Compounds	Reporting Limit Range**
1668A	Filters designed for PCB collection High resolution GC/MS	Mono/Di-PCBs	Contact lab
U.S. EPA 3C	Tedlar® bag / Canister GC / FID	Methane nitrogen, oxygen, carbon dioxide, carbon monoxide	10 ppmv 0.1% (1,000 ppmv)
ASTM D-1946	Tedlar ® bag/ canister GC / TCD / FID	Methane, nitrogen, oxygen carbon dioxide, carbon monoxide	1000 – 2000 µg/m^3
ASTM D-1945	Tedlar ® bag / canister GC / FID	Natural gases	1000-2000 µg/m^3

NOTE: the laboratory should be consulted prior to choosing the analytical method. The laboratory can advise sampler on holding times and any method specific requirements.

* The indicated methods use a sorbent-based sampling technique. The detection limits will depend on the amount of air passed through the media.

** Reporting limits are compound specific and can depend upon the sample collection and the nature of the sample. Detection limits shown are for the range of compounds. Consult laboratory for specific information.

[#] ECD – electron capture detector; FID – flame ionization detector; GS – gas chromatography; MS – mass spectrometry; PID – Photoionization detector; TCD – thermal conductivity detector

[$] High volume collection (may require large sample volume; *e.g.*, 300 m^3)/ chilled 4^{o}C

APPENDIX G. Comparison of Tubing Type to Vapor Absorption

Researcher Tubing	Ouellette (2004)	Hayes, et. al. (2006)	Nicholson, et. al. (2007)	Hartman (2008)
LDPE	Sorption of hexane and pentane	Sorption of numerous compounds	N/A*	Sorption of TCE and PCE
Tygon	Sorption of hexane, butane, and pentane	N/A	N/A	Acceptable for TCE
Nylaflow	Acceptable	Sorption of naphthalene and 1,2,4-TCB	Sorption of aromatic hydrocarbons	Acceptable for TCE
Teflon	Acceptable	Acceptable	N/A	Acceptable for TCE
Vinyl	Sorption of hexane and pentane	N/A	N/A	N/A
PEEK	N/A	Acceptable	N/A	Acceptable for TCE
Copper	N/A	N/A	N/A	Sorption of TCE and PCE

*N/A – not analyzed