

Montana Vapor Intrusion Guide

**Montana Department of
Environmental Quality**

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Executive Summary

The Montana Department of Environmental Quality (DEQ) prepared this guidance to assist responsible/liable parties, environmental professionals, and DEQ technical contacts in evaluating actual and potential vapor intrusion (VI) at contaminated sites. VI is the migration of volatile chemicals from the subsurface into structures or buildings. This guidance addresses VI in residential and non-residential settings potentially impacted with volatile and semi-volatile compounds (including solvents and petroleum hydrocarbons) and other volatile contaminants in the State of Montana. Recognizing that the field of VI continues to advance, DEQ will update this guidance periodically to incorporate State-specific information and technological advancements in the science of VI.

Acute health effects and fire hazards from high concentrations of vapors are beyond the scope of this guidance. **Situations involving fire, explosion, or serious acute health affects should be referred to local fire or emergency response teams.**

Montana's approach identifies and evaluates exposure pathways by developing and continuing to refine conceptual site models with site-specific information. This iterative process continues until site-specific information either eliminates a completed pathway or confirms it. When VI investigations indicate that volatile compounds are entering structures or may affect future structures and pose an unacceptable health risk, actions are taken to mitigate the risk of exposures.

Petroleum Vapor Intrusion (PVI) differs from vapor intrusion associated with chlorinated compounds due to the ability of petroleum hydrocarbons to naturally biodegrade in the vadose zone through the actions of microorganisms found naturally in soil. At sites with sufficient oxygen supply from the atmosphere, biodegradation of petroleum hydrocarbons can occur relatively quickly and will generally produce less harmful compounds (i.e., biodegradation products), resulting in attenuation of petroleum hydrocarbon vapors over relatively short distances in the vadose zone. Numerous site-specific factors can influence the biodegradation rate of petroleum hydrocarbons; therefore, a 3-step screening process has been adopted for sites contaminated with **only** petroleum hydrocarbons to evaluate the PVI pathway. The screening approach is based on peer-reviewed, empirical studies by Lahvis et al. (2013a) and USEPA (2013a).

Analytical data from other states and national studies may not be appropriate for application in Montana. Background VOC concentration data from indoor air and ambient outdoor air studies at locations outside of Montana may include higher concentrations than those found in Montana. Also, the seasonal hard ground freeze conditions (common to northern states, such as Montana) may affect VI differently compared with areas subject to warmer winter temperatures. Moreover, Montana's unique set of exposure scenarios may necessitate adaptability of, preclusion of, or render certain screening procedures either unnecessary or impractical. As such, in order to provide a better regional understanding of VI risk and exposure, in August 2012, DEQ published the results of a Montana-specific background indoor air investigation (DEQ 2012), which is discussed later in this document.

Evaluation of releases of volatile contaminants in soil and groundwater is needed to determine what risk they pose to existing structures or future construction. The first step in developing a VI conceptual site model is the evaluation of VOC concentrations in the groundwater and soil, potential current and future exposure pathways, soil type, and distance of the contamination (both lateral and vertical) to existing or future structures and preferential pathways. Buried utility lines and other pathways of preferential VOC migration may also pose a risk to structures and should always be evaluated. When the release and site characteristics indicate VI is a probable risk, further investigation, including the collection and analysis of air/vapor samples, is necessary to evaluate the risk to human health. Several different types of environmental samples may be collected including: soil vapor samples, near-slab and sub-slab vapor samples, samples of the air found in crawlspaces, indoor air samples, and outdoor air (sometimes referred to as "ambient air") samples. Because some VOCs are present in common consumer products, evaluation of VOC sources inside structures should be identified as part of a VI investigation. Thorough preplanning is necessary to ensure sufficient information is collected to evaluate VI in the most efficient manner.

This guidance document is organized into the following sections:

Section 1: Introduction: This section explains VI and the purpose of the guidance.

Section 2: Preliminary Screening Phase: This section discusses the development of a conceptual site model to determine whether further VI investigation is necessary.

Section 3: Sampling and Analysis Plan Development: This section guides the development of a plan to conduct a VI investigation when the preliminary screening indicates a VI risk may exist.

Section 4: Sampling Protocols: This is the "how to" portion of the document that discusses sampling methods and procedures for collecting VI samples.

Section 5: Laboratory Analysis of Vapor Samples: This section explains the different analytical methods for analyzing VI samples.

Section 6: Screening Levels: This section discusses screening levels used to determine when VI risks may warrant further investigation.

Section 7: Data Evaluation: This section discusses use of VI data to evaluate risks to human health to determine whether mitigation is needed.

Section 8: Mitigation and Property Development: This section discusses methods to mitigate VI risks.

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Definitions and Acronyms

1,2-DCA – 1,2-Dichloroethane.

Aerobic Soils – Soils that contain sufficient oxygen concentrations to support aerobic respiration.

AF – Attenuation Factor – The ratio of the indoor air concentration arising from vapor intrusion to the subsurface vapor concentration at the source or a depth of interest in the vapor intrusion pathway.

Ambient Outdoor Air Sample – Air that is representative of site-specific outside conditions.

Anaerobic Soils – Soils that contain insufficient oxygen concentrations to support aerobic respiration.

APH – Air-Phase Petroleum Hydrocarbons – Analytical method developed by the Massachusetts Department of Environmental Protection for the determination of the presence of individuals of a group of petroleum hydrocarbons that includes the non-target petroleum fractions typically found in gasoline and other lighter petroleum products. The method can also quantify target analytes from gasoline and other lighter petroleum products. Also known as volatile petroleum hydrocarbons (VPH).

ARM – Administrative Rules of Montana.

Background – Contaminant concentrations (or contaminants of concern) that can be attributed to natural or man-made sources but are not associated with contaminant sources at the site.

Barometric Pumping - Variation in the ambient outdoor atmospheric pressure that results in subsurface motion of air in porous and fractured earth materials.

bgs – Below ground surface.

Biodegrade/Biodegradation – The breakdown of organic contaminants by microbial organisms into smaller compounds.

CAP – Corrective Action Plan – Work plans developed to investigate or cleanup a contaminated site.

Carcinogen – A compound that the EPA has determined causes cancer based on the weight of peer-reviewed scientific evidence. Some carcinogens may also have non-carcinogenic effects.

CCV – Continuing calibration verification – A mid-range calibration standard used to check a laboratory instrument's initial calibration on a daily basis.

Chimney effect – The tendency of gas (vapor) to rise into a building due to negative pressure gradients that commonly result from existing heating, ventilation, and air conditioning systems. In Montana, the chimney effect is likely to be most prevalent in the winter when ground is frozen, buildings are being actively heated, and windows/doors are closed.

Chlorinated Solvent – An organic compound containing at least one covalently bonded chlorine atom, such as trichloroethylene, dichloroethylene, and vinyl chloride.

Circular DEQ-7 – The Montana Numerical Water Quality Standards, applicable to state surface water and groundwater, adopted by rule and published by DEQ in Circular DEQ-7.

COC/COCs – Contaminant of concern/contaminants of concern – Specific compounds that are identified in a contaminant source that have the potential to impact indoor air via the vapor intrusion pathway.

Commercial/Industrial Structure – Property used as a place of business with employees present regularly on a typical five days on, two days off schedule with no one living on the property.

Contaminant Source – With respect to vapor intrusion, soil, soil vapor, groundwater contaminated with volatile chemicals, NAPL, or other sources of volatile chemicals that can generate vapors beneath the ground surface or within structures.

COPC/COPCs – Contaminant of Potential Concern/Contaminants of Potential Concern – Compounds that are initially identified for evaluation for potential vapor intrusion.

Crawlspace – A low or narrow space where people do not live or work, beneath the lower story of a structure.

CSM – Conceptual Site Model – A simplified version of the site or physical settings and known or suspected contaminant sources, contaminant migration pathways, potential human receptors and the exposure routes by which these receptors may come in contact with contaminants on a site-specific basis.

DEQ – Montana Department of Environmental Quality.

DEQ-7 – See Circular DEQ-7 (above).

DFA – Difluoroethane.

DQOs – Data quality objectives – Qualitative and/or quantitative metrics that define the investigation goals and should be met to allow the results of an investigation to support decision making.

EDB – Ethylene dibromide.

EDD – Electronic Data Deliverable – An electronic data file provided in a format that is easily downloaded into a data management system.

EPA – United States Environmental Protection Agency.

EPH – Extractable Petroleum Hydrocarbons – A group of petroleum hydrocarbons that includes the petroleum fractions typically found in diesel and other heavier petroleum products. EPH is comprised of C₉ through C₁₈ aliphatic hydrocarbons, C₁₉ through C₃₆ aliphatic hydrocarbons, and C₁₁ through C₂₂ aromatic hydrocarbons. EPH is also the analytical method developed by the Massachusetts Department of Environmental Protection to determine the fractional composition of these non-target compounds.

Equilibration Testing – Collecting vapor samples for laboratory analysis periodically to evaluate if equilibrium has been achieved.

Exposure – The contact of a receptor with a contaminant of concern.

Exposure Pathway – The route a chemical or physical agent takes from a contaminant source to an exposed receptor. An exposure pathway describes a unique mechanism by which an individual or population is exposed to contaminants of concern at or originating from a release. Each exposure pathway includes a contaminant source, an exposure point, and an exposure route. If the exposure point differs from the contaminant source location, a transport/exposure medium (e.g., air) or media (in cases of transfer between media) will also be included.

Examples of complete exposure pathways may include, but are not limited to:

- ♦ inhalation of vapors from impacted soils by a person on site;
- ♦ inhalation of vapors by a person resulting from the off-site migration of NAPL; and
- ♦ inhalation of vapors from impacted groundwater migrating through soil to the surface or into a structure.

GC – Gas chromatography – An analytical laboratory technique that uses a separation column to detect the presence and quantity of a compound in a sample.

GC/MS – Gas chromatography/mass spectrometry – An analytical laboratory technique the uses a separation column followed by precise measurement of mass to identify compounds and their quantities.

Hazard Index – The sum of more than one hazard quotient for multiple substances and/or multiple exposure pathways that affect the same target organ.

Hazard Quotient – The ratio of a single substance exposure level over a specified time period to a reference dose for that substance derived from a similar exposure period.

HVAC – Heating, ventilating, and air conditioning.

Inches Hg – Inches of mercury.

LCS – Laboratory Control Sample – A laboratory-prepared quality control sample that consists of a laboratory method blank injected with contaminants of concern to be analyzed in associated field samples.

Lead Scavengers – Compounds such as 1,2-DCA and EDB that were added to leaded gasoline to help volatilize or scavenge tetraethyl lead so it would not accumulate in an engine.

LMB – Laboratory Method Blank – A laboratory-prepared quality control sample that consists of a clean sample container identical to those that are used to collect associated field samples filled with a clean sample of the same matrix to be analyzed in the field samples.

LNAPL/NAPL – Light nonaqueous-phase liquid/nonaqueous-phase liquid.

MBTEXN – Methyl tertiary-butyl ether, benzene, toluene, ethylbenzene, xylenes, and naphthalene.

MCA – Montana Code Annotated.

Mitigation System – A process using a mechanical system or barrier to interrupt the vapor intrusion pathway either by preventing contaminated soil vapors from entering the structure or by removing the vapors that are inside the structure.

MTBE – Methyl Tertiary-Butyl Ether – A synthetic chemical added to most commercial gasolines as an anti-knock additive or oxygenate from 1979 to 2005.

µg/L – Micrograms per liter.

µg/m³ – Micrograms per cubic meter.

Multiple Lines of Evidence – The evaluation of several independent factors that may impact vapor intrusion. These factors include analytical data from indoor air, ambient outdoor air, soil vapor, sub-slab vapor, soil, and groundwater. Additional lines of evidence that may be considered include building construction, potential indoor sources, weather conditions, constituent ratios, proximity to contaminant sources, and time needed to remediate contaminant sources.

Near Slab Sample – A vapor sample collected by installing a vapor probe as close to the structure foundation as possible but no more than 10 lateral feet from the structure and extended vertically below the footings or basement floor of the structure.

Non-Carcinogen – A compound that the EPA has determined to have toxic effects but has not been determined to be a carcinogen. Some carcinogens may also have non-carcinogenic effects.

O₂ – Oxygen in its common gaseous state.

OM&M – Operation, maintenance, and monitoring.

OSHA – Occupational Safety and Health Administration.

PAHs – Polycyclic aromatic hydrocarbons (a.k.a. polynuclear aromatic hydrocarbons).

PCE – Tetrachloroethene (also called perchloroethene or tetrachloroethylene).

Petroleum Release – A release of petroleum hydrocarbon product into the environment. (See definition of “release” below).

PVI – Petroleum Vapor Intrusion – Vapor intrusion of solely petroleum compounds. The three step screening process and other PVI specific considerations should not be used when other volatile compounds are present.

QC – Quality control – A process employed to ensure an appropriate level of certainty in an environmental sample or set of environmental samples.

RBCA – Risk-based corrective action – A decision-making process based on the protection of public health, safety, and welfare, and the environment, which results in the consistent assessment, remediation and/or resolving (closure) of petroleum releases.

RBSL – Risk-Based Screening Level – A chemical concentration considered acceptable for a given exposure scenario based on estimated risk to potential receptors. Published in Tables 1 through 3 in Montana Tier 1 Risk-Based Corrective Action for Petroleum Releases (RBCA, May 2018, or most recent).

Reasonably Anticipated Future Uses – Reasonably anticipated future uses as defined in §75-10-701(18), MCA, means likely future land or resource uses that take into consideration:

- ♦ local land and resource use regulations, ordinances, restrictions, or covenants;
- ♦ historical and anticipated uses of the site;
- ♦ patterns of development in the immediate area; and
- ♦ relevant indications of anticipated land use from the owner of the site and local planning officials.

Receptor – Regarding vapor intrusion, a receptor is any person that is or could potentially be adversely affected by contamination at a site.

Release – Any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, placing of waste, or disposing of a hazardous or deleterious substance directly into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles containing any hazardous or deleterious substance) as defined in MCA 75-10-701(19) or as define by any appropriate statute or rule.

Remedial Action – Actions at a site that may include, but are not limited to: investigation, site assessment, emergency response, abatement, underground storage tank removal, cleanup, operation and maintenance of equipment, monitoring, reclamation, and termination of the corrective action.

Residential Structure – Any building or enclosed structure used as a place of residence. Residential structures also used for businesses are considered residential for evaluation purposes.

RP – Responsible Party – An owner, operator, generator, transporter, or other person responsible for cleanup of a contaminated site.

RSL – Regional Screening Level – EPA’s chemical-specific concentrations for individual contaminants in air, drinking water and soil that may warrant further evaluation. EPA’s RSLs can be found at <https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables>.

Sampling train – Equipment utilized to collect air samples that includes the sample port, associated tubing, and the sample collection device.

SAP – Sampling and analysis plan.

Screening Levels – Risk-based screening levels (RBSLs), EPA regional screening levels (RSLs), or vapor intrusion screening levels (VISLs) – Screening levels may be different than site-specific cleanup levels.

SIM – Selective(ed) ion monitoring – A mode of mass spectrometer instruments that selectively scans for characteristics of compounds of interest and allows for increased sensitivity.

Soil Gas/Soil Vapor – The air existing in the pore spaces between soil particles in the soil matrix.

Sorbent Tube – A sampling tube typically made of glass and containing various types of solid adsorbent material used for sampling hazardous gases and vapors in air.

SMD – Sub-membrane Depressurization – A mitigation system which uses a soil vapor retarder consisting of plastic sheeting or other suitable membrane material and is installed over the earthen floor and sealed against the structure.

SSD – Sub-slab Depressurization – A mitigation system that typically uses a fan or blower to draw air from the soil beneath the slab of a structure.

Sub-slab Vapor Sample – A soil vapor sample collected from immediately below (generally 3-4 inches) a structure’s slab.

Summa Canister – A stainless steel canister used to collect an air sample.

SVE – Soil vapor extraction – An environmental cleanup technology that extracts vapors from the soil above the water table by applying a vacuum to pull the vapors out.

SVOC – Semi-volatile organic compound – A subgroup of VOCs that tend to have a higher molecular weight and higher boiling point temperature than other volatile organic compounds.

TCE – Trichloroethene (also called trichloroethylene).

Tedlar Bag – A bag manufactured from polyvinyl fluoride (Tedlar) film and used to collect air samples for analysis of solvents, hydrocarbons, and many other classes of compounds.

TO-15 – A laboratory analytical method developed by the U.S. EPA for the determination of volatile organic compounds in air collected in specially-prepared canisters (i.e. Summa canisters) and analyzed by gas chromatography/mass spectrometry.

TO-17 – A laboratory analytical method developed by the U.S. EPA for the determination of semi-volatile organic compounds in air collected on sorbent tubes and analyzed by thermal desorption onto a gas chromatograph with a mass spectrometer.

Vadose Zone – The area between the top of the ground surface and the water table.

Vapor – A substance in the gaseous state as distinguished from the liquid or solid state.

VI – Vapor Intrusion (VI) – The migration of volatile chemicals from the subsurface into nearby or overlying structures. Volatile chemicals in buried wastes and/or contaminated soil or groundwater can emit vapors that may migrate through subsurface soils and into air spaces of overlying structures. In some cases, the vapors may accumulate in structures to levels that may pose safety hazards, acute or chronic health effects, or aesthetic problems.

VISL – Vapor Intrusion Screening Levels, as calculated from the Environmental Protection Agency’s Vapor Intrusion Screening Level Calculator – The VISL calculator identifies chemicals that are sufficiently volatile and toxic to warrant an investigation of the soil gas intrusion pathway when they are present as subsurface contaminants. EPA’s VISLs can be found at <https://www.epa.gov/vaporintrusion/vapor-intrusion-screening-level-calculator>.

VOC – Volatile Organic Compound – An organic chemical compound that has a high vapor pressure and under normal conditions is capable of vaporizing and entering the atmosphere.

Volatile Chemicals – chemicals that generate vapors and mainly include volatile organic compounds (VOCs), and some semi-volatile organic compounds (SVOCs). Although VI is most commonly associated with chemicals possessing high vapor pressures, some pesticides, polynuclear aromatic hydrocarbons (PAHs), and other SVOCs may have sufficient volatility and toxicity to pose a VI risk. Inorganic substances, such as elemental mercury or radon, may also pose a risk. Radon is not within the scope of this document.

VPH – Volatile Petroleum Hydrocarbons – Please see Air-phase petroleum hydrocarbons (APH).

1.0 Introduction

The Montana Department of Environmental Quality (DEQ) prepared this guidance to assist responsible parties, environmental professionals, and DEQ technical contacts in evaluating actual or potential vapor intrusion (VI) into indoor air at contaminated sites.

1.1 Applicability

This guidance addresses VI in current and future residential and non-residential settings potentially impacted with solvents (chlorinated and non-chlorinated), petroleum, and other substances that can generate vapors in the subsurface soils in the State of Montana. Departures from this guidance should be discussed with the appropriate DEQ technical contact. **Acute health effects and fire hazards from high concentrations of vapors are beyond the scope of this guidance. Situations involving fire, explosion, or serious acute health affects should be referred to local fire or emergency response teams, and the Montana Department of Public Health and Human Services.**

This document contains guidance, not regulation. Adherence to the requirements outlined in the relevant statutes and regulations is mandatory; however, adherence to this guide is not. This guidance does not create any requirements or obligations on the regulated community. Instead, the sources of authority and requirements for addressing VI are the relevant statutes and regulations, including but not limited to, the Comprehensive Environmental Cleanup and Responsibility Act (CECRA) contained in §§ 75-10-701 through 752, MCA, Petroleum Storage Tank Cleanup Act, contained in §§ 75-11-301 through 321, MCA, and the Montana Underground Storage Tank Act, contained in §§ 75-11-501 through 526, MCA. These recommendations do not supersede any statutory or regulatory requirements, are subject to change, and are not independently binding on DEQ. Additionally, if a conflict exists between this guidance and the statutory or regulatory requirements, the conflict must be resolved in favor of the statute or regulation.

Work plans and corrective action plans that follow this guidance are likely to contain the information necessary for DEQ to approve the work plan. DEQ developed this guidance using its scientific and technical expertise and based on a review of relevant Montana-specific information, as well as other technical documents. DEQ encourages parties to contact DEQ with any additional or clarifying questions about this document, or if the party believes that DEQ has incorrectly characterized a particular process or recommendation.

1.2 Vapor Intrusion

The phrase "vapor intrusion" refers to the process by which volatile chemicals migrate from subsurface contaminant sources such as contaminated soils or groundwater, to the soil vapor phase, and into the indoor air of current or future nearby or overlying structures. Potential contaminant sources for VI are any volatile chemicals that can generate vapors beneath the ground surface or within structures including, but are not limited to, the following:

- Groundwater or soil that contains volatile chemicals;
- Non-aqueous phase liquid (NAPL);

- Buried wastes;
- Underground storage tanks or drums;
- Contaminated utility lines and corridors; and
- Other sources of subsurface contamination.

Soil vapor is the air found in the pore spaces between soil particles. Soil vapor can become contaminated when chemicals volatilize from contaminant sources and migrate into the pore spaces. "Volatile chemicals" are chemicals that generate vapors and mainly include volatile organic compounds (VOCs), and some semi-volatile organic compounds (SVOCs). Although VI is most commonly associated with chemicals possessing high vapor pressures, some pesticides, polynuclear aromatic hydrocarbons (PAHs), and other SVOCs, including emerging contaminants like fluorinated compounds, may have sufficient volatility and toxicity to pose a VI risk. Inorganic substances, such as elemental mercury or radon, may also pose a risk. While the investigation and mitigation of naturally-occurring radon is beyond the scope of this guidance, DEQ has radon-related resources available (see: <https://deq.mt.gov/Energy/radon>).

When contamination is present near or beneath buildings, it may move as a vapor through soil gas and into structures (EPA, 2005). Soil vapor can enter a structure whether the structure is old or new, or whether it is on a slab or has a crawlspace or basement (Figure 1). However, the subsurface source of the contaminated vapor (e.g., contaminated soil or groundwater) does not need to be directly beneath a structure to impact the vapor beneath the structure's foundation as suggested in Figure 1.

Contaminated soil vapors may enter structures through cracks in slabs or basement floors and walls, through the junction between the slab footing and the basement floor, through dirt floors, and through openings around sump pumps or where pipes and electrical wires go through the foundation. Buried utility lines (gas, electric, sewer, communication lines) may pose a greater risk than undisturbed ground because the utility trench may serve as a preferential pathway allowing vapors to migrate easily to a structure at locations where the utility penetrates the foundation (ITRC, 2007). Heating, ventilation, and air-conditioning systems increase the risk of drawing contaminated soil vapor into structures by reducing the air pressure inside structures, (ITRC, 2007).

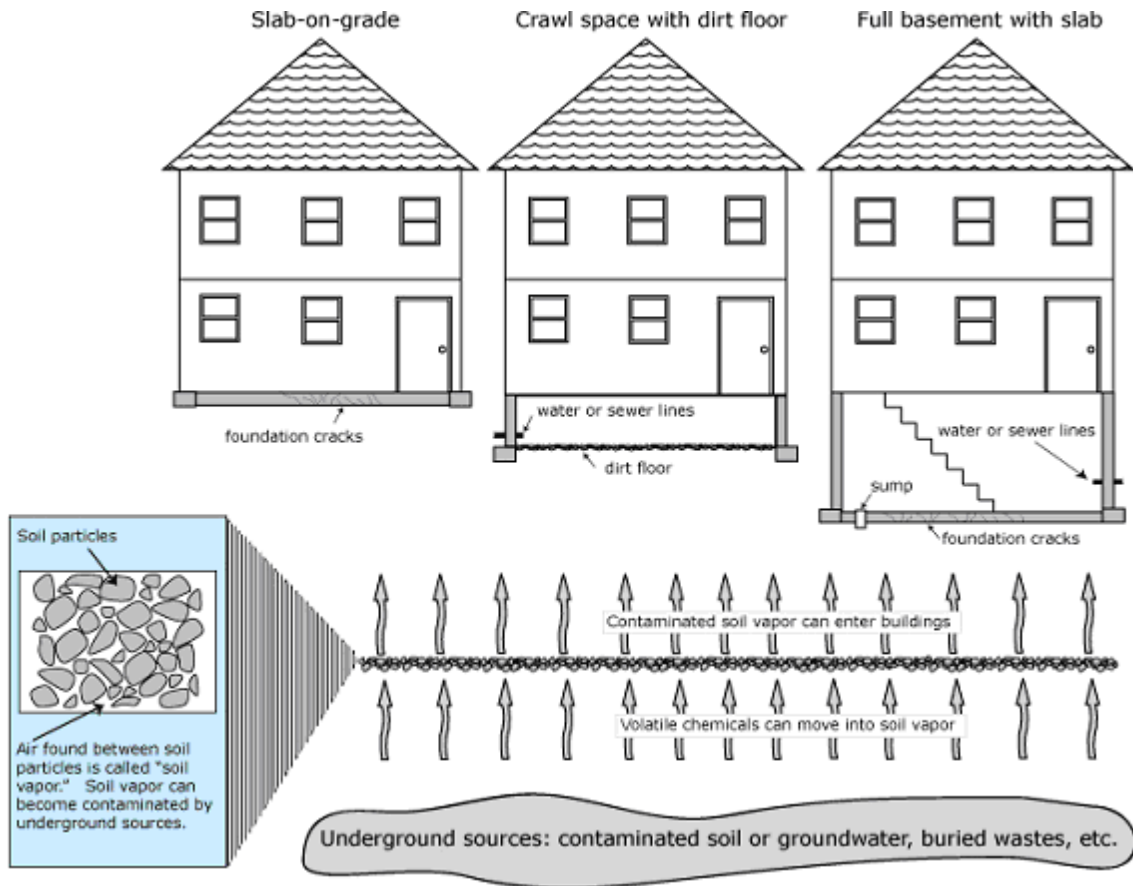


Figure 1.2.1 (NYSDOH, 2006)

1.3 Exposure to Vapors

In the context of VI, vapors are contaminants or chemicals in a gaseous state that are diffused or suspended in air. Humans can be exposed to contaminated soil vapor indoors when vapors from beneath or near a structure migrate through cracks and openings in the foundation and mix with the indoor air. These vapors may be inhaled along with the indoor air. The potential for VI exists when contaminated soil vapors could move to existing structures not currently affected, or when new structures may be built over existing subsurface vapor contamination. Exposure to underground vapors may also occur when construction workers are working in trenches or excavations.

Inhaling a volatile chemical does not necessarily mean that a person will experience adverse health effects. Whether or not a person experiences adverse health effects depends on several factors, including: the length of time a person is exposed, the concentration or amount of the chemical in the air, the number of times a person is exposed, the toxicity of the volatile chemical, and the person's sensitivity to the chemical. DEQ separates health effects into two categories: carcinogenic and non-carcinogenic. Carcinogenic compounds may cause cancer. Non-carcinogenic compounds are not expected to cause cancer but may disrupt or affect the body's normal function. Some carcinogenic compounds may also disrupt or affect the body's normal function without causing cancer.

Inhaled contaminated vapors can cause acute or chronic health effects depending on the exposure concentration and duration. Chronic health effects may occur over an extended period of exposure and some symptoms may develop after exposure has ceased. Examples of chronic health effects associated with volatile compounds include cancer, effects on the blood or lungs, impaired kidney function, impaired liver function, impaired motor function, etc. Acute health effects are apparent over a very short period of time. Examples of acute health effects associated with volatile compounds include shortness of breath, dizziness, headaches, or asphyxiation, etc. Both chronic and acute health effects can be caused by concentrations of volatile compounds that are below olfactory (smell) thresholds and can only be analyzed with sensitive sampling and analysis procedures. **Acute health effects and fire hazards from high concentrations of vapors are beyond the scope of this guidance. Situations involving fire, explosion, or serious acute health effects should be referred to local fire or emergency response teams, and the Montana Department of Public Health and Human Services.**

Situations may arise where concentrations of indoor air contaminants are elevated above screening levels, but negative/acute effects have not been reported. In these situations, additional resources may be needed to determine whether a situation needs immediate response and include the Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels, or consultation with the Montana Department of Public Health and Human Services. ATSDR's October 2016 guide entitled "Evaluating Vapor Intrusion Pathways, Guidance for ATSDR's Division of Community Health Investigations" provides detailed information on this topic.

While the focus of this guidance is on vapors from VI, it is important to recognize that indoor air can contain contaminants from indoor air sources (for example: cleaning supplies, air fresheners, hobby/craft products, paints, carpets, personal care products, cigarette smoke, etc.) as well as from outside ("ambient") sources (for example: vehicle emissions, forest fires, industrial and commercial processes, etc.). In August 2012, DEQ published the results of its indoor air sampling investigation of 50 non-smoking residential homes across Montana in both rural and urban areas to determine "typical" background indoor air quality in the state (DEQ, 2012). The results of the Montana Background Indoor Air investigation can be used to evaluate indoor air sample results in the context of indoor air levels typically found in Montana homes not impacted by vapor intrusion.

1.4 Evaluating and Investigating Vapor Intrusion

Both VI that is documented in a structure and potential future VI should be evaluated. Potential future VI exists when volatile chemicals are present, or are accumulating, in the vapor phase beneath a structure but have not yet affected indoor air quality or when a structure may be built in the future. All releases of volatile chemicals in soil and groundwater should be evaluated to determine what risk they pose to existing structures or future construction.

The first step to evaluate VI is to identify the release characteristics which include: nature and extent of volatile chemicals in the groundwater and soil, soil type, depth to groundwater and flow direction, groundwater temperature, groundwater well locations, distance to buried utilities and surface structures, and other factors discussed in this guidance. This information forms the conceptual site model (CSM). When the release and site characteristics indicate VI is a probable

risk, further investigation including the collection and analysis of air/vapor samples is recommended.

Several different types of environmental samples may be collected including, but not limited to: groundwater samples, soil vapor samples, near-slab soil vapor samples, sub-slab soil vapor samples, samples from the air found in crawlspaces, indoor air samples, and ambient outdoor air samples. The process of investigating VI typically involves more than one set of samples to determine the extent of vapor contamination and whether the pathway is complete or potentially complete. DEQ reviews the results from different sample sets and different types of samples in a “multiple lines of evidence” approach (see Section 2.7).

The following paragraphs list common VI investigative samples and how they may be used in refining a conceptual site model or directly measuring VI in structures.

- Groundwater samples characterize the nature and extent of volatile contaminants in groundwater. Volatile contaminants can move from groundwater into soil vapor where they can pose a threat of VI.
- Soil vapor samples characterize the nature and extent of vapor contamination in the soil in each area. Soil vapor samples may be collected before sub-slab vapor and/or indoor air samples to help identify structures or groups of structures that may need to be investigated. Soil vapor samples may be collected from utility bedding/fill material to assess vapors in utility corridors. Soil vapor samples are used to determine the potential for vapors to accumulate beneath structures. Soil vapor samples are also collected to assess undeveloped properties for VI in future structures. Please note that soil vapor samples are not the same as soil samples. Soil vapor samples assess contamination present in the soil vapor between the soil particles. Soil samples measure the total amount of contamination present in the soil, including contaminants that adhere to soil particles and are not detected in a soil vapor sample.
- Near-source soil vapor samples are collected to evaluate worst-case (highest) vapor concentrations immediately above or near known sources of volatile contaminants. Examples of near-source vapor samples include samples collected immediately above the groundwater table, immediately above NAPL, or near known soil sources. Near-source vapor samples can be compared to other types of samples to evaluate concentration gradients.
- Near-slab soil vapor samples are a specialized type of soil vapor sample that is collected by installing a vapor probe as close to the structure foundation as possible but no more than 10 lateral feet from the structure and extends vertically below the footings or basement floor of the structure. Near-slab soil vapor samples can be used to determine potential for VI when the more accurate sub-slab soil vapor samples cannot be obtained, or as a precursor to the more invasive sub-slab sampling.

- Sub-slab soil vapor samples characterize the nature and extent of vapor contamination in the soil immediately beneath a structure with a concrete slab. Sub-slab vapor results are used to determine the immediate potential for VI within the structure.
- Crawlspace air and/or soil vapor samples may be collected below structures without a slab. Like sub-slab vapor results, crawlspace and soil vapor samples are used to determine the potential for VI within the structure.
- Indoor air samples characterize the nature and extent of vapors within a structure. Indoor air sample results help to evaluate whether vapors are currently present inside a structure. They are also compared to sub-slab vapor and ambient outdoor air results to help determine where volatile chemicals may be coming from (indoor sources, outdoor sources, and/or soil vapor beneath the structure).
- Ambient outdoor air samples characterize site-specific background air conditions. Ambient outdoor air results are used to evaluate the extent to which outdoor sources, such as automobiles, lawn mowers, oil storage tanks, gasoline stations, or commercial/industrial facilities may be affecting indoor air quality. However, the presence of a contaminant in the ambient outdoor air does not necessarily mean that the contaminant will be present in indoor air. When a structure may be impacted through both a subsurface VI pathway and a surface air pathway from the same contaminant source, a more detailed ambient outdoor air survey may be needed.
- Utility air samples may be collected from the air inside sewer lines and storm drains to assess these utilities as VI pathways.

Evaluating and investigating VI is covered in detail in Sections 2 through 7 of this guidance document.

1.5 Mitigating Vapor Intrusion

When VI investigations indicate that volatile compounds may enter structures and pose an unacceptable health risk to actual or potential occupants, actions should be taken to disrupt the VI exposure pathway. An obvious long-term solution is to remove the chemicals that are generating vapors from the subsurface. However, in many cases, timely contaminant source removal is not possible, and other short- or long-term measures should be taken to prevent vapors from intruding into structures. The decision to mitigate will be site-specific. Structure mitigation is discussed in Section 8.

2.0 Preliminary Screening Phase

2.1 Initial Evaluation and Conceptual Site Models

Although all releases of volatile chemicals should be evaluated for their VI potential, this does not mean that a VI investigation will be completed for every release. This section discusses the steps needed in an initial evaluation to determine if a VI investigation may be needed. The first step in assessing the vapor intrusion pathway is the development of a conceptual site model based on all available site data. An initial screening level evaluation is also completed to ensure that those sites most likely to pose unacceptable risk from vapor intrusion are retained for a more detailed evaluation. It is also expected that some sites will be removed from further evaluation if one or more of the following can be demonstrated (ITRC, 2007):

- the exposure pathway is and will remain incomplete,
- the COCs are not deemed sufficiently volatile to pose a hazard, or
- the concentrations of the volatile chemicals fall below generic screening levels.

2.2 Develop a Conceptual Site Model

A conceptual site model (CSM) should be used to develop a general understanding of the site, evaluate potential risks to human health and the environment, and assist in identifying and setting priorities for the activities to be conducted at the site. The CSM identifies potential contaminant sources, types of contaminants and affected media, release mechanisms and potential contaminant pathways, and potential current and future human and environmental receptors. A preliminary CSM documents current site conditions, such as site geology, hydrogeology, and volatile organic compound (VOC) distribution and composition relevant to soil gas migration, and should be supported by maps, cross sections, and site diagrams (ITRC, 2007).

For a complete VI exposure pathway to exist there needs to be a volatile contaminant source; a pathway involving contaminated soil, groundwater, or other materials; and a current or future receptor. A CSM should be developed from these elements to evaluate potential risks to human health and the environment and to design an investigation approach. The CSM can be dynamic but should be as site-specific as possible. EPA's June 2015 *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway From Subsurface Vapor Sources Into Indoor Air* (EPA, 2015a), the Interstate Technology and Regulatory Council's (ITRC's) January 2007 *Vapor Intrusion Pathway: A Practical Guide* (ITRC, 2007) and the *Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A)* (EPA, December 1989), and DEQ's *Risk-Based Corrective Action Guidance for Petroleum Release* (DEQ 2018b) provide information regarding CSMs and the DEQ *Voluntary Cleanup and Redevelopment Act Application Guide* (DEQ, May 2018a) provides an example of a CSM for multiple pathways. For an example of a CSM for PVI sites, ITRC's *Petroleum Vapor Intrusion Fundamentals of Screening, Investigation, and Management* (ITRC, 2014) and the *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites*. (EPA, June 2015) can be referenced.

Following are some of the questions that should be asked to develop the CSM:

- Where are the contaminant source areas?
- What is the contamination (e.g., petroleum hydrocarbons, chlorinated solvents, other VOCs, or mixture)?
- What is the age of the release? When did it occur?
- Is the contaminant plume stable or expanding?
- Is the extent of contamination defined?
- What are the contaminated media (e.g., soil, soil vapor, groundwater, or NAPL) and what is the extent of the contamination in each contaminated media?
- What is the depth and flow direction of groundwater?
- What are the soil types and geology of the site (e.g. tight clay soils, gravels, bedrock)?
- What is the size of the site (or extent of contamination)?
- Does the contamination extend beyond property boundaries?
- What is the current and reasonably anticipated future use of the site (e.g., residential, commercial, etc.)?
- Is the area of contamination developed or undeveloped?
- What types of structures are present or reasonably anticipated (e.g., basement, slab-on-grade, earthen floor, crawlspace)? What is the use and occupancy of the buildings?
- What are the vertical and horizontal distances between an occupied structure and contaminated media?
- Are preferential pathways (e.g., utility corridors, sumps, fractures) present?

The CSM should be refined as additional phases of investigation and site characterization are conducted to provide more accurate predictions of risk. Phased investigations, with an increasing level of detail and information at each phase, may be an effective and efficient approach to evaluating VI risks and refining the CSM to support project decisions. Approved by the DEQ technical contact, phased investigations may include adding sample locations and analytes, dropping sample locations or analytes, and/or sampling the same locations at different times. Additionally, phased investigations may be planned with the “worst first” concept, focusing resources and investigations on areas and structures that have the highest potential for VI. Ultimately, the CSM should identify the major and minor exposure pathways and processes through which a receptor can be exposed to contaminants at a particular site.

2.3 Bounding the Vapor Intrusion Area

Due to the lateral diffusion and advection of vapors in the subsurface, vapors can move vertically and laterally away from the contaminant source and can move independently of the groundwater flow direction. Soil vapors can migrate at varied rates in different soil lithologies and will follow preferential pathways, if present. It is possible for structures located outside of the areal extent of a groundwater plume to be subject to VI due to the lateral diffusion and advection of vapors through certain lithologies (EPA, 2015a)) and preferential pathways. Vapors of different chemical composition behave differently. Petroleum hydrocarbons, for instance, can biodegrade as they migrate through aerobic soil, while chlorinated solvents are generally unaffected under the same

conditions (ITRC, 2007). Please refer to Section 2.4 of this document regarding evaluation of data for PVI decision making and discussion of the site-specific details with the DEQ technical contact.

While many factors affect vapor migration, the VI pathway should initially be considered a potential threat for all current or potential future structures located within finite distances from contaminated soil, soil vapor, or groundwater. Due to the different properties of chlorinated solvents versus petroleum chemicals, initial recommended evaluation distances are different at petroleum-only (PVI) sites versus sites that have other kinds of volatile contaminants. Refer to Section 2.4 of this document for information regarding the evaluation of PVI initial pathway evaluation and bounding the VI area. Structures within the following distances from measured contamination should be initially evaluated:

- 100 feet laterally of chlorinated solvent contamination and sites with mixed contaminants (EPA, 2015a) (there is no presumed minimal vertical separation distance for chlorinated solvent vapors because these are not expected to biodegrade in the subsurface),
- 30 feet laterally and 8 feet vertically for dissolved phase at industrial petroleum facilities such as refineries, terminals, etc.
- 30 feet laterally and 18 feet vertically for LNAPL at industrial petroleum facilities such as refineries, terminals, etc. (ITRC, 2014)
- For smaller PVI sites (underground storage tank sites, tanker truck spills, etc.) please refer to Section 2.4 of this document

The distance between the contaminant source and the edge of the VI investigation area may be referred to as the “preliminary VI investigation area.” These distances may be overly protective for shallow or relatively small sources of VOCs; or they may be less protective for sites with preferential pathways. The actual investigation boundary will be site-specific, so please discuss with the DEQ technical contact before reducing or expanding the preliminary VI investigation area. Scenarios for which the 100-foot bounding distance may be too small (EPA, 2015a), include:

- Landfills (methane)
- Leaks from pressurized sources/lines

All structures falling within the VI investigation area do not necessarily need to be individually sampled. However, all current and future (contemplated to be developed) structures or properties within the investigation area should be assessed using a CSM. The potential for VI should be considered until the VI pathway is eliminated by evaluating multiple lines of evidence as discussed in Section 7 or by directly sampling the structure. As an investigation progresses, the results of soil vapor sampling and other types of sampling will be used to establish site-specific boundaries for areas with VI concerns. As mentioned earlier, VI investigations may need to proceed with the “worst first” approach (EPA, 2015a).

Buried utility lines or other preferential pathways that run through or near a contaminant source area are a special case and should always be evaluated for VI when they fall within the preliminary VI investigation area for either petroleum or chlorinated solvent sources (NJDEP, 2005). The presence

of preferential pathways such as utility conduits with granular backfill, which intersect a contaminant source and connect to a building, may result in enhanced VI (Golder, 2006).

2.4 Petroleum Vapor Intrusion Screening

PVI differs from vapor intrusion associated with chlorinated compounds due to the ability of many petroleum hydrocarbons to naturally biodegrade in the vadose zone through the actions of microorganisms found naturally in soil. At sites with sufficient oxygen supply from the atmosphere, biodegradation of petroleum hydrocarbons can occur relatively quickly and will generally produce less harmful compounds (i.e., biodegradation products), resulting in substantial attenuation of petroleum hydrocarbon vapors over relatively short distances in the vadose zone. Additionally, numerous site-specific factors can influence the biodegradation rate of petroleum hydrocarbons. Although PVI may be possible under certain environmental conditions, McHugh et al. (2010) noted that “the most common cause of petroleum vapor intrusion is dissolved PHCs [petroleum hydrocarbons] or LNAPL [light nonaqueous phase liquid] in direct contact with building structures such as sumps, basements, or elevator pits.”

The approaches in this section are recommended for evaluating the VI pathway for petroleum hydrocarbons that arise from petroleum that has been released from RCRA Subtitle I UST systems in accordance with EPA’s Technical Guide For Addressing Petroleum Vapor Intrusion At Leaking Underground Storage Tank Sites (EPA 2015b) and ITRC’s (Interstate Technology Regulatory Council’s) Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation and Management. (ITRC 2014). The approach in this section may also be appropriate for other finite petroleum-only releases including tanker truck rollovers and pipeline releases.

The approaches in this section are NOT recommended for evaluating the vapor intrusion pathway for sites with petroleum hydrocarbons that are mixed with other types of volatile hazardous chemicals. Refer to Section 2.2 & 2.3 for guidance on evaluating the VI pathway at these sites.

Screening for Petroleum Vapor Intrusion is a 3-Step Process (See PVI Decision-Making Flowchart for Leaking Underground Storage Tank Sites in Appendix B).

Step 1: Completion of a CSM (Section 2.2) and Identification of Precluding Factors.

Completion of a CSM was discussed in Section 2.2. For more information on developing a CSM specific to PVI please refer to ITRC’s Petroleum Vapor Intrusion Guide (ITRC, 2014) and EPA’s Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites (EPA 2015b).

The PVI Screening Process should **NOT** be used if the answer to any of the following questions is YES:

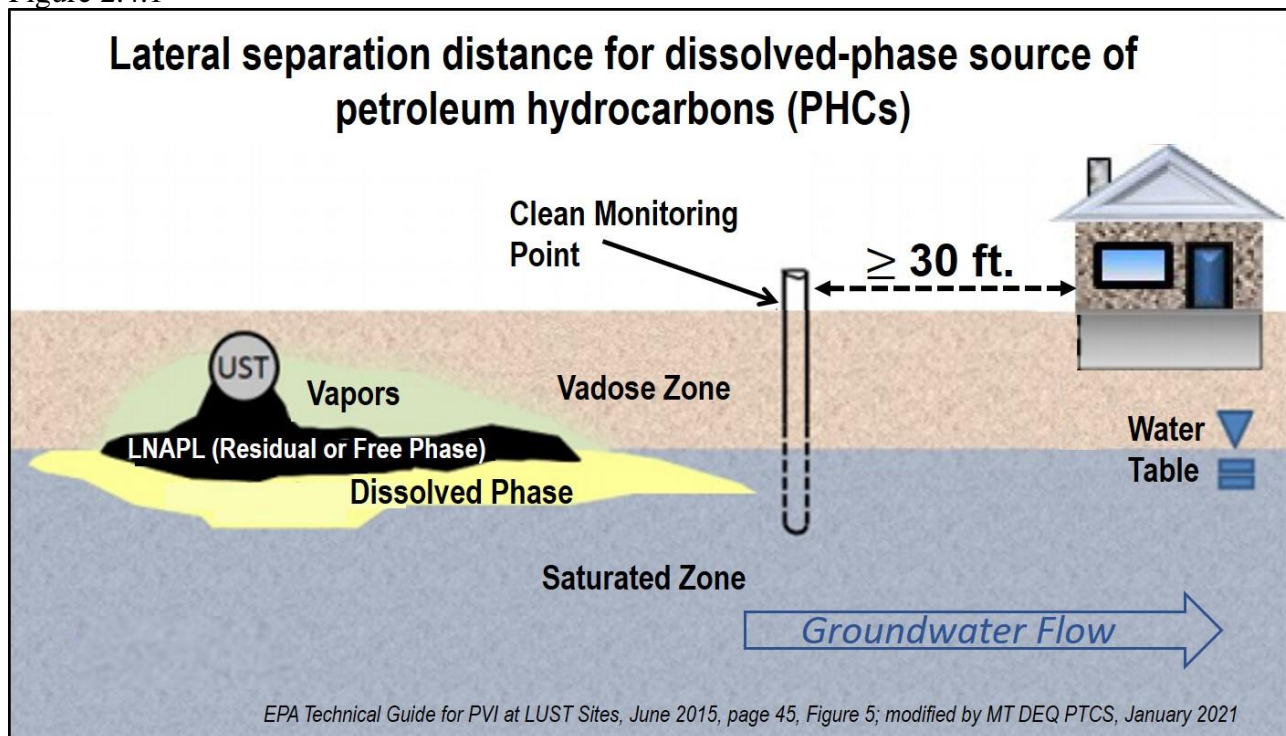
- Are lead scavengers 1,2 DCA or EDB present?
- Is methane present?
- Did the fuel contain greater than 10 % ethanol or other alcohol?
- Is the basement floor made of dirt or does it have a cracked foundation?

- Is there a sump present?
- Do utility corridors intersect contaminated soil or groundwater?
- Is any part of the building in direct contact with petroleum contamination?
- Do preferential pathways exist?
- Is the plume expanding or advancing or is there a continued source of release?
- Are there peat soils or excessively dry soils (<2% oxygen present)?
- Are there large buildings present (greater than 66 feet on shortest side)?
- Is there extensive impermeable surface coverings? (i.e. asphalt, concrete, etc.)

Step 2: Identify the Lateral Inclusion Zone

After completion of a CSM and in the absence of any precluding factors, a lateral screening distance can be applied as the next step in the PVI screening process due to the biodegradation of petroleum hydrocarbons in the subsurface. The lateral screening distance should only be used on releases where the lateral extent and magnitude of petroleum contamination is defined. Any buildings within 30 feet of petroleum contamination (soil and/or groundwater contamination above risk-based screening levels) should be considered at risk for a potentially completed VI pathway.

Figure 2.4.1



Step 3: Determine the Appropriate Vertical Screening Distance

Once buildings have been identified within 30 feet laterally of petroleum contamination, a vertical screening distance can be applied to further identify buildings at risk of a completed VI pathway. The vertical screening distance is the distance between the highest point of petroleum contamination in soil and groundwater and the lowest point on the building foundation.

- The vertical screening distance for large petroleum sites (i.e. refineries, terminals, etc.) is 18 feet for LNAPL. (refer to section 2.3)
- The vertical screening distance for LNAPL is 15 feet.
- The vertical screening distance for dissolved phase petroleum contamination is 8 feet (Only applicable when LNAPL is not within 15 feet of structure).

Figure 2.4.2

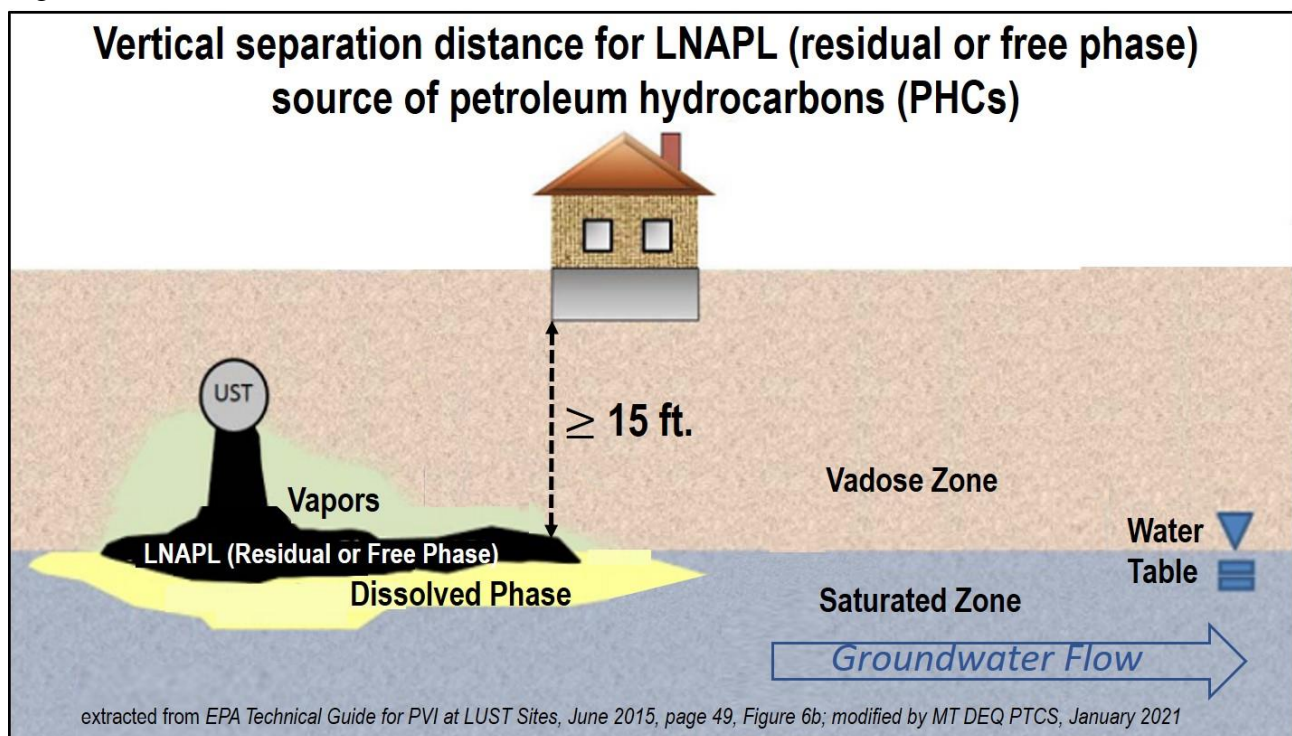


Figure 2.4.3

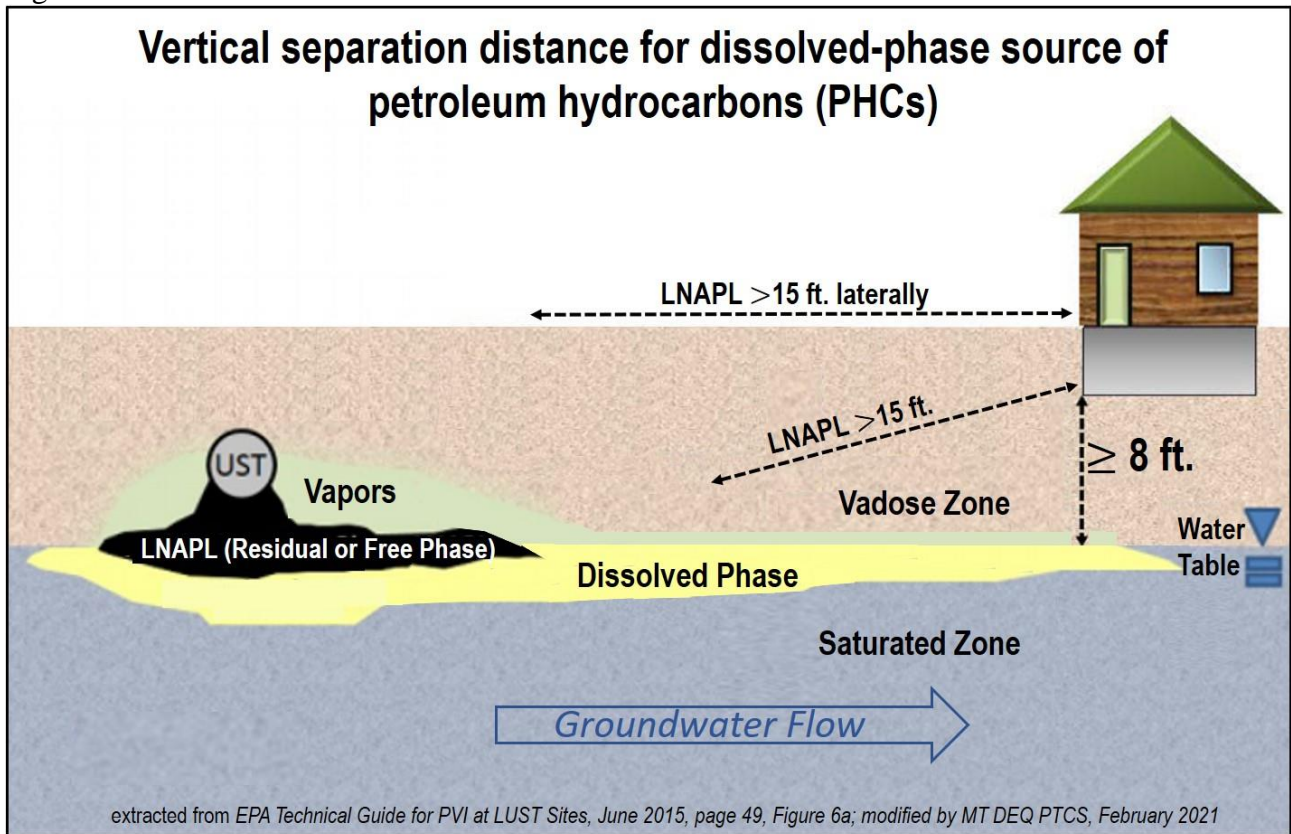


Table 2.4.1 (below) should be referenced to identify when LNAPL is present in soil and/or groundwater in order to apply the appropriate vertical screening distance for a structure.

Table 2.4.1

Required Vertical Separation Distance Between Petroleum Contamination and a Building Basement Floor, Foundation, or Crawlspace Surface					
Media	Benzene	Petroleum Phase Indicated	Total Petroleum Hydrocarbons (TPH)	Petroleum Phase Indicated	Separation Distance (feet)
Soil (mg/Kg)	≤10	dissolved	≤100 (unweathered gasoline), or ≤250 (weathered gasoline, diesel)	dissolved	8
	>10	LNAPL	>100 (unweathered gasoline), or >250 (weathered gasoline, diesel)	LNAPL	15
Groundwater (ug/L)	≤5,000	dissolved	≤30,000	dissolved	8
	>5,000	LNAPL	>30,000	LNAPL	15

When the PVI pathway cannot be eliminated using lateral and vertical screening distances additional assessment and investigation will be necessary to evaluate PVI risk. This may include soil vapor sampling, sub-slab sampling, indoor air and ambient air sampling or a combination of sampling options. When a preferential pathway is identified, mitigation along with indoor air sampling may be necessary. Additional information on PVI sampling can be found in Section 3.5. Please discuss options based on site-specific factors with the DEQ technical contact. In some situations, such as when preferential pathways exist, the site may go directly into vapor mitigation prior to investigation. For additional information on vadose zone biodegradation please refer to section 6.3.

2.5 Evaluate Existing Data

Existing information should be evaluated to determine what additional data should be collected. Existing data can help identify 1) if the potential for VI exists; 2) where VI is likely to occur; and 3) the most likely receptors. If existing data are sufficient and show that VI is not occurring in accordance with Section 7 of this guide, further investigation may not be necessary. Please verify this with the DEQ technical contact. If a review of the existing data identifies data gaps, the VI investigation should be designed to fill those data gaps.

In some cases, a remedial investigation may have already occurred at the site, and soil and groundwater data are available. Understanding the areas of soil and groundwater contamination is a critical first step in developing a VI CSM. If contaminants of potential concern (COPCs) are only detected in the soil, the area of potential VI may be limited to an area adjacent to the soil contamination, depending upon lithology and preferential pathways. If COPCs are or were historically detected in groundwater, the area for potential VI may extend beyond the contaminant

source area. Soil vapor data may be used to further refine the CSM by evaluating whether the VOCs are volatilizing into the soil vapor from the contaminant source. However, existing soil vapor data may not have been collected in accordance with this guidance, and its quality and validity should be assessed on a site-by-site basis (see Section 3.2 for a discussion on data quality objectives (DQOs)). Please refer to Section 7 of this document regarding evaluation of data for VI decision making and discuss with the DEQ technical contact.

2.6 Generic Screening Levels

When existing indoor air and sub-slab sample data meet data quality objectives (DQOs), these data can be compared to screening levels for an initial evaluation to determine whether the VI exposure pathway is complete and whether there is a potential for risk associated with the inhalation of vapors from contaminated subsurface media (ITRC, 2007). For preliminary screening purposes, evaluate the building occupancy scenarios. Occupancy scenarios include evaluating building use (e.g., residential, commercial, industrial, schools and day care) as well as potentially exposed populations (e.g., children or adults) (ITRC, 2007). EPA generic screening levels (found in EPA's Regional Screening Levels tables) are developed for both the residential receptors and commercial/industrial building uses and are meant to provide a conservative evaluation of the risks to these receptors. If sites have additional receptors or building uses, then a more site-specific evaluation will be needed while working with the DEQ technical contact.

If VI sample concentrations are less than applicable generic screening levels, additional investigations may not be needed. To make this determination, the data should also indicate that the contaminant source is not increasing or migrating and should represent anticipated seasonal variations, including worst-case conditions. All sampling data should be evaluated in terms of the CSM and the multiple lines of evidence approach described in Section 2.7 as outlined in DEQ's VI Decision-making Flowchart and Indoor Air Screening Flowchart (both in Appendix B). An exceedance of applicable screening levels does not necessarily mean that mitigation is necessary. However, it does mean that additional investigation or evaluation may be needed. Section 6 provides a detailed discussion of the generic screening process and the appropriate generic screening levels for both PVI sites and sites containing a mixture of contaminants.

2.7 Multiple Lines of Evidence

Evaluating multiple lines of evidence is an accepted approach for evaluating whether VI is occurring. This approach involves evaluating several independent factors that may impact VI. These factors include analytical data from indoor air, ambient outdoor air, soil vapor, and sub-slab vapor. Additional factors that may be considered include building construction, potential indoor sources, weather conditions, contaminant concentration ratios, proximity to contaminant sources, data from nearby locations, and time needed to remediate contaminant sources. Soil and groundwater data are also considered. For more information on multiple lines of evidence, please refer to Section 7.1. In most cases, empirical (directly observed or measured and not computer modeled or predicted) evidence is used for regulatory VI decision making purposes. It is very important to coordinate any VI investigation with the DEQ technical contact, to ensure the appropriate information is collected.

Computer or predictive models are generally less precise than empirical evidence for VI decision making and may have limited use in evaluating VI. Please discuss with the DEQ technical contact if modeling efforts are appropriate. (See Section 7.1.14 for further discussion on uses of modeling.)

2.8 VI Sampling Considerations

VI investigation may include sampling a combination of ambient air, indoor air, sub-slab air, and soil vapor. The sampling density and design will depend on contaminant source media (NAPL, soil, groundwater, soil vapor), contaminant source size, lithology, preferential pathways, and receptor types. For example, if there is a large mass of soil contamination, variable soil lithology, variable building construction, and/or NAPL near structures, an increased sample density may be appropriate within the area of investigation, including collecting sub-slab/indoor air samples from existing structures. If the extent of contamination is not known, if the extent of contamination extends off the originating contaminant source property, or if the extent of contamination covers a large area, it may be appropriate to conduct a soil vapor investigation to delineate the vapor plume before collecting sub-slab/indoor air samples. Conversely, if groundwater contamination is the primary source of vapors, the vapor concentrations may be more homogenous, and a decreased sample density may be appropriate within the defined area of investigation. An established area of investigation does not automatically necessitate the evaluation of every structure that exists within it.

Potentially impacted areas that are currently developed or have structures are investigated differently than undeveloped areas. If people reside or work in structures near the contaminant source, then a soil vapor investigation may be appropriate to determine the presence of contaminated soil gas vapors in the area between the contaminant source and the structures. If the contaminant source is very close to structures, or if a soil vapor survey indicates soil vapor contamination is in the area where structures exist, then sub-slab/indoor air samples should be collected to evaluate whether VI is occurring. If the site is undeveloped or no structures exist, it is not possible to collect sub-slab/indoor samples. In these instances, soil vapor samples, including near-source vapor samples, may provide the best data to determine if VI is a concern for future structures. This type of investigation should be conducted with input from the DEQ technical contact.

Sub-slab/indoor air samples are a direct way of determining if vapors from the contaminant source are present beneath a structure and if those vapors are detected inside the structure. To provide useful information about VI, sub-slab and indoor air samples should be collected concurrently in each structure (Section 3.4.3 discusses the timing of these kinds of samples). When all the samples are collected concurrently, the data can be used to conduct comparisons among the sample sets at a single point in time and eliminate temporal interference.

Sub-slab/indoor air measurements should be collected during “worst case” conditions. The worst-case conditions in Montana will generally occur during the winter months when the ground is frozen for most sites. Not only are vapors limited in their ability to travel through frozen soil and out into the atmosphere during this time of year, but structures are heated, creating a stack or chimney effect that can draw vapors into the structures. In addition, because of the extreme winter weather conditions that may occur in Montana, structures are typically well insulated and kept

closed during the winter, thereby allowing vapors to accumulate indoors. Indoor air and sub-slab samples should be collected during the winter for appropriate VI decision-making in Montana. However, at some sites, contaminated groundwater elevations may vary significantly, and groundwater may become very shallow during the spring or early summer, which may affect VI. Indoor air and sub-slab sampling may be necessary during these time periods at some sites to determine if high groundwater elevations create an alternative worst-case condition. Additional discussion on worst case sampling is provided in Section 7.1.4.

Prior to VI sampling, an occupant questionnaire or survey should be completed to identify any potential indoor air sources. Please see Section 7.1.9 for additional information on occupant questionnaires.

Once sample types and locations are determined, a sampling and analysis plan (SAP) should be prepared in accordance with Section 3.

3.0 Sampling and Analysis Plan Development

3.1 Introduction

If a potentially complete VI pathway for current and/or future structures is identified during CSM development, then an investigation is needed to determine if VI is occurring. A VI investigation sampling and analysis plan (SAP) should be prepared that includes background and CSM information, an initial evaluation of existing data, and identifies what information is needed for decision making. Montana law may require DEQ approval of a SAP. Please check with a DEQ technical contact for site-specific requirements. Some sections of Montana law use the term “Corrective Action Plan” (CAP) to describe work plans developed to investigate or cleanup a contaminated site. A SAP is considered a specialized type of CAP under these laws and should contain the details outlined by this section (Section 3). If a SAP or comparable document for other investigations has already been prepared for the site, this document can be referenced in the VI SAP, as appropriate (e.g., background, history, etc.). Please confirm with the DEQ technical contact what should be included in a SAP, whether some information from an existing SAP can be used in the VI SAP, and if DEQ approval is required.

For purposes of simplicity, the term SAP is used in this guidance to describe the information, data, and sampling needs for VI investigation. However, this information could be in a remedial investigation work plan or investigation plan or other planning document. Please consult with the DEQ technical contact for the plan naming convention.

The introduction of the SAP should include:

- Site location and description;
- Site operational history (a brief summary with reference to an existing DEQ-approved document for more information may be appropriate);
- Regulatory involvement and previous investigations (a brief summary with reference to an existing DEQ-approved document for more information may be appropriate);
- Site geology and hydrogeology (a brief summary with reference to an existing DEQ-approved document for more information may be appropriate); and
- Statement of specific problem.

In most instances, the above information can be found in previous investigation reports. Sections 3.2 through 3.9 outline other information to include in the SAP.

3.2 Project Objective

3.2.1 PROJECT DATA QUALITY OBJECTIVES

A well-defined, detailed CSM will facilitate the identification of additional data needs and development of appropriate DQOs. The purpose of the VI investigation should be established before sampling and analysis is conducted. The DQOs define the investigation goals; identify COPCs and appropriate screening levels; identify sampling methods and analytical methods with appropriate detection and reporting limits; describe the pre-sampling building survey; establish appropriate sampling conditions, types of samples (e.g., near slab, near source, sub-slab, indoor air,

ambient outdoor air), sample locations, numbers of samples, and duration of sampling; identify what meteorological data will be collected and how; describe quality control sample needs; and establish data validation procedures and electronic data deliverable (EDD) formats.

3.2.2 PROJECT TASK AND PROBLEM DEFINITION

The SAP should clearly state the specific problem(s) to be solved (e.g., is VI causing an unacceptable risk?), and/or decision(s) to be made (e.g., is additional investigation needed?), or outcome(s) to be achieved (e.g., do structures/vapors need to be mitigated?). Sufficient background information needs to be provided in the SAP to explain what has already occurred at the site (e.g., releases, investigations, remedial actions, etc.). The SAP should also identify any regulatory requirements for the work (permits, etc.). In addition to reviewing this document, the DEQ technical contact should verify the regulatory requirements.

The SAP provides a summary of and framework for all work to be performed, including reporting documents, and the schedule for implementation. The SAP includes maps that show areas of contaminant sources and proposed sample locations for the investigation. This discussion need not be lengthy or overly detailed but should give an overall picture of how the problems described above will be resolved. It should also discuss any flexibility built into the plan should problems arise due to access, utilities, etc.

3.2.3 DATA REVIEW AND VALIDATION

The SAP contains a quality assurance (QA) section or plan for the project, which states the criteria used to review and validate (i.e. accept, reject, or qualify) data, in an objective and consistent manner. The QA section or plan identifies the level of validation that will be performed and describes how that level of validation will be completed (e.g., validation report). It also discusses how data issues will be resolved. Please verify the data validation needs with the DEQ technical contact.

When validating and reviewing vapor intrusion data, it is important to note that ambient/outside air samples are not the same as “blanks.” Ambient air sample results are evaluated and validated in the same manner as other air samples (indoor, sub-slab, etc). Results from ambient samples should not be used to qualify other investigation samples during data validation. Rather, the ambient air samples are used in the multiple lines of evidence data evaluation.

3.2.4 DATA MANAGEMENT

The SAP should describe the use of the electronic data deliverable (EDD) described in Section 5.3 and supplemental field VI sampling form included as Appendix C. Please confirm how the data should be managed with the DEQ technical contact.

DEQ is beginning to use a new database, Montana EQuIS, that has a data management component. In preparation for using this system, both field and laboratory data collected during site work should be formatted in DEQ’s EDD formats, in addition to any format that may be used by the party collecting the data. The DEQ EDD formats, reference values, and user guidance, including step-by-step instructions, are available on DEQ’s website: <http://deq.mt.gov/Land/rem/etreads>. Most of the

major laboratories in Montana are aware of DEQ’s EDDs. Please ensure that work plans and reports indicate that the DEQ EDDs will be used and uploaded into DEQ’s system.

3.3 Sampling Rationale

The rationale for collection of the various types of samples is identified in the SAP and is described below.

3.3.1 NATURE AND EXTENT

If contaminated groundwater and/or contaminated soil exists, but vapor presence and extent is unknown, a soil vapor investigation may be appropriate. This investigation should be designed to determine if, and to what extent (e.g., vertical and horizontal), vapors are present in the subsurface at concentrations exceeding screening levels (refer to Section 6).

This investigation can be conducted using the “worst first” approach by initially identifying “hot spots,” collecting “near source” samples (EPA, 2015a), and then progressively moving out or in using a phased “step-out” or “step-in” approach. This method may be appropriate for larger sites or for areas with no structures overlying the contamination. Please confirm with the DEQ technical contact if a “step-out” or “step-in” approach is appropriate. Please see Section 3.4.1 for additional information regarding soil vapor sampling.

3.3.2 EXPOSURE PATHWAY EVALUATION

If soil vapors are present at concentrations exceeding screening levels (see Section 6) and receptors are present or may be present (future use), an investigation should be conducted to determine if the VI pathway is complete. This investigation generally involves collecting indoor air, ambient outdoor air, crawlspace air, and/or sub-slab samples. In some situations, additional soil vapor samples may be appropriate to better define the extent of soil vapors and identify potential receptors. Please confirm with the DEQ technical contact. The data collected during this investigation may eventually be used to calculate site-specific clean up levels. Therefore, it is important that the data quality objectives be clearly defined.

3.3.3 EXPOSURE POINT CONCENTRATIONS

In addition to determining whether the VI exposure pathway is complete, indoor air samples may be collected to determine the concentrations of contaminants human receptors may be inhaling. Therefore, it is important to collect indoor air samples over an appropriate period of time (please see Section 3.4.4.).

3.4 Sample Types

3.4.1 SOIL VAPOR PROBE SAMPLES

Soil vapor probe samples can be used to define the nature and extent of soil vapor contamination. Soil vapor probes should be placed directly above the contaminant source (e.g. groundwater, soil, etc.). These samples are generally grab samples but can be collected over a longer period of time depending on the objectives of the sampling event. Fluctuations in barometric pressure may cause atmospheric air to migrate several meters into the subsurface affecting soil vapor results (Massmann and Farrier, 1992). Some states have taken the position that soil vapor samples collected less than 5

feet below ground surface may be affected by changes in barometric pressure, temperature, or breakthrough of ambient outdoor air from the surface (DTSC, 2003; IDEM, 2006; NJDEP, 2005; NYSDOH, 2006; ODEQ, 2010). Therefore, DEQ recommends that soil vapor probes be deeper than 5 feet unless otherwise approved by the DEQ technical contact. Please see Section 3.4.3 if groundwater is less than 5 feet below ground surface (bgs).

At undeveloped sites (where no structures are present), soil vapor probes may be the only means to evaluate potential VI issues. The collection of “near source” soil vapor samples may be appropriate to determine worst-case contaminant concentrations (EPA, 2015a). Ultimately, the placement of soil vapor probes will be determined on a site-specific basis, depending on the extent and magnitude of soil and groundwater contamination, soil lithology, contaminant dispersion, depth to groundwater, contaminant type, and current/future land development plans, if known.

At sites where existing soil or groundwater contamination data are insufficient, it may be necessary to collect soil vapor samples on a grid pattern. Due to the heterogeneity of the soils across the state, the spacing of the grid pattern will also need to be developed on a site-specific basis. For example, the grid pattern may need to be more tightly spaced in finer grained soils and less closely spaced in coarser soils. Coordinate the spacing of any potential sampling grid with the DEQ technical contact. Please see Section 4.1 for probe installation, sample protocols, and a diagram.

3.4.2 NEAR-SLAB VAPOR PROBE SAMPLES

Sub-slab vapor probe samples may not be feasible if a basement is finished or if the basement slab has been installed with radiant heat or a vapor barrier. If this is the case, near slab vapor probes may be appropriate. If used, near slab vapor probes should be placed as close to the structure foundation as possible. DEQ recommends no more than 10 lateral feet from the structure. Near slab vapor probes should extend vertically below the footings or basement floor of the structure. Near slab vapor probes should be collected from at least two sides of a single-family home (NJDEP, 2005). Structures with larger footprints, such as multi-family units, commercial/industrial or retail structures may need more near-slab samples. Locations will be based on site-specific conditions, including the location of the groundwater plume, the location of potential preferential pathways, and the location of other known contaminant source areas.

As explained in the previous section, DEQ recommends that soil vapor probes be at least 5 feet deep unless otherwise approved by the DEQ technical contact. Please see Section 3.4.3 if groundwater is less than 5 feet bgs. These samples are generally grab samples but can be collected over a longer period of time depending on the objectives of the sampling event.

Soil vapor concentrations can vary significantly between near slab vapor samples and sub-slab vapor samples (Abreu and Johnson, 2006; Luo et al, 2009). Because of this variability and because of the potential barometric pressure effect on shallow soil vapor samples, soil vapor samples should not be collected less than 5 feet bgs if extrapolating to represent soil vapor concentrations beneath a slab. If the nearby structure has a basement, the depth of the basement slab should be measured so that the sampling interval reaches below the depth of the slab. It may also be necessary to advance borings to a depth that is directly above the contaminant source. If groundwater contamination is the vapor source, the probe may need to be placed within two feet of the soil/groundwater interface.

Please consult your DEQ technical contact to discuss site-specific conditions. If possible, it may be appropriate to angle near slab vapor probes using directional drilling, so the sample is collected beneath the structure (EPA, 1992). Please see Section 4.1 for probe installation and sample protocols.

3.4.3 SUB-SLAB VAPOR PROBE SAMPLES

Sub-slab vapor probe samples are preferred over near slab probe samples because of the proximity of the sample location to the receptor, the ability to measure vapors directly beneath the slab, and the elimination of background interferences (ITRC, 2007). Sub-slab samples are collected by drilling a hole through a slab and collecting a soil vapor sample from the fill material immediately below the slab. Depending on fill material and site conditions the sample can be taken from immediately below the concrete slab to as deep as 12 inches below the slab.

The number of sub-slab soil vapor samples collected depends upon the size of the structure, in addition to the structure's construction and possibly other factors. There can be variability between sub-slab locations even beneath small structures. DEQ recommends a minimum of three sub-slab samples per structure where possible. However, at least one sub-slab soil vapor probe should be installed as close to the center of the structure foundation as possible in a standard size home and in a location where the potential for ambient outdoor air infiltration via floor penetrations is minimal. DEQ recommends that, for most structures, one sub-slab soil vapor probe sample be collected for every 1,000 square feet in foundations greater than 5,000 square feet (DTSC, 2005). Some buildings may be sitting on more than one foundation or slab (for example, if a building was expanded, or if it was built on different levels), and an effort should be made to collect sub-slab samples from the different parts of the building. If multiple sub-slab samples are being collected in a structure, they should be spaced appropriately throughout the structure as the structure footprint and construction allow (e.g., floor coverings, furnishings, utilities, etc.).

Frequencies for sub-slab sampling events are determined on a site-by-site basis, recognizing that for decision-making, DEQ typically needs a minimum of two sampling events during expected "worst-case" conditions (see DEQ's VI evaluation flowcharts in Appendix B). Typically, winter conditions will lead to worst-case vapor intrusion scenarios, when heating systems can create a chimney effect within the structure. However, at some sites, especially those with shallow groundwater, another type of "worst case" condition for VI may occur during the season when the groundwater table is the shallowest (known as high groundwater), and it may be appropriate to sample during high groundwater in addition to winter. High groundwater usually coincides with the rainy seasons but could also be influenced by irrigation systems. Resampling may be needed within the same season to confirm results. The DEQ technical contact should be consulted to determine when VI sampling should be conducted at a particular site.

As mentioned earlier, sub-slab samples should be collected concurrently with other VI samples. However, in order to minimize the potential for cross-contamination, sub-slab samples should generally be collected immediately after the indoor air sampling is complete. During the sub-slab probe hole installation, it is likely that some sub-slab vapors may escape to indoor air. If sub-slab vapors contain elevated levels of contaminants, fugitive sub-slab vapors could create false-positive results in indoor air samples.

DEQ prefers the collection of sub-slab soil vapor samples when any slab is present. If the structure is constructed with different methods and materials (basement, crawl space, dirt, cobblestone, etc.) in discrete portions of a building, sampling strategies should be designed to evaluate VI in each portion of the building. For instance, when a structure has both a concrete slab and an earthen floor, it may also be appropriate to collect a soil vapor sample from 5 feet below the earthen basement floor to evaluate the VI pathway. If the structure has both a concrete slab and a crawlspace it may be necessary to collect both a soil vapor sample and an air sample from the basement and the crawlspace for pathway analysis. See Section 3.4.5 for additional information on crawlspace samples. If the basement floor is earthen and no slab is present, collect a soil vapor probe sample from a depth of 5 feet below the basement floor. If encountering groundwater is a concern or a sample depth of 5 feet cannot be obtained because of the lithology beneath the structure or it is not possible to access the subsurface beneath the structure, it may be acceptable to install a shallower soil vapor probe beneath the basement floor, or collect an indoor/crawlspace air sample only. Please confirm what samples are appropriate for the site with the DEQ technical contact.

Sub-slab sampling may not be feasible if high groundwater exists near the base of the sub-floor. In these cases, the high moisture content in the soil can mask results and the reduced permeability may inhibit movement of soil vapor. Buildings in areas of high groundwater are often constructed with sumps in the basement floor for dewatering purposes. If a sump is present, it may be appropriate to collect an indoor air sample near the sump instead of collecting a sub-slab sample because the sump may act as a preferential pathway for soil vapor to migrate into the structure. Please confirm what samples are appropriate for the site with the DEQ technical contact. Please see Section 4.2 for probe installation and sample protocols.

3.4.4 INDOOR AIR SAMPLES

Indoor air samples are the most direct measurement of human exposure to contaminants and represent contaminants that are a result of VI as well as potential indoor or background contaminant sources. Indoor air samples should be collected immediately before sub-slab samples (see Section 3.4.3) and concurrently with crawlspace and ambient samples. The combination of indoor air, sub-slab vapor, ambient outdoor air sample results, and information obtained from building owner surveys (see Section 7.1.9) are a critical part of the “multiple lines of evidence” approach in identifying likely indoor air sources and verifying whether a VI contaminant source exists below the structures (NJDEP, 2005).

To characterize contaminant concentration trends and potential exposures, indoor air samples should be collected from at least the lowest two levels of the structure (e.g., basement and main level). The sample duration should represent the building-specific exposure scenario being evaluated (8-hour sample for a single work shift, 24-hour sample for a residence, etc.) (NYSDOH, 2006). Given that indoor air concentrations can be highly variable, longer-term time-integrated samples likely provide a more accurate assessment of exposure than short-term samples. Even in non-residential buildings, 24-hour samples may be appropriate because businesses and buildings can be occupied outside of the typical workday (e.g. with custodial staff, or staff with alternate work schedules). Additionally, 24-hour samples can be more convenient to coordinate than shorter duration samples. Summa canisters can be controlled to collect air samples over periods time up to

24 hours. Other sampling methods that allow longer collection times may become available. Please confirm the most appropriate exposure scenario with the DEQ technical contact.

The intake for indoor air samples should be between 3 and 5 feet above the floor, preferably near the center of the structure, to represent the breathing zone and the overall room conditions. This sample interval represents the breathing zone where people spend most of their time inside a structure (sitting or sleeping) (ITRC, 2007). However, it may be appropriate to place the sampling intake at a lower level for a sensitive population (e.g., school or daycare) (MADEP, 2002). Other indoor air sample locations may be appropriate depending on the objectives of the sampling event, for example an investigation of utility lines may necessitate air samples in bathrooms. Please see Section 4.3 for sampling protocols.

Prior to collecting indoor air samples, a chemical inventory and pre-sampling questionnaire are completed during a building owner survey (see Section 7.1.9). The information obtained in the building survey should be used to select indoor air sample locations in an environment that is representative of normal structure use (DTSC, 2005).

Background conditions for a VI study area should not be measured from indoor air samples of structures. Background, or “ambient air” samples should be collected from carefully chosen outdoor locations (see Section 3.4.6). Indoor air concentrations can vary greatly between structures, even if each structure is used for similar purposes (DTSC, 2005). Therefore, the use of a structure as a “control” is unreliable.

3.4.5 CRAWLSPACE SAMPLES

Crawlspace samples provide data for pathway analysis. Crawlspace air samples are generally collected following the same protocols as an indoor air sample for a period of up to 24-hours (ITRC, 2007), and are collected concurrently with indoor air samples and other VI samples. If a structure has both a concrete slab and a crawlspace, it may be necessary to collect both a crawlspace air sample as well as a sub-slab sample.

The Summa canister should be placed on the ground in the middle of the crawlspace. If the crawlspace is inaccessible, Teflon tubing inserted into the crawlspace and connected to the Summa canister may also be an acceptable sampling strategy. DEQ has found that metal plywood trim (C-channel shaped sheet metal used to protect the edge of plywood) works well as a conduit to insert the sample tubing up to 8 feet toward the center of the structure.

3.4.6 AMBIENT OUTDOOR AIR

Ambient outdoor air data can be used as a qualitative tool to provide information regarding outside influences on indoor air quality (DTSC, 2005). The ambient outdoor air sample should be collected from a representative upwind location every day that indoor sampling is conducted (MADEP, 2002; DTSC, 2005). Samples should be located away from obvious sources of volatile chemicals (e.g., automobiles, gas stations, lawn mowers, industrial facilities, or dry cleaners (ITRC, 2007).

Downwind samples can also be collected. The intake of the ambient outdoor air samples should be about 3-5 feet off the ground (at the approximate midpoint of the ground level of the structure)

(ITRC, 2007). In some circumstances, it may be appropriate to place the intake at a greater height (for example, to discourage vandalism). In general, DEQ recommends starting the collection of ambient air samples first (immediately prior to the start of indoor air samples) to evaluate the effect of outside air infiltration into structures. Please see Section 4.4 for sampling protocols.

3.5 SAP DEVELOPMENT: Area of Vapor Intrusion Investigation

3.5.1 PETROLEUM HYDROCARBONS – MBTEXN AND VPH FRACTIONS

DEQ typically evaluates potential PVI threats for all current or potential future structures within an area equal to or less than 30 feet laterally from petroleum hydrocarbon contaminated soil, soil vapor, or groundwater. In addition, a vertical screening distance is applied within that 30-foot lateral range. (see Section 2.4). Please confirm with the DEQ technical contact what the appropriate investigation area is for a specific site.

PVI investigation sampling may include a combination of indoor air, sub-slab, and soil vapor probe sampling locations. The number and locations of samples will depend on the contaminant source media (NAPL, soil, groundwater, soil vapor), contaminant source size, lithology, potential preferential pathways, and receptor types. For example, if there is a large mass of soil contamination, variable soil lithology, variable building construction, and/or NAPL near structures, an increased sample density may be appropriate within the area of investigation. Conversely, if groundwater contamination is the primary contaminant source of vapors, the vapor concentrations may be more homogenous, and a decreased sample density may be appropriate within the defined area of investigation. As discussed in Section 2.4, all structures falling within the VI investigation area do not necessarily need to be individually sampled. However, all current and future (contemplated to be developed) structures or properties within the investigation area should be assessed using a CSM. The potential for VI should be considered until the VI pathway is eliminated by applying the 3-Step approach as discussed in Section 2.4 or through PVI sampling. As an investigation progresses, the results of soil vapor sampling will be used to establish site-specific boundaries for areas with VI concerns.

When any part of a building's foundation is in direct contact with petroleum contamination, indoor air sampling and ambient outdoor air sample should be conducted. (see Sections 4.3 and 4.4). Indoor air sampling may also be appropriate when vapors are observed in a structure or a preferential pathway is identified such as a sump or utility corridor, etc.

If the building is not in direct contact with petroleum contamination and in the absence of preferential pathways, sampling should be phased beginning with using nested soil vapor probes (see Section 4.1). When soil vapor data cannot rule out the PVI exposure pathway, sub-slab sampling should be conducted (see Section 4.2). When sub-slab sampling cannot rule out the PVI exposure pathway, the need for crawlspace, sub-slab, and possibly indoor air-sampling should be assessed.

3.5.2 CHLORINATED SOLVENTS

VI at chlorinated solvent sites should be evaluated within an area 100 feet laterally from chlorinated solvent contaminated soil, soil vapor, or groundwater (see Section 2.3).

As discussed in Section 2.3, all structures falling within the VI investigation area do not necessarily need to be individually sampled, and phased sampling using the “worst first” approach may be appropriate. However, all current and future (contemplated to be developed) structures or properties within the investigation area should be assessed using a CSM. The potential for VI should be considered until the VI pathway is eliminated by evaluating the multiple lines of evidence as discussed in Section 7 or by directly sampling the structure. As an investigation progresses, the results of soil vapor sampling will be used to establish site-specific boundaries for areas with VI concerns.

Chlorinated solvents can biodegrade in soil and groundwater under anaerobic conditions via microbial oxidation-reduction reactions (ITRC, 2007). Importantly, biodegradation of chlorinated solvents can create additional compounds of interest. For example, anaerobic microbial degradation of PCE can lead to the formation of TCE or vinyl chloride down-gradient of the PCE source area. Daughter compounds, like vinyl chloride, may be considered more hazardous than the parent compound because of increased carcinogenicity (ITRC, 2007). Therefore, biodegradation products should be evaluated (i.e. sampled) in addition to the parent compound. Please confirm the appropriate analyte list for the investigation with the DEQ technical contact. In general, DEQ recommends analyzing for a full suite of VOCs until DEQ approves a site-specific limited analyte list.

3.5.3 OTHER CHEMICALS

Petroleum hydrocarbons and chlorinated solvents are the most common VOCs that cause VI issues. If other VOCs, certain SVOCs, emerging contaminants including fluorinated compounds, or inorganic substances such as elemental mercury are present, potential VI issues should be evaluated on a site-by-site basis. This evaluation may be similar to the evaluation of VI for petroleum or chlorinated solvents discussed in this guide. Please contact the DEQ technical contact for specific issues regarding other potentially volatile chemicals.

3.6 SAP DEVELOPMENT: Field Methods and Procedures

The SAP should include a description of the following information:

- Site Access
- Sampling Methodology
- Analytical Methods
 - The appropriate analytical method selected should be based on the potential contaminants of concern (described in detail in Section 5.1). In addition, the method detection or reporting limits need to be lower than the applicable screening levels or site-specific cleanup levels (See Section 6 for discussion). If reporting limits are higher than the applicable screening or site-specific cleanup levels, the results may

not be useful, and resampling may be needed. If it is not possible to achieve a given reporting limit, the lowest achievable limit should be chosen.

- Sampling/Field Equipment
- Sample Location(s)
- Underground Utility Clearance (if needed).
- Sample Containers and Certification
 - Please verify with the laboratory that the appropriate sample containers and certification methods are used for the chosen analytical method and method detection/reporting limits (See Section 5.2).
- Decontamination Procedures
 - Sub-slab or soil vapor probe installation equipment should be properly decontaminated between sample locations. DEQ recommends using dedicated sampling equipment (e.g., tubing) whenever possible for the collection of soil vapor samples.
- Disposal of investigation derived waste
- Site Restoration (e.g. slab/floor repairs)

3.7 SAP DEVELOPEMENT: Quality Control

Because of the sensitivity of the data and the low reporting limits and screening levels, quality control is crucial for VI investigations. The SAP should address the following VI quality control issues.

3.7.1 SAMPLE CONTAINER INTEGRITY

The integrity of the sample canister should be checked prior to sample collection. The laboratory prepares the canisters and establishes the necessary flow rate based on the barometric pressure and temperature inside the laboratory. Once in the field, temperature, and atmospheric pressure changes (including those due to elevation changes) will affect pressure in the canister and the rate of sample collection (MADEP, 2002). The initial field vacuum measurement of the canister might not be the same as was measured at the laboratory due to changes in elevation between the laboratory and the site location. For example, the laboratory may be close to sea level while the elevation of a site in Montana may be close to a mile above sea level. Please see Section 4.3 and 4.8.1 for additional information. The work plan should specify what minimum initial canister vacuum is acceptable and state that a canister with less vacuum will not be used. In addition, the target final vacuum measurement should also be specified in the work plan. Some vacuum (typically -5 inches of mercury (inches Hg)) needs to remain in the canister to confirm that there is no leakage during the transit back to the laboratory, and to ensure that the sample was collected over the specified sampling period.

3.7.2 SOIL VAPOR SAMPLING LEAK DETECTION METHODS

To verify the integrity of the soil vapor probe seal and the connection between the canister and the probe, a tracer test should be conducted prior to and/or during the collection of soil vapor samples from temporary and permanent soil vapor probes, near slab probes, and sub-slab sample probes. A properly conducted tracer test will verify if the probe surface seals are preventing ambient (indoor or outdoor) air from being drawn into the soil vapor sample. In addition to tracer tests, other testing

may be appropriate, including “shut in” tests, which are pressure/vacuum tests of the sampling train. The sampling plan should specify the leak detection method to be used and the criteria to be used to determine if a soil vapor probe passes or fails the leak detection test and what will be done if a soil vapor probe fails. Please refer to Section 4.7 for additional information on leak detection methods and criteria.

3.7.3 DUPLICATE SAMPLES

Field duplicate samples should be collected at a minimum of 10% (one duplicate per every 10 samples) of the soil vapor, ambient outdoor, or indoor air samples collected per sampling day per laboratory (HTGM, 2009). See Section 4.7 for a description of how duplicate samples should be collected. Please confirm the appropriate number of duplicate samples to be collected with the DEQ technical contact.

3.8 SAP DEVELOPMENT: Documentation and Reporting

At a minimum, the SAP should include a discussion of each of the following:

- Field notes (logbook, field forms, etc.)
- Sample designation and naming conventions
- Pre-sampling survey
- Sample labeling
- Sample receipts
- Chain-of-custody
- Photographs
- Packaging and shipment
- Reporting
- Data validation
- Electronic Data Deliverable (EDD) format
- Records management (where will the original records be maintained?)

Please confirm specific reporting needs with the DEQ technical contact.

3.9 SAP DEVELOPMENT: Schedule

The SAP should specify the schedule for the following:

- Sample access arrangements
- Pre-sampling survey
- Sample collection (per location if multiple locations)
- Sample results submittal to DEQ
- Resampling, if necessary
- Report submittal to DEQ

Please confirm the schedule with the DEQ technical contact.

4.0 Sampling Protocols

This section will discuss the proper sampling protocols for different sampling methods. Prior to implementation, a SAP should be submitted for DEQ review and approval. DEQ recognizes that the science and methods of vapor intrusion sampling continue to advance. New or different sampling protocols may be proposed and discussed with the DEQ technical contact.

4.1 Soil Vapor Sampling

Soil vapor probes may be installed by traditional drilling methods or direct-push drilling methods. Traditional methods such as hollow stem auger, sonic, or air-rotary can alter the subsurface through the introduction of air or heat, the smearing of the boring sidewalls, and the release of volatile contaminants. The newly installed soil vapor probe should be allowed sufficient time to equilibrate and should also be properly purged prior to the collection of any samples. Probe installation time should be recorded in the field logbook (DTSC, 2003). To allow for subsurface conditions to equilibrate, DEQ recommends the following minimum equilibration times prior to conducting purge volume tests, leak tests, and soil gas sampling:

- 20 minutes following probe installation for probes installed with the direct push method where the drive rod remains in the ground.
- 30 minutes following probe installation for probes installed with the direct push method where the drive rod does not remain in the ground.
- 48 hours following probe installation for probes installed with hollow stem drilling methods (depending on site lithologic or drilling conditions).

Probe equilibration times should be documented in the SAP, and questions about calibration times should be discussed with the DEQ technical contact.

DEQ recommends that permanent soil vapor probes be installed so that samples may be collected during different times of year and site conditions (such as high and low groundwater) that could influence soil vapor concentrations. However, temporary soil probes may be appropriate in some cases. Both soil vapor probe types are discussed below.

A temporary soil vapor probe is installed by advancing a steel rod into the ground. Since the annular seal consists of only native soil against the exterior of the steel rod, the best seal is achieved when the probe tip is smaller than the steel rod. The boring around the steel rod is temporarily sealed near the surface with bentonite and allowed to set for a minimum of 20 minutes prior to sample collection.

All temporary soil vapor probes or wells should be abandoned in accordance with Montana law (see ARM 36.21.670). Temporary soil vapor wells should be abandoned by completely filling the borehole with sealing material, such as bentonite, to within three feet of the ground surface in order to prevent vertical movement of water or vapors within the annular space.

Permanent soil vapor probes are installed by inserting 1/8-inch to 1/4-inch outer diameter tubing with a perforated tip to the desired depth. The borehole is filled with 10/20 silica sand around the perforated tip and then it is sealed with bentonite. Use of other material should be discussed with the DEQ technical contact. In many situations, multiple samples may be necessary to document the depth of worst-case vapor concentrations and establish whether vapors are attenuating with distance from the contaminant source. In these situations, multiple depth samples will be needed (e.g., at five feet bgs and at two feet above the vapor contaminant source, which might include the soil/groundwater interface) and more than one boring may be necessary. If multiple probes are inserted into the borehole, they will need to be sealed from each other with layers of bentonite. See Figure 2 for details on soil vapor probe installation.

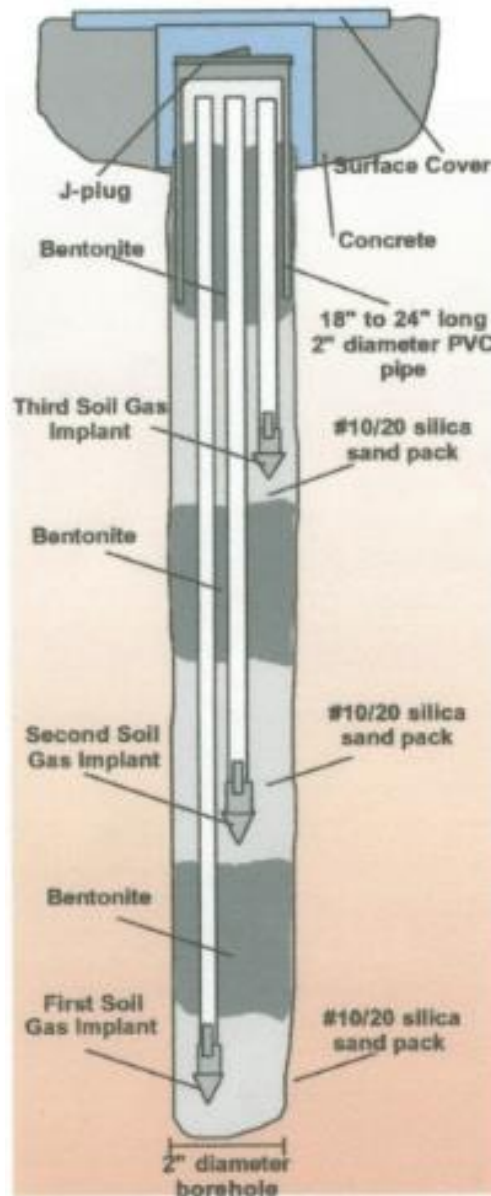


Figure 4.1.1. Figure of soil vapor probe, courtesy H & P Mobile Geochemistry.

Once the vapor probe is installed, a minimum of three volumes of air should be purged through the probe and associated tubing. The volume of air is defined by calculating both the interior volume of the tube itself and if it is installed in a boring, the volume of sand in the annular space around the probe tip between the layers of bentonite seal. Purging at a high rate could strip volatile compounds out of the subsurface soils and create a short circuit in the sampling train (i.e., drawing ambient outdoor air, instead of soil vapor). Therefore, it is recommended that purging be conducted at a maximum rate of 200 milliliters/minute (mL/minute). If the permeability of the geologic material is too low to allow sufficient flow, the probe should be purged to the maximum extent possible and then the air within the sand pack should be allowed sufficient time to equilibrate with the surrounding soil vapor. This time will vary based on geologic conditions. These factors can be evaluated when conducting equilibration testing. Samples of purged air may be field-tested with a PID and/or fixed gas meter to determine when these parameters have stabilized (EPA 2018).

Once the probe has been purged and field leak checks completed (see Section 4.7), a soil vapor sample (typically a grab sample) may be collected by connecting the probe and tubing to a Summa canister, a Tedlar bag, or a sorbent tube (see Section 4.8), as per the approved SAP. The sampling port can be designed so that a sample container can be attached through simple quick-connect or threaded connections.

Multiple samples from the soil vapor probes may be necessary on a site-specific basis. In situations where near slab or exterior soil vapor sampling is being done to evaluate contaminant patterns or to assess background contamination, the frequency of sampling should be determined on the data needs of the site.

4.2 Sub-slab Samples

The collection of sub-slab samples is the preferred investigative method to determine the concentrations of VOCs present in soil vapor beneath a structure because they provide the most direct measurement of soil vapors beneath the structure. Sub-slab samples are typically grab samples, but they can be collected over a longer interval depending on the DQOs. Sub-slab sampling involves drilling through the structure's concrete slab and collecting a soil vapor sample directly underneath, preferably within the engineered fill, which is likely to be more porous than the native soil. Please refer to Section 3.4.3 for information regarding the appropriate number of sub-slab samples to collect in a structure. Sub-slab sampling is generally not appropriate in slabs with radiant floor heat or with a vapor barrier underneath.

As a general rule, sub-slab sampling should be employed when the basement slab covers 50% or more of the building footprint. If the structure has both earthen floor and a basement slab, it may be necessary to collect a combination of sub-slab soil vapor samples from the concrete area and soil vapor samples from the earthen area (NJEP, 2005). **Appendix F provides step-by-step instructions and photographs of a relatively straight-forward sub-slab sampling procedure for one-time/temporary sub-slab samples.**

Prior to installing sub-slab probes, all sub-slab utilities (e.g., electric, gas, water, sewer) and structural tension rods should be located and clearly marked on the slab prior to drilling. These

structures may be located by evaluating the locations of above ground lines and utilities (e.g., furnace, water heater, toilet, etc.) and consultation with the property owner or a utility-locate contractor may be hired to perform the evaluation.

Sub-slab soil vapor probes are installed by drilling small-diameter holes through the concrete of the foundation slab. Typically, holes are 0.5 to 1.25 inches in diameter. Either an electric hammer drill or concrete corer is used to drill the holes. The sub-slab probes should be installed after removing any floor covering. The covering should be replaced to the property owner's satisfaction after the sample is collected. If the covering cannot be adequately replaced, another more suitable location should be chosen (e.g., a utility room, under an appliance, etc.). If a suitable location cannot be found, it may not be possible to sample beneath the structure and a near slab sample may be appropriate. The DEQ technical contact should be consulted to discuss this possibility. Once the hole is drilled through the concrete, the probe should be installed immediately. If the probe cannot be installed immediately, then the hole should be covered to prevent the mixing of sub-slab vapors and indoor air.

Sub-slab sampling ports can be either temporary (one-time use) or they can be designed for longer-term use (i.e. for multiple events over several years). EPA 2018 indicates that probes installed with flexible tubing, a hydrated bentonite seal, and concrete upper seal (as described in Appendix F) have a tendency to develop cracks as they dry out, and as a result should be used only for the day of sampling before they are abandoned (i.e. filled with concrete). Sampling ports designed for longer term use (for example, brass vapor pins set in silicone) may be sealed with a cap so that they can be sampled again in the future. Sub-slab samples should be collected from 3 to 4 inches below the slab in the sub-slab fill material.

Once the hole is drilled, a sub-slab sampling probe should be installed. The sub-slab sampling probe should be constructed of 1/8 inch or 1/4 inch stainless steel or other inert tubing and stainless steel compression fittings, with a permeable probe tip or an open tip. The annular space around the probe tip should be filled with 10/20 silica sand up to the bottom of the concrete slab. Other probe configurations may be acceptable and should be diagrammed in the site-specific SAP for approval by DEQ.

Once the 10/20 silica sand is placed around the probe tip, bentonite should be used to fill the borehole annular space between the probe tubing and boring wall from the top of the sand to within approximately 1.5 inches of the surface of the concrete foundation. Sufficient water should be added to hydrate the bentonite to insure proper sealing. Care should be used in placement of the bentonite to prevent post-emplacement expansion, which might compromise both the probe and cement seal. The probe tubing should be tightly sealed to the foundation slab with quick-setting contaminant-free Portland cement or a non-VOC sealant putty.

Another option for probe installation is the use of a vapor pin, which is a brass or stainless steel hollow pin set in a silicone sleeve, which is hammered snugly into the hole in the concrete.

For permanent or long-term probes, the concrete may be over-drilled so that the probe cover does not protrude from the floor surface. The probe may also be constructed with a recessed threaded

cap and a brass or stainless-steel threaded fitting or compression fitting so the probe completion is flush with the foundation slab.

The concrete/hydrated bentonite should be allowed to set for a minimum of 30 minutes after probe installation and prior to purging the probe, conducting the leak check, and collecting a vapor sample. Immediately prior to sampling, it is necessary to purge three volumes of soil vapor, calculated by the tubing volume and the volume of sand in the annular space around the probe tip prior to sample collection. Sub-slab vapor probes will have less annular space, so purge volumes will be much less than a soil vapor probe. The sub-slab port should be designed so that a sample container can be hooked up through simple quick connect or thread connections.

In order to document that purging is complete, a PID or other field meter may be used to measure parameters in aliquots of purged air to determine when readings stabilize (EPA 2018). Leak detection procedures should be performed as described in Section 4.7.

Decontamination of reusable sampling and probe installation equipment should occur at a predesignated location. Decontamination procedures are described in Section 4.9.

DEQ recommends that oxygen, carbon dioxide, methane, nitrogen, and hydrogen measurements also be collected during both soil vapor and sub-slab sampling events. These measurements may be useful in determining if biodegradation, particularly of hydrocarbons, is occurring in the subsurface vadose zone.

All temporary sub-slab soil vapor probes should be removed after sampling. All equipment that can be removed from each sub-slab sample location should be removed. If tubing cannot be removed, then the tubing may be cut flush with the surface and plugged to prevent surface water infiltration or vertical migration of vapors. If the sub-slab sample point is installed through asphalt or concrete, then asphalt or cement grout should be used to seal the sampling point. Photos should be taken of the sealed sampling point to document completeness.

4.3 Indoor Air Samples

Indoor air concentrations are the only measurement that reflect culmination of all variables in terms of human exposure to contaminants of concern in indoor air. To determine whether VOCs are present, and if so, whether their concentrations pose a risk to receptors, indoor air samples should be collected within structures over an appropriate period of time, as specified in an approved SAP. Indoor air concentrations can be variable, even over a few hours, so time-integrated sampling methods (methods that allow air to be drawn into a sampling media or container at a defined rate over a specified period of time) are preferred to grab sampling methods for determining long term risk. Indoor air “grab” samples may be appropriate in scenarios involving short term risk.

A great deal of communication, coordination, attention to detail, and scientific interpretation is needed for indoor air sampling. Because risk-based indoor air screening levels are typically very low, it is probable that other sources, such as household cleaners, cigarette smoke, dry cleaning, attached garages, and the use of any aerosols may influence the results of indoor air sampling.

DEQ recommends that an on-site visit be conducted prior to collecting any indoor air samples. The occupant should complete a survey (example in Appendix A). The survey should identify any potential source of vapors inside the structure, particularly sources that are site-specific contaminants of concern. However, DEQ recognizes that some indoor VOC sources may be integral to the building's structure (carpet, paint, glues, caulk, furniture, attached garages).

In the April 2011 version of DEQ's Montana Vapor Intrusion Guide, DEQ recommended removing indoor vapor sources from buildings prior to sampling. However, this may be impractical, not all indoor sources can be removed (paint, caulk, building materials), and the effects of indoor sources can linger (EPA 2015a). The length of time needed to clear residual vapors from indoor air sources can vary between buildings. Because of these factors, DEQ has determined that the decision to remove indoor air sources from buildings should be made on a case-by-case basis. If a decision is made to remove indoor sources, the sampler should coordinate with the occupant to remove any items that might interfere with the analytical results 24-72 hours prior to the collection of air samples (EPA 2015a). If possible, windows should remain closed for a minimum of one day before and for the duration of the indoor air sampling.

When collecting indoor air samples, sample containers or sample container intakes should be placed in the breathing zone located approximately 3-5 feet above the floor. Summa canisters are typically used because they are constructed out of an inert material that enables low reporting limits and they have a much longer holding time than alternatives such as Tedlar bags. This allows for adequate time to transport the sample to the laboratory. A minimum of one sample should be collected from each of the lowest two levels of the structure, if applicable. In addition, if an obvious route of entry is established during the initial site visit (e.g., sump in basement) an extra sample may be placed in that worst-case area. This worst-case sample does not necessarily need to be placed in the breathing zone. Please refer to Section 3.4.4 for more information.

Communications are necessary with the laboratory to equip the Summa canister with an appropriate flow controller for the specified sampling interval. Once the flow controller is properly connected to the Summa canister, the initial vacuum measurement, time, and sample identification should be clearly marked on the identification tag using a writing utensil that does not contain any VOCs that may cross contaminate the sample. Final vacuum measurements and the time should be recorded at the completion of the sample interval.

If there is a crawlspace, an air sample may be collected utilizing the same procedure as an indoor air sample. The Summa canister should be placed on the ground in the middle of the crawlspace. If the crawlspace is inaccessible, Teflon tubing inserted into the crawlspace and connected to the Summa canister may also be an acceptable sampling strategy. DEQ has found that metal plywood trim (C-channel shaped sheet metal used to protect the edge of plywood) works well as a conduit to insert the sample tubing up to 8 feet toward the center of the structure.

All non-disposable equipment that is connected to the Summa canister, such as flow controllers, should be decontaminated (see Section 4.9). The laboratory will supply cleaned flow controllers, splitting T's, and pressure gauges along with Summa canisters, and all this equipment is then sent back to the laboratory.

4.4 Ambient Outdoor Air Samples

For every day indoor air sampling is conducted, an ambient outdoor air sample should also be collected in the prevailing upwind direction. The ambient air samples should also be placed away/upwind from roads or other obvious sources of volatile contamination. The ambient outdoor air sample should be collected in the same manner and over the same interval as the indoor samples. There may be situations where more than one outdoor sample may be needed when the indoor air samples are being collected over a larger area and it is evident that the ambient outdoor air sample on one side of the site may not represent the ambient conditions on the other side.

If necessary, inert tubing may be connected to a canister to change the actual location of the air being collected. It is important to prevent water from entering a Summa canister. In outside air samples, DEQ has successfully used a loop of tubing connected to a canister to prevent precipitation from entering the canister.

Because the appearance of Summa canisters could raise concerns, DEQ has found it helpful to place a laminated notice on canisters left outside indicating “Air Sampling In Progress” and provide a contact name and telephone number should members of the public have questions. In addition, DEQ has also provided the local sheriff with a notice of when and where the canisters will be placed, along with a photograph of a Summa canister.

4.5 Buried Utility Line Sample

Scenarios exist where the most direct pathway into a structure is through the utilities. Backfill in utility trenches is generally more porous than the surrounding soil. This is especially true in lithologies consisting of silts and clays. Contamination following the path of least resistance may travel faster and further within the more porous backfill. Therefore, many utility trenches can act as preferential pathways for migration of contaminated vapors.

If the utility intersects groundwater or intersects soil contamination, dissolved phase VOCs or NAPL may impact the utility line by permeating through the pipe wall or by entering directly through mechanical defects, such as cracks and holes in the pipe or joints, and contaminate the utility or the water inside the utility. Contaminants may also enter as vapors within the air space inside utility lines (such as in sewers) and have a direct route to the inside the building. Buried utilities do not have to be in contact with contaminant sources to be susceptible to permeation of vapors. Contamination does not have to be fresh to pose a threat. In some cases, vapors have even permeated piping and gasket material (EPA 2002). Therefore, pipes and gaskets do not necessarily need to be in contact with contaminated soil or groundwater to be at risk if vapors are present.

The construction and condition of buried utilities can significantly affect a utility’s ability to transport contaminants, particularly with storm and sanitary sewer lines. The utility lines may be constructed with clay, or there may be cracks or gaps that allow inflow of vapors and groundwater at sites with shallow groundwater.

An initial utility survey may be necessary, including or followed by air sampling. Indoor air samples from locations at the terminus of utility lines, tap water samples from potentially impacted

water lines, and/or soil gas samples from along the utility corridor/trench may be necessary. Sampling of vapors from utility fill or of vapors inside utilities (for example, gases inside a sewer) needs careful planning, access, and coordination to ensure the safety of the samplers and the utilities.

Situations involving potential fire, explosion, or serious acute health risks should be referred to local fire or emergency response teams.

4.6 Flux Chambers

A flux chamber is usually a metal bowl that is sealed to the basement or slab-on-grade floor. A vacuum is applied to the chamber, followed by an incubation time where vapor flux is allowed to enter the chamber. The flux chamber then has a port from which the air sample can be collected.

Air sampling utilizing flux chambers has many limitations. If there is a basement, a flux chamber sample will not include the flux exchange of the four walls. If not properly placed, a flux chamber will not collect vapor from the worst-case vapor exchange areas, such as a crack in the basement slab. Flux chamber samples also will not account for the connection between the footing and the walls, nor will they detect any vapor exchange where underground conduits enter the structure. There are additional concerns as to whether the air-flow conditions inside a chamber match the air-flow conditions in a room. If the air flow in the chamber is less than the air flow in the room, fluxes could be reduced. If the airflow in the chamber are higher than in the room, measured fluxes could be incorrectly estimated. Fluxes may be over-estimated if upward advection is created, or underestimated if chamber air is pushed downward into the subsurface (H&P Mobile, 2003).

However, flux chambers may be useful under certain circumstances (e.g., an indoor spill where contamination has seeped into the concrete floor.) The use of a flux chamber should be discussed with the DEQ technical contact.

4.7 Quality Assurance/Quality Control

For a large sampling event, a minimum of one duplicate sample per 10 samples per sample type (e.g. sub-slab, indoor air, etc.) should be collected. A duplicate sample involves two Summa canisters connected to one controller via a specially designed splitter provided by the analytical laboratory, or, if a splitter is not available, two canisters can be set up side-by-side (collocated) and collected over the same time interval. Split samples may be collected by DEQ or its contractor. Split samples may be collected in the same manner as a duplicate sample or collected utilizing collocated canisters. The collection of blanks during VI sampling with Summa canisters is generally unnecessary, because the use of 100% clean certified canisters ensures that the sample media are not contributing to concentrations found in samples. However, if samples are being collected with sorbent media, a sealed (unopened and unused) tube of sorbent media can be used as a blank.

4.7.1 TRACER/LEAK TESTING

To verify the integrity of the soil vapor probe seal and the connection between the sample container and the probe, a tracer test is conducted prior to and/or during the collection of soil vapor samples from temporary and permanent soil vapor probes, near slab probes, and sub-slab sample probes. Leak checks may be performed using either gaseous or liquid tracers. In addition, the fittings between the probe and the canister may be leak-tested using a shut-in test (EPA 2018).

4.7.1.1 Gaseous Tracers (Helium Gas)

Gaseous compounds, such as helium, may be used as tracers for leak detection. Helium is DEQ's preferred tracer. Other gaseous tracers are available (EPA 2018), but the use of tracers other than helium should be discussed with the DEQ technical contact prior to sampling. To perform a leak check with helium gas, a shroud (e.g., polyethylene sheeting weighted at the ground surface, clear Rubbermaid container, etc.) is placed around the surface seal of the subsurface sampling probe and tubing, and filled with a minimum of a 20% helium gas that is measured in the field with a helium gas meter. The soil vapor probe tubing should then be purged while beneath the helium filled shroud. Helium gas readings should be recorded either directly from the sample tubing immediately following the purge, or from the purged soil vapor collected in a Tedlar bag. If helium gas concentrations collected from the purge vapor or directly from the sample tubing show helium concentrations to be less than 10% of the helium concentration in the shroud, then the surface soil vapor probe seal may be considered valid in the field and the soil vapor samples collected. Should the concentration of helium in the purge gas or sample tubing exceed 10% of the shroud concentration, the surface seal should be reset, and the leak check performed again. For an added check on the connections to the sampling container and verification of field readings, the soil vapor samples may also be collected under a suitably sized helium filled shroud and the sample analyzed for helium gas at the laboratory (ITRC, 2007).

Helium is available as ultra-high purity, high purity, and balloon grade. Balloon grade helium may be acceptable for most uses and is typically available in easier to handle canisters. However, there is a slight possibility that balloon grade tanks may contain a very small percent of atmosphere and these tanks may have been used previously for argon or nitrogen. High purity tanks contain 99.99% helium and the tanks are dedicated. Ultra-high purity tanks contain 99.999% helium, are dedicated, and are evacuated prior to filling. The grade of helium to be used should be discussed with the DEQ technical contact.

The buoyancy (or tendency to rise) of helium should be considered when leak-testing deeper soil vapor probes. The vacuum used to purge a deep probe should be high enough to overcome helium's tendency to rise (EPA 2018).

4.7.1.2 Liquid Tracers

Leak checks may also be performed using liquid tracers such as difluoroethane (DFA), isopropyl alcohol, pentane, and freons. DFA is the most commonly used liquid tracer for VI investigations in Montana. It is a refrigerant found in many aerosol products, most notably an office cleaning supply known as "Dust-Off". However, the purity of off-the-shelf products should be considered to determine whether they are appropriate for use as a tracer (EPA 2018). The use of liquid tracers should be discussed with the DEQ technical contact prior to sampling and adequate justification

should be provided for choosing DFA over helium. To perform a leak test with DFA or another liquid tracer, the tracer is sprayed onto towels, which are placed around the vapor probe surface seal. The soil vapor sample is then collected and later analyzed at the laboratory for the liquid tracer. A small amount of tracer in a sample does not necessarily indicate an unreliable sample. Tracer concentrations up to 1,000 µg/L are appropriate to account for the possibility that the starting concentration of the liquid tracer is not equal to the vapor pressure. This value corresponds to a 1% leak, assuming a starting concentration equal to the vapor pressure of the compound or a 10% leak if the starting concentration is only 10% of the vapor pressure, a conservative assumption (ITRC, 2007).

4.7.1.3 Pros and Cons of Helium vs. Liquid Tracers

Helium gas and liquid tracers both have advantages and disadvantages for their use as a tracer gas in performing surface leak checks on subsurface soil vapor probes (Table 1). Helium gas offers the advantage of providing real time data in the field, which can be used to correct leaking surface seals and ensure that valid soil vapor samples are collected, potentially eliminating costly re-sampling events. Helium gas is inert and will not raise laboratory reporting limits if it is present in the soil vapor sample. Using helium gas as a tracer does add to the amount of time needed to collect soil vapor samples and results in transportation of helium gas cylinders and use/rental of a helium gas meter. The use of liquid tracers as a tracer gas offers the advantages of being inexpensive and does not add any significant time to the collection of soil vapor samples. However, liquid tracers do not provide field data as to whether or not surface seals are tight and this may result in expensive re-sampling events should liquid tracers be found in the soil vapor samples at significant concentrations. If liquid tracers are found in soil vapor samples in significant concentrations, this may raise the laboratory reporting limits for all VOCs, making the data collected unusable. Helium may be a better tracer gas for collecting soil vapor samples from “tight” soils such as clays and silts as these soils have smaller pore spaces and contain less soil vapor, which results in a greater likelihood of leaks occurring in surface seals. The real time field data indicating whether or not surface seals are preventing ambient (indoor or outdoor) air from being drawn into the soil vapor sample can be invaluable in these situations.

Table 4.7.1.3: Advantages and Disadvantages to Helium and Liquid Tracers as tracers (ITRC, 2007)

Tracer	Advantages	Disadvantages
Helium	<ul style="list-style-type: none"> • Can check for leaks on site with handheld detector • Can quantify amount of leakage accurately • Does not interfere in TO-15 analysis • May work better in low-permeability soils 	<ul style="list-style-type: none"> • Balloon (“Party”)grade helium may be contaminated with low levels of VOCs • Process is more cumbersome than some others • Cannot be analyzed by TO-15 • Can be difficult to apply to sampling train connections • Helium’s buoyancy needs to be overcome to assess leaks in deep soil probes.
Liquid Tracers (e.g. DFA)	<ul style="list-style-type: none"> • Easy to use in identifying leaks • Can be detected by VOC analytical methods • Easy to use 	<ul style="list-style-type: none"> • Concentrations on sample train are estimated • Large leak may lead to VOC analysis interference. • No simple field screening method • May leave residual contamination on sample train • Off-the-shelf products may contain impurities

4.8 Sample Containers

There are different types of sample containers that may be used in different circumstances. In most cases, Summa canisters are the most appropriate sample container for VI investigation samples. However, there may be circumstances where Tedlar bags or flux chambers may be used for sample collection. In addition, sorbent tubes or cartridges may be needed to collect samples for SVOC analysis. Following is a detailed discussion on sample containers.

4.8.1 SUMMA CANISTERS

Summa canisters are used when COPCs are VOCs and EPA Method TO-15 and/or Air-Phase Hydrocarbons (APH) are needed. Summa canisters are constructed out of an inert material that minimizes reactions with the sample and maximizes the recovery of target compounds from the container; thus, enabling lower reporting limits and longer holding times. Canisters range in volume from less than 1 liter to greater than 6 liters (Air Toxics, 2007). Six-liter canisters are generally used to collect time-integrated indoor air and ambient outdoor air samples. One-liter canisters are generally used for taking grab samples or samples where higher reporting limits are acceptable, such as soil vapor or sub-slab samples. It may also be appropriate to use 6-liter canisters to collect soil vapor or sub-slab samples. However, indoor air and ambient outdoor air samples that will be analyzed for VOCs, including petroleum hydrocarbons, should be collected in 6-liter canisters. Please see Section 5.0 for additional discussion on analytical methods.

The laboratory selected to analyze the samples will provide the sampler with passivated stainless-steel canisters (Summa canisters), flow controllers, and vacuum gauges. Prior to canisters and flow controllers being sent out to clients, they are thoroughly cleaned, leak tested, and certified. The cleaning process consists of electropolishing and chemical deactivation to produce a surface that is nearly chemically inert (passivation). This cleaning process is crucial to the analysis of soil vapor or indoor air samples. Laboratories provide certification of Summa canister and flow controller cleaning.

Two types of certification are available: batch certification and individual certification. A batch certified Summa canister means that after a group of canisters and flow controllers is cleaned, one set is selected from that group for analysis to verify that the cleaning process was successful. Usually, the set with the highest air contaminants from the previous sampling event is selected to run the additional verification analysis. If that Summa canister and flow controller set passes the verification test, then it is assumed that the other canisters and controllers will pass the verification analysis as well. Therefore, a Summa canister that is batch certified most likely has not been tested to ensure that the cleaning process was a success. Individual certification requires that each canister and flow controller supplied to a client be tested and certified to below the method reporting limit for every compound that will be analyzed.

Sampling indoor air calls for extreme sensitivity, and individually certified canisters are critical to a successful sampling event. Therefore, individually certified Summa canisters and flow controllers are used to collect all indoor air samples. Additionally, ambient outdoor air sample canisters are also individually certified. A false positive in an ambient outdoor air sample, if considered in the

multiple lines of evidence when determining VI, may affect the action taken, adversely affecting those exposed to vapors where further investigation or remedial measures might otherwise be needed.

Soil vapor sample canisters may be 10% batch certified. However, samples collected in batch certified canisters are at risk for false positive results, which would likely lead to further sampling. Individually certified canisters may be necessary in subsequent follow-up rounds of soil vapor sampling after a positive result is detected.

For applications such as soil vapor or sub-slab samples, individually certified canisters may not be necessary. However, when sampling indoor air, individually certified canisters provide assurances for this sensitive sampling. For further discussion on appropriate sample containers and certification, see Section 5.

The maximum holding time for samples collected in a Summa canister for TO-15 and APH analysis is 30 days. Ship the canisters (plus vacuum gauges and flow controllers) back to the laboratory in the boxes in which they were originally sent. The laboratory will provide return shipping labels for convenience. Do not ship the canisters back to the laboratory on ice. Follow the proper chain of custody procedures.

When collecting soil vapor or sub-slab samples, it is appropriate to connect the Summa canister to a dedicated flow controller supplied by the laboratory to control the rate of the sample collection. The sample should not be collected at a rate that exceeds 200 mL/minute, in order to minimize risk of creating a short circuit. For time-integrated samples, the flow controllers are set by the laboratory to achieve a desired flow rate and thus, the desired sampling interval (e.g., 8-hour or 24-hour). Please discuss sample objectives and needs with the laboratory to ensure that the appropriate sample equipment is used.

The laboratory will provide dedicated sample tags attached to the Summa canister. Sample tags should not be switched between canisters because the sample tags provide decontamination information and generally link the canister to a specific flow controller. The sample identification (e.g. name, location, and time) should be neatly written on the canister tags at the time of collection. Never write on the canister. Beginning and ending vacuum measurements should be neatly written on the canister tags at the time of collection. Avoid using pens that contain VOCs (For example Sharpie pens) when completing tags and other paperwork.

Initial vacuums measured at the laboratory should be 30 inches Hg, but some vacuum may be lost in transit or affected by changes in elevation. A canister will lose approximately 1 inches Hg for every 1,000 feet of elevation gain. Therefore, initial vacuum measurements of 25-30 inches Hg are acceptable for locations in Montana. Canisters that contain a vacuum of less than 25 inches Hg should be considered unusable, unless otherwise agreed by the DEQ technical contact. At the conclusion of the sampling interval, it is desirable to have a minimum of 5 inches Hg of vacuum left to confirm that there is no leakage within the canister during the transit back to the laboratory. The

initial vacuum should be written on the sample tag at the beginning of sampling and the final vacuum should be written on the sample tag at the conclusion of the sampling.

4.8.2 TEDLAR BAGS

Tedlar bags may not have the appropriate detection levels for many vapor and indoor air samples. However, Tedlar bags may be appropriate for soil vapor probe purging, field screening, or on-site analysis. Tedlar bags may sometimes be used to collect soil vapor probe or sub-slab samples for petroleum hydrocarbon analysis (i.e., Air-Phase Petroleum Hydrocarbon; See Section 5.1.1). The DEQ technical contact should be consulted prior to the use of Tedlar bags for sample collection and analysis.

Tedlar bags, if utilized, should only be filled to half capacity to accommodate potential expansion/compression during transit. Overfilled bags may rupture during air transit.

Please discuss sampling objectives and method detection limits with the laboratory to ensure that the appropriate sample equipment is used.

4.8.3 SORBENTS

If SVOCs (generally compounds heavier than naphthalene) are COPCs at a site, then EPA method TO-13a (or other methods) may be needed. In some circumstances, EPA Method TO-17 may be used for VOCs. Please verify with the laboratory which analytical method is needed for specific SVOCs. Methods TO-13a and TO-17 collect samples using a sorbent (also called adsorbent) device.

Using a sorbent to collect an air sample normally involves “active” sampling, unlike an evacuated canister that can be filled “passively” by simply opening the valve (Air Toxics, 2008). Typically, a pump is used to draw soil gas through the sorbent tube, and the sorbent tube is then analyzed by a laboratory. A variety of adsorbent cartridges and pumping systems are available from commercial vendors. When using active pumping methods, it is important that the pump be calibrated and that the start/stop times of sample collection are recorded so that an accurate sample volume is determined. It is also important to be mindful of pump battery capacity or AC power needs when planning for active sampling.

The collection issues and criteria discussed elsewhere in this guidance (sample locations, analyte lists, etc.) apply when using adsorbents. In addition, to eliminate the chance for cross-contamination, it is essential that the soil gas be drawn through the sorbent by the pump, not pumped into the adsorbent. The use of two tubes in series is recommended to avoid breakthrough losses in areas of suspected higher concentrations. The sorbent, purge rate, and sample volume are determined through discussion with the analytical laboratory (ITRC, 2007). Also, please discuss the VI investigation DQOs with the DEQ technical contact.

Additional sorbent methods may be available, including passive sorption collection methods for longer-term sampling, and the use of such methods would be site-specific.

4.9 Decontamination Procedures

Because of the sensitivity of VI sampling and the low concentrations involved, the use of disposable sampling equipment whenever possible is highly recommended. However, probe installation equipment such as drills and drill rigs should be decontaminated between samples. After each use, drive rods and other reusable components should be properly decontaminated to prevent cross contamination. A standard decontamination procedure includes a 3-stage wash and rinse (e.g., wash equipment with a non-phosphate detergent, rinse with tap water, and finally rinse with distilled water); and/or steam cleaning (DTSC, 2003).

5.0 Laboratory Analysis of Vapor Samples

Laboratory analysis of vapor samples is an integral part of the assessment of the VI pathway. Specific analytical methods and appropriate quality control standards should be used to ensure that high quality data are used for assessment and VI decision making. This section addresses analytical needs for vapor sampling at petroleum hydrocarbon and chlorinated solvent sites.

5.1 Analytical Methods

Specific analytical methods are used to analyze various types of VI samples. The following sections discuss typical analyses for petroleum hydrocarbon, chlorinated solvent, and other VOC and SVOC contamination. Sites with multiple types of contaminants may need multiple analyses. Sites where little is known about the contamination may need analysis for more contaminants. As sample results become available, the analyte list and analytical methods used may be refined. The DEQ technical contact can provide guidance for specific site needs.

5.1.1 PETROLEUM HYDROCARBONS

DEQ recommends that all air samples at sites with volatile petroleum hydrocarbon contamination, such as gasoline, mineral spirits, kerosene, #2 diesel, jet fuels, and certain petroleum naphthas, be analyzed using EPA's *Determination Of Volatile Organic Compounds (VOCs) In Air Collected In Specially-Prepared Canisters And Analyzed By Gas Chromatography/Mass Spectrometry (GC/MS)* (TO-15), dated January 1999 (EPA, 1999b), and using the *Method for the Determination of Air-Phase Petroleum Hydrocarbons (APH)*, developed by the Massachusetts Department of Environmental Protection, dated December 2009 (MADEP, 2009).

Method TO-15 provides analysis of a multitude of VOCs which may vary by the laboratory. Prior to sampling, verify with the laboratory the analytes that will be included in the TO-15 method. Depending upon the site history and conceptual site model, it is generally appropriate to limit the analyte list based upon contaminants anticipated to be present in vapors at the site. A limited analyte list should be approved by DEQ.

At petroleum release sites, the TO-15 analysis should include lead scavenger's ethylene dibromide (EDB) and 1,2-dichloroethane (1,2-DCA) unless the DEQ technical contact advises that these contaminants are not COPCs for the site.

The APH method provides analysis of volatile petroleum hydrocarbon target compounds and ranges, namely:

- MTBE
- Benzene
- Toluene
- Ethylbenzene
- Xylenes
- 1,3-Butadiene
- Naphthalene
- C5-C8 Aliphatics
- C9-C12 Aliphatics
- C9-C10 Aromatics

Analytical reporting limits for the TO-15 analysis should be lower than the established screening or site-specific cleanup levels (see Section 6). The APH method will typically have a higher reporting limit than the TO-15 method, and target compounds analyzed using this method will not likely meet screening levels. Prior to sampling, discuss the analytes and reporting limits with the selected laboratory to ensure that the necessary COPCs will be included in the APH and/or TO-15 analysis, as laboratories' analyte lists typically differ, and verify that analytical reporting limits will be lower than the established screening level. It may be necessary to analyze samples using TO-15 selected ion monitoring (SIM) in order to achieve analytical reporting limits that are less than screening levels. If reporting limits that are less than screening levels cannot be achieved, the lowest achievable reporting limit should be requested.

After the initial samples are collected from a particular location in the vicinity of a petroleum release, the DEQ technical contact may determine that subsequent samples may be analyzed only for APH. This may be the case in a location where levels of contamination are high enough that they will be detected by the APH method, where no constituents are detected in the TO-15 analysis that cannot be detected by the APH method, and where soil and groundwater contaminant levels are well documented and are expected to remain static. As contamination drops to lower levels than the APH method can detect, the TO-15 analysis will once again be needed.

5.1.2 CHLORINATED SOLVENTS AND OTHER VOCS

At chlorinated solvent or other VOC release sites where VI is a concern, air samples should be analyzed by method TO-15. COPCs vary between solvent sites, and the analytes included in the TO-15 analysis will be determined using the CSM (see Section 2.0). Depending upon the site history and previous investigations, it is generally appropriate to limit the analyte list based upon contaminants anticipated to be present in vapors at the site. DEQ should approve limited analyte lists.

As with petroleum hydrocarbons, analytical reporting limits for the TO-15 analysis should be lower than the established screening or site-specific cleanup levels (see Section 6). It is likely the TO-15 SIM analysis will be necessary for chlorinated solvent sample analysis. After the initial samples are collected from a particular location, the DEQ technical contact may determine that subsequent samples can be analyzed using TO-15, rather than TO-15 SIM. This may be the case in a location where levels of contamination are high enough that they will be detected by the method and where soil and groundwater contaminant levels are well documented and are expected to remain static. As contamination drops to levels lower than the TO-15 method can detect, the TO-15 SIM analysis will once again be needed.

5.1.3 SVOCS

If SVOCS (generally compounds heavier than naphthalene) are COPCs at a site, then EPA's *Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling Onto Sorbent Tubes (TO-17)*, (EPA, 1999a), or another analytical method, may be needed. Please verify with the laboratory what analytical method(s) is appropriate for the COPCs. As discussed above, analytical reporting limits for the TO-17 analysis should be lower than the established screening or site-specific cleanup levels (See Section 6.1.3).

5.1.4 FIXED GASES AND OTHER ANALYTES

The fixed gases oxygen, carbon dioxide, methane, nitrogen, and hydrogen may be analyzed in the field or in the laboratory to support lines of evidence in a VI investigation.

Fixed gases can be used as a practical means of evaluating subsurface fixed gas concentrations relative to atmospheric levels. If sub-surface gases are distinguishable from atmospheric air, the different levels can be used to assess when atmospheric air has been removed during purging of the vapor sampling point. Additionally, analysis of fixed gases may show leaks in a sampling system if atmospheric levels of oxygen are detected at a subsurface sample point that is known to contain lower levels of oxygen.

Fixed gases may also be used to assess biodegradation at petroleum sites. Methane may be of interest in determining biodegradation and may be analyzed in conjunction with oxygen and carbon dioxide.

At sites with free product in an anaerobic aquifer, samples should be collected for methane. In this scenario, DEQ has seen elevated sub-slab methane concentrations that present a flammability safety issue.

Please discuss with the DEQ technical contact whether monitoring fixed gases in the field or in a laboratory is more appropriate in each case. In the field, fixed gases may be analyzed using a portable gas monitor. Samples analyzed in a laboratory will be collected in a Tedlar bag or Summa canister, and may be analyzed using ASTM method *D1946 - 90(2006) Standard Practice for Analysis of Reformed Gas by Gas Chromatography*, (ASTM, 2006) or EPA method 3C –

Determination of Carbon Dioxide, Methane, Nitrogen, and Oxygen from Stationary Sources, (EPA, 1996). Please verify with the laboratory which method they perform, and any sampling methodologies that should be followed.

If there are any other COPCs present at a site that are not mentioned in this document, please discuss sampling and analytical methods with the DEQ technical contact.

5.2 Laboratory Quality Controls

Once samples are received at the laboratory, they should be logged into the laboratory information management system. If the sample is in a Summa canister, the canister’s pressure will be measured and documented. Along with each batch of samples, the analytical method required laboratory quality control (QC) samples will also be analyzed. Laboratory QC parameters for APH, TO-15, and TO-17 are detailed in Table 2. These laboratory QC samples are described more fully in the text below the table. All QC samples and field samples will be injected with an internal standard that will be measured to demonstrate the consistency of the method.

Table 5.2. Laboratory Methods for Analysis of Air Samples

Analysis	Cost Range	QC Parameter				
		Tune	CCV	LMB	LCS	Lab Duplicate
TO-15 & TO-15 SIM	\$165-\$230	Required daily	Required daily	Required daily	Not required	Not required
TO-17	\$225	Required daily	Required daily	Required daily	Not required	Not required
APH	\$275-\$300	Required daily	Required daily & per batch of 20 samples	Required for each batch of 20 samples	Required for each batch of 20 samples	Required for each batch of 20 samples

Laboratories use a daily instrument performance **tune** to verify the mass calibration and resolution of the GC/MS prior to analyzing any other QC or samples. The instrument performance check standard used as the tune is an aliquot of bromofluorobenzene.

A **continuing calibration verification (CCV)** is the mid-level calibration standard used to check the initial calibration on a daily basis. It is analyzed on a GC/MS that has met tuning criteria prior to analyzing any other QC or samples. All compounds to be analyzed in the samples should be included in the CCV.

A **laboratory method blank (LMB)** is an unused, certified canister that has not left the laboratory. The blank canister is pressurized with humidified, ultra-pure zero air and undergoes the same analytical procedure as a field sample. The injected aliquot of the blank contains the same amount

of internal standards that are added to each sample. The LMB is analyzed after the CCV and before the samples to monitor for possible laboratory contamination.

The **laboratory control sample (LCS)** is a LMB that has been injected with the target and range compounds and is required for an APH analysis. The purpose of the LCS is to demonstrate that the laboratory can perform the overall analytical approach in a matrix free of interferences.

The analytical method requires the laboratory to prepare and analyze one **laboratory duplicate sample** for each batch of 20 samples in an APH analysis. The purpose of the sample duplicate is to determine the homogeneity of the sample matrix, as well as analytical precision. Sample duplicates are prepared in the laboratory by analyzing one sample in duplicate. Please refer to the APH analytical method for further discussion of precision and accuracy requirements for each of the QC samples mentioned above.

Laboratories should submit analytical reports with appropriate QC packages as determined by the project quality assurance project plan. Analytical results for APH, TO-15, and TO-17 need to be reported in $\mu\text{g}/\text{m}^3$. Reports should be submitted in hard copy and electronically, both in a portable document format (PDF) and electronic data deliverable (EDD) format. The EDD formats necessary to import laboratory data into DEQ's WMRD-EQuIS Database as well as step-by-step instructions are available via the DEQ MT-WMRD EQuIS Support website:
<https://deq.mt.gov/Land/rem/etreads>.

6.0 Screening Levels

6.1 Vapor Screening Levels

The following section discusses the various screening levels used in a VI investigation.

6.1.1 REGIONAL SCREENING LEVELS

For initial screening of soil gas/vapor, ambient air, sub-slab soil gas and indoor air data, DEQ compares concentrations to the most recent EPA Regional Screening Levels (RSLs) for residential and/or industrial air. The results of this screening step will generate a list of contaminants of potential concern (COPCs) for each data set, based on the residential receptor and the industrial/commercial worker receptor. Since the residential indoor air RSLs are the most protective of the exposure scenarios, if all gaseous contaminants at a site fall below those levels then additional screening may not be necessary. For sites with COPCs above residential RSLs and with additional receptors including trench and excavation workers that may be exposed to soil gas or buildings with unique exposures such as school buildings, churches etc. a more site-specific evaluation may be needed (see Section 6.1.5 below).

For each compound, EPA develops RSLs for both cancer and non-cancer effects, and the lowest (most conservative) of those screening levels is used for screening purposes and is displayed in EPA's RSL Summary Tables (see link at end of this section). EPA calculates non-cancer RSLs with a Target Hazard Quotient (THQ) of 1 and 0.1. Initial screening should be based on the THQ of 0.1 to account for multiple compounds that may impact the same target organs or have the same critical effects. Non-cancer risks are considered additive as exposure may affect the same organs or result in the same critical effects.

EPA calculates cancer risk using a 1×10^{-6} (or one in one million) excess lifetime cancer risk which allows for as many as 10 cancer-causing compounds to be present at their screening levels before the Montana-allowable 1×10^{-5} , (or one in one hundred thousand) excess lifetime cancer risk, is exceeded. All cancer risk is considered to be additive regardless of the type of cancer that may result from exposure.

Montana's screening process also incorporates state-determined indoor air background concentrations (see Section 6.1.3 and the Indoor Air Screening Flowchart in Appendix B). For any compound where the EPA indoor air RSL is less than Montana's indoor air background levels, the background level can be used for initial screening. When the EPA RSL is higher than Montana's background indoor air level, the EPA RSL can be used for screening. Since EPA updates their RSL tables on a regular basis, it is important to remember to check whether or not the update has triggered a change in the previously determined screening level.

The EPA RSLs and additional information on their derivation can be found at <https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables>.

6.1.2 AIR-PHASE HYDROCARBONS (APH) SCREENING LEVELS AND CALCULATOR

DEQ has developed generic screening levels for the petroleum fractions reported by the Massachusetts Air-Phase Petroleum Hydrocarbons (APH) method which are not found in EPA's RSL table. DEQ calculated these screening levels using the same assumptions as those used by EPA to calculate the indoor air RSLs (please see Section 6.1.1 for a discussion of this process). Table 6.1.2.1 displays the screening levels that should be used for the listed petroleum fractions. Consistent with DEQ's screening process, the calculated screening levels were compared to the Montana Background Indoor Air concentrations (DEQ, 2012) and if the background concentrations were higher than the derived screening level, the Montana Background Indoor Air level was used.

Table 6.1.2.1. Generic APH Fraction Screening Levels

APH Fraction	Residential Screening Level ($\mu\text{g}/\text{m}^3$)	Industrial Screening Level ($\mu\text{g}/\text{m}^3$)
Aliphatic (C5-C8)	94*	260
Aliphatic (C9-C12)	44*	44*
Aromatic (C9-C10)	10	44

*Montana Background Indoor Air concentrations (DEQ 2012)

DEQ has developed the APH Calculator, a generic screening tool for common petroleum compounds. This calculator is intended for use at PVI sites only and is **not appropriate for use at sites with any contaminants not listed in this calculator**. This calculator is not meant to be used with solvent sites or mixed waste sites containing a combination of petroleum and other contaminants. The calculator and instruction document can be downloaded from DEQ's website at <http://deq.mt.gov/Land/statesuperfund/aphvicalc>.

To use this calculator simply compare the soil gas, sub-slab soil gas, and/or indoor air analytical results to the screening levels shown in Table 1 of the calculator. Any compounds that exceed their corresponding screening levels in Table 1 of the calculator should be added to Table 2 of the calculator by clicking on the drop-down tabs in each cell until all compounds have been added. As compounds are entered into Table 2, the calculator will display the site-specific residential and industrial screening levels. These site-specific screening levels can be compared to the same analytical results to determine the vapor intrusion contaminants of concern (COCs) for a particular site.

6.1.3 SCREENING WITH THE MONTANA BACKGROUND INDOOR AIR LEVELS

In 2012 DEQ completed an investigation looking at typical indoor air concentrations from non-smoking residences around the state. This investigation was meant to provide background values to be used for screening that represented indoor air concentrations typically found in residential dwellings in Montana. DEQ's Montana Background Indoor Air investigation found several compounds (1,2-dichloroethane, benzene, VPH fractions, ethylbenzene, and naphthalene) present in indoor air at concentrations higher than EPA's indoor air RSLs. Table 5.1.3 of DEQ's Montana Background Indoor Air investigation report summarizes these compounds. For initial screening of

sub-slab, soil gas, and indoor air data, it is acceptable to incorporate these background concentrations in the screening process, along with other lines of evidence. These values can also be helpful in showing members of the public who are concerned about vapor intrusion that certain compounds can typically be found in indoor air at residences not impacted by vapor intrusion.

Montana's Background Indoor Air investigation report can be found on DEQ's website at: <https://deq.mt.gov/Land/statesuperfund/vaporintrusion>.

6.1.4 EPA VAPOR INTRUSION SCREENING LEVELS

EPA has developed Vapor Intrusion Screening Levels (VISLs) and a VISL Calculator for groundwater, near-source soil gas, sub-slab soil gas, and indoor air. The indoor air VISLs are the same screening levels (calculated with the same equations, toxicity information, exposure assumptions) as the EPA RSLs. The other, medium-specific VISLs are derived from the indoor air RSLs, but with default attenuation factors applied. EPA indicates that the primary objective of the VISL screening process is to identify sites or buildings that are unlikely to pose a health concern through the VI pathway (EPA 2015a). An exceedance of a VISL does not necessarily trigger mitigation or remediation, but generally indicates that additional evaluation of the VI pathway is warranted. EPA's VISL calculator, user's guide, and other information are available online: <https://www.epa.gov/vaporintrusion/vapor-intrusion-screening-level-calculator>.

The use of VISLs for groundwater, near-source soil gas, and sub-slab soil gas is not appropriate at all sites. According to EPA, "*A critical assumption...is that site-specific subsurface characteristics will tend to reduce or attenuate soil gas concentrations as vapors migrate upward from the source and into overlying structures,*" (EPA 2015a). VISLs are not appropriate at a site or building where conditions exist that would allow enhanced or unattenuated entry of soil gas into a building. Of key importance in the use of VISLs is that the following conditions and underlying assumptions are met:

- Groundwater is at least five feet deeper than a building's foundation.
- Buildings have poured concrete foundations that may be susceptible to VI (for example, through standard utility penetrations), but do not have significant openings to the subsurface that would readily allow soil vapor into buildings (sumps, large openings in the concrete, earthen floors, unlined crawlspaces).
- There are no significant preferential pathways including fractured bedrock or utility corridors.
- The vapor source at a site is not a landfill where methane generation is produced in amounts that induce advective transport in the vadose zone.
- The vapor source is not a pressurized gas line or other pressurized source. (Vapors from pressurized sources likely necessitate immediate response.)
- Vapor source cannot be of a type where concentrated vapors have been released within an enclosed space (likely at a commercial/industrial facility) and the density of the chemicals' vapor may result in significant advective transport of the vapors downward through cracks and openings in floors and into the vadose zone.

At this time, EPA does not generate tables of VISLs like it does for RSLs. The EPA VISL Calculator does allow the use of some site-specific parameters, including groundwater temperature, which users may enter, if known. For initial screening, users should enter into the VISL calculator a cancer risk of 1 in 1 million (10^{-6}) and non-cancer hazard index of 0.1.

Contaminants dissolved in groundwater are one part of the VI conceptual site model. DEQ reviewed EPA's Groundwater VISL calculator and determined for most groundwater contaminants, DEQ's Circular DEQ-7 Standards and EPA Maximum Contaminant Levels (MCLs) are numerically lower than EPA's Groundwater VISLs. However, under particular scenarios, some dissolved contaminants at concentrations less than their respective DEQ-7 Standard or MCL will still exceed the EPA VISL, and therefore pose a potentially unacceptable risk of vapor intrusion. As a result, when evaluating sites for vapor intrusion (when developing the site conceptual model and during screening), all detected volatile groundwater contaminants should be screened using the EPA Groundwater VISL calculator regardless of their concentrations. In circumstances where groundwater concentrations exceed Groundwater VISLs, additional factors may be considered (for example, vertical and lateral separation distances for petroleum sites) in determining whether a VI investigation is necessary. Coordinate with the DEQ technical contact to ensure that appropriate VISLs are being used and to determine whether a VI investigation is needed.

6.1.5 SITE-SPECIFIC EVALUATIONS AND CLEANUP LEVELS

Following initial screening and the determination of site COCs, it may be appropriate to develop site-specific cleanup levels (SSCLs). It is not appropriate to calculate numeric risks on a structure-specific basis since VI data are so variable. Cleanup levels should be developed for all compounds considered COCs for the site and should represent the current and future site receptors. Standard receptors should include the residential and commercial/industrial worker receptors however, other exposures and receptors may also be present at a site. The equations provided in the EPA's Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) (EPA, 2009b) and reproduced in the EPA Regional Screening Levels User's Guide (EPA, 2009a) are used to develop site-specific cleanup levels. Site-specific cleanup levels should be calculated to ensure a cumulative risk of 1×10^{-5} and a cumulative hazard index of 1 for each target organ or critical effect are not exceeded. Since the EPA Regional Screening Level tables are updated regularly, these tables generally include the most up-to-date toxicity information used for site-specific cleanup level calculation.

Cleanup levels may also be developed for site-specific receptors outside of the standard residential and industrial/commercial worker scenarios. For example, sites with school buildings or other buildings with varied use may need other exposures and receptors evaluated. The site-specific receptors and exposure scenarios should be discussed with the DEQ technical contact. Excavation and trench workers are also a site-specific scenario that should be discussed with the DEQ technical contact.

6.1.6 OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION LEVELS

Occupational exposure concentrations, such as those set by the Occupational Safety and Health Administration (OSHA), are not appropriate for use as screening or cleanup levels. First, these levels were calculated using out-of-date toxicity information and were developed to protect healthy adult male workers. They are based upon risk levels, such as 1 in 100 excess cancer risk, that are not appropriate for the situations addressed by this guidance. These levels do not account for exposure to multiple contaminants. Finally, OSHA levels are meant to be applied in the presence of a Hazard Communication Program, engineering controls, and other protective measures that are not likely to exist for contaminants released into the environment.

6.2 Attenuation Factors

DEQ's 2011 VI Guide did not allow the use of generic attenuation factors for VI decision-making. However, in this updated 2021 guidance, DEQ accepts the generic attenuation factors set forth by EPA (EPA 2015a). EPA's attenuation factors were calculated to protect human health while recognizing that, under specified conditions, a minimum level of attenuation occurs between the subsurface and indoor air. As with the VISLs, one objective of the EPA's default attenuations factors is to screen out buildings and sites that are unlikely to pose health concerns through the VI pathway. The attenuation factors in EPA 2015a are the same default attenuation factors used in the calculation of VISLs (see Section 6.1.4). As with the VISLs, the use of the generic attenuation factors depends upon meeting the criteria and factors bulleted in Section 6.1.4. The EPA attenuation factors should be used as part of a multiple lines of evidence approach, and site-specific data should be used to the extent possible.

In instances where site conditions are not consistent with EPA's generic model that underlies the VISLs and attenuation factors (see section 6.1.4), empirical evidence should be used for VI decision-making rather than attempting to apply generic attenuation factors.

Table 6.2, below, summarizes EPA's Recommended Attenuation Factors for Risk-Based Screening of the Vapor Intrusion Pathway in Table 6-1 of EPA 2015a:

Table 6.2

Sampling Medium	Medium-specific Attenuation Factor for Residential Buildings
Groundwater , generic value, <u>except</u> for shallow water tables (less than five feet below foundation) or presence of preferential vapor migration routes in vadose zone soils	1E-03 (0.001)*
Groundwater , specific value for fine-grained vadose zone soils, when laterally extensive layers are present	5E-04 (0.0005)*
Sub-slab soil gas , generic value	3E-02 (0.03)
“Near-source” exterior soil gas , generic value <u>except</u> for sources in the vadose zone (less than five feet below foundation) or presence of routes for preferential vapor migration in vadose zone soils	3E-02 (0.03)
Crawl space air , generic value	1E-00 (1.0)**

*The EPA attenuation factors for groundwater do not allow for a direct comparison of groundwater concentrations to indoor air concentrations due to the differing units and other factors. The EPA VISL calculator should be used to determine the relationship between groundwater concentrations and indoor air.

** EPA’s attenuation factor for crawlspace are is 1.0, indicating that there is no attenuation between crawlspace air and indoor air.

It is important to note that EPA’s attenuation factors apply to groundwater and soil gas, but not to contaminated soil. No reliable screening mechanism has been developed for determining if soil contaminated at specific concentrations results in VI. If volatile COPCs are present in the soil (see discussion regarding distance from the contaminant source in Section 2.3), additional data (soil vapor or sub-slab/indoor air) should be collected to determine if the COPCs are volatilizing from the contaminant source. Soil gas samples collected immediately above contaminated soil are referred to as “near source” samples (EPA 2015a). Based upon site-specific conditions the VI investigation area may extend into areas where VOCs are present in groundwater or soil at concentrations less than the DEQ-7 standard or the RBSL. Soil vapor data can be used to determine if COPCs are present in soil vapor and help define the area of investigation.

It is not appropriate to use radon samples to determine site-specific attenuation factors for vapor intrusion of VOCs (DEQ, 2009a and b), because radon and VOCs may migrate differently. However, as discussed in Section 7.1.4, radon measurements can be used as an indicator to help plan the timing of vapor intrusion investigations.

6.3 Vadose Zone Degradation

Studies have shown that, under some conditions, aerobic biodegradation in the unsaturated zone can significantly degrade petroleum hydrocarbon vapors (Lahvis et al. (2013a), USEPA (2013a), Davis, et al., 2009; Luo, et al. 2009; Lundegard et al., 2008, DeVaul, 2007; McAlary et al., 2007; Abreu and Johnson, 2006; Sanders and Hers, 2006; Pasteris et al., 2002; Roggemans, et al. 2001; Hers et al., 2000; Fischer, et al., 1996). However, the rate of degradation for petroleum hydrocarbons in the vapor phase has not been quantified (NJDEP, 2005). Unlike petroleum hydrocarbons, chlorinated VOCs have not been found to biodegrade under aerobic conditions in the unsaturated zone (EPA 2015a).

A study conducted by Lundegard, et al. (2008) suggests that the significance of VI into a building overlying an aerobically biodegradable source (i.e., petroleum-impacted soil) depends upon the relative position of the vapor source and building, and the rate of oxygen (O₂) transport from the atmosphere to the soil vapor beneath the building. Some studies have shown that when O₂ is present in the soil profile, hydrocarbons vapors degrade or are absent (Davis, et al. 2005; Davis, et al 2004; Ostendorf, et al. 1996). The magnitude of biodegradation of hydrocarbon vapors is related to the availability of oxygen, subsurface hydrocarbon concentration distribution, and hydrocarbon source concentration and depth (Abreu, et al., 2009). Due to aerobic biodegradation in the vadose zone at sites contaminated with only petroleum hydrocarbons, lateral and vertical separation distances can be used to screen sites for PVI. These factors should be considered on a site-by-site basis when evaluating VI. Please confirm with the DEQ technical contact what VI investigation information is needed.

7.0 Data Evaluation

Once VI data are collected, the data are validated to determine whether they are of adequate quality for decision-making. A thorough data validation is necessary. The data validation includes evaluating holding times, sample condition, Summa canister pressures, instrument performance and calibration, duplicates, laboratory quality assurance/quality control samples, and any other information to determine the quality of the data (EPA, 1999c; EPA, 2001; EPA, 2006; EPA, 2008a). Since VI decisions may be based upon very low concentrations, having valid data are particularly important. A tool for conducting a thorough data validation is available at <https://deq.mt.gov/Land/StateSuperfund/resources>. If data validation indicates that data are unusable or that the data are biased, resampling under worst case conditions may be necessary.

7.1 Multiple Lines of Evidence

As recommended by the EPA and ITRC, multiple lines of evidence should be used throughout the process of evaluating VI data. The following sections describe the primary lines of evidence to consider. Uncertainty in the data will lead to the use of conservative assumptions in risk management and other decisions.

7.1.1 VOC CONCENTRATIONS IN VARIOUS MEDIA

In general, samples from only one media do not provide sufficient information for VI decision-making. Rather, a combination of soil, groundwater, soil vapor, sub-slab, near-slab, crawlspace, and indoor air data for the site should be used to determine whether a subsurface contaminant source exists and whether a pathway into indoor air exists.

7.1.2 PROXIMITY OF STRUCTURE TO CONTAMINATED MEDIA

Both vertical and lateral proximity of structures to contaminated media should be considered in VI decision-making. It may be appropriate to extend the initial VI investigation of 100 feet to a greater distance from the edge of the dissolved plume depending upon the COPCs (see Section 2.3), the conceptual site model, the presence of preferential pathways, and actual sample results. It is important to remember that vapor sources may include residual soil contamination and high concentrations of soil vapor, as well as contaminated groundwater or NAPL. It is possible that all contaminant sources of vapors at a given site may not be characterized. Therefore, additional investigation may be necessary to ensure that all contaminant sources of VI have been adequately defined.

7.1.3 CONCENTRATION GRADIENTS

The relative concentrations of COPCs in different locations/media may be considered as a line of evidence, particularly when evaluating the presence of indoor air sources. In the absence of indoor air sources, it would be expected that COPC concentrations in indoor air that are a result of vapor intrusion would be less than the COPCs in the sub-slab air.

7.1.4 WHETHER SAMPLES WERE COLLECTED DURING WORST CASE CONDITIONS

Worst case conditions typically occur during the winter months when the ground is frozen for most facilities in Montana. Not only are vapors limited in their ability to travel through soil into ambient outdoor air during this time of year, but heated structures can create a chimney effect that can draw in vapors. In addition, because of the extreme winter weather conditions that can occur in Montana, structures are typically well insulated and kept closed during the winter, thereby allowing vapors to accumulate indoors. Indoor air and sub-slab samples should be collected during the winter for VI decision-making. However, at some sites contaminated groundwater may vary significantly in elevation throughout the year. Groundwater can rise to shallow depths under high water table conditions during the spring or early summer, thus affecting VI. Indoor air and sub-slab sampling may be necessary during high water table periods to determine if vapor intrusion conditions have worsened.

Long term investigations of vapor intrusion study sites (Sun Devil Manor in Utah, for example) are providing evidence that suggest various methodologies may be available to track and predict “worst case” times for VI (i.e. when VI is “turned on”). These methods include using temperature, pressure, and radon as indicators of VI. The most straightforward (and least invasive) method is the use of differential temperature for timing of VI sampling. According to Schuver, 2019, when the difference between indoor and outdoor temperature averages 38 degrees F over 24 hours, the chances of collecting a worst-case indoor air sample in Utah are increased significantly. Thus, if an

indoor air temperature of 68 degrees F is assumed, then worst case VI would be likely to occur when the average outdoor air temperature over 24 hours is less than 30 degrees F. These findings support the collection of VI samples in the winter in Montana, preferably when conditions are very cold. For more information about using differential temperature as an indicator VI, please refer to EPA's Science in Action fact sheet entitled Measuring Temperature as an Indicator for Vapor Intrusion Studies (EPA, 2020a).

The timing of VI sampling may also be supported by trends in longer-term, continuous radon measurements and/or pressure measurements. EPA has prepared fact sheets that provide more information about the use of radon and pressure measurements in VI studies (EPA 2020b and EPA 2020c). The use of these VI indicators should be discussed with the DEQ project manager and outlined in the DEQ-approved work plan.

7.1.5 TEMPORAL VARIABILITY

Long term investigations at vapor intrusions sites have found that contaminant concentrations in indoor air that are a result of VI, as well as sub-slab concentrations, can vary significantly over time (EPA, 2015a). As described above, in Section 7.1.4, sampling for VI should be planned for worst-case VI conditions.

More than one round of VI samples will generally be necessary to determine whether temporal variability exists within a structure. While indoor air concentrations may be lower at certain times of the year than others, decisions should be based upon the worst-case conditions.

The timing of multiple rounds of VI sampling at a building/site should be considered, and decisions regarding the time between sampling will be made on a site-specific basis. EPA makes no specific recommendations regarding time between VI sampling events, other than to say that multiple events should be spaced to allow for some assessment of temporal variation (EPA 2015a). The State of Wisconsin (Wisconsin, 2014) recommends VI sampling intervals as short as 4 weeks. Enough time should be scheduled between sampling events to allow an increased chance for collecting samples during a period of reasonable maximum exposure (Schuver 2019). Back-to-back VI sampling may be acceptable in some circumstances (for example, where access is problematic and multiple days of access over a longer timeframe are not possible).

7.1.6 THE TIME NEEDED TO REMEDIATE THE CONTAMINATION

The length of time anticipated to remediate a site should be considered in determining whether a VI investigation is necessary and in determining the need for mitigation measures. At facilities where cleanup of contaminant sources is anticipated to occur within a short time period, such as one year, a VI investigation may not be necessary. If cleanup goals are not achieved in the anticipated timeframe, a VI investigation at a later date may be necessary. In addition, if VI is found to be occurring above acceptable screening levels but it is possible to implement a remedy that may address the contaminant sources within a short time period, such as one year, mitigation of particular structures may not be necessary. Again, if the cleanup goals are not achieved in the timeframe projected, mitigation may be necessary at a later date. For facilities or sites with

contaminant sources near structures for which remediation will not likely be complete for an extended period of time, a VI investigation and mitigation may be necessary if VI is found to be occurring above acceptable risk levels.

7.1.7 WHETHER THE DATA SUGGEST A SIGNIFICANT CONTAMINANT SOURCE EXISTS DIRECTLY BELOW THE STRUCTURE

If samples collected from soil, groundwater, soil vapor, or sub-slab indicate that product or heavily contaminated soil or groundwater exists below a structure, mitigation of the structure may be necessary regardless of whether indoor air samples are collected or whether indoor air sampling indicates that unacceptable risks from exposure to indoor air currently exist. For example, if sampling indicates that LNAPL exists under a home and subsurface vapor concentrations are several orders of magnitude above the screening levels, mitigation to prevent any VI from occurring in the future may be necessary whether it is currently occurring or not.

7.1.8 BUILDING CONSTRUCTION AND CURRENT CONDITIONS

Building construction and the current condition of the structure should be considered in making VI determinations. The building substrate and the structural integrity of the structure can play a significant role in VI. For example, structures with radiant heat in the slab or a vapor barrier, and structures like mobile homes with crawlspaces may not be as likely to have VI as other types of structures. Structures with basements without slabs or with thin or highly degraded slabs may be more likely to have VI.

7.1.9 BUILDING OWNER SURVEYS AND THE POTENTIAL CONTRIBUTION OF INDOOR SOURCES

Building owners should complete surveys for all structures requiring VI sampling (See examples in Appendix A). These surveys should be as detailed as possible in identifying and documenting potential indoor sources of the contaminants of concern for the structure. The questionnaire should include, but not be limited to, a floor diagram, showing the floor layout, chemical storage areas, garages, doorways, stairways, basement sumps, utilities entering/exiting the structures, elevator shafts, and any other pertinent information (NYSDOH, 2006). Appendix A includes questionnaire examples for both residential and commercial/industrial properties. If a structure includes both types of usage, both questionnaires should be completed. Potential indoor sources (i.e. paints, gasoline cans, gun cleaners, etc.) and the consumer products' names and locations should be documented on the questionnaire. In buildings with many chemicals (for example, beauty salons, automotive/contracting supply stores, floral shops, service stations, etc.), taking photographs of chemical storage areas can be helpful. On a site-specific basis, removal of some indoor air sources prior to sampling may reduce indoor source interference with VI sample results.

Indoor air sample data may be necessary from multiple levels of a structure, as well as substructure sample data, to determine whether indoor air sources may be contributing to indoor air contaminant concentrations. If concentrations indoors are higher than those below the structure or concentrations on upper levels are higher than those on lower levels, an indoor source may be present. However, under this scenario, it is also possible that subsurface contaminants have traveled

via preferential pathways (i.e. plumbing) to an upper level of a building. Indoor sources may include contributions from attached garages. If VI and indoor sources are both contributing to indoor air concentrations, mitigation may be necessary to reduce the indoor air concentrations by removing the amount contributed by the subsurface contaminant source. In cases where indoor sources may be contributing to elevated vapor concentrations, DEQ can assist the property owner regarding ways that they can reduce these concentrations.

In August 2012, DEQ published the results of its indoor air sampling investigation of 50 non-smoking residential homes across Montana in both rural and urban areas to determine “typical” background indoor air quality in the state (DEQ, 2012). The results of the Montana Typical Indoor Air investigation can be used to evaluate indoor air sample results in the context of indoor air levels typically found in Montana homes not impacted by vapor intrusion.

7.1.10 The Potential Contribution of Outdoor Sources

Ambient outdoor air samples should be collected every day that indoor air samples are collected. Ambient outdoor air concentrations may impact indoor air concentrations. However, VI sites in Montana have shown that indoor air concentrations are not always as high as outdoor concentrations. Therefore, ambient outdoor air concentrations should not simply be subtracted from indoor air concentrations. The contribution of outdoor ambient air concentrations should be considered on a site-specific basis as part of the evaluation of indoor air concentrations.

7.1.11 REPORTING LIMIT COMPARISON TO SCREENING LEVELS

Reporting limits for indoor air and soil vapor samples should be low enough so that the data may be used to determine whether screening levels are exceeded and so that samples collected from below the structure may be compared to those collected from inside.

7.1.12 CONTAMINANT RATIOS IN VARIOUS MEDIA (E.G., INDOOR AIR, SOIL VAPOR, GROUNDWATER, ETC.)

The presence and concentrations of various contaminants in various media at the site may be evaluated relative to other media at the site. For example, if the predominant contaminant in soil vapor at a site is PCE with lower concentrations of TCE, then one can expect that the same relative concentrations would be found in indoor air impacted by VI from soil vapor. If TCE concentrations in indoor air exceed those of PCE, an indoor source likely exists. It is important to consider whether other lines of evidence indicate that a subsurface contaminant source may also be impacting indoor air at unacceptable levels. Removal of potential indoor sources and resampling may resolve these issues. When considering ratios of COPCs in groundwater relative to soil vapor and indoor air, it is important to recognize that the partial pressure of a volatile solute is dependent upon both the mole fraction (concentration) of the compound and the vapor pressure of the compound. For example, while TCE and PCE could be present in groundwater at equimolar ratios ($[TCE] = [PCE]$), the vapor pressure of TCE (approximately 58 mmHg) is more than three times greater than that of PCE (approximately 18.5 mmHg), and would result in TCE being a more prevalent constituent in the soil vapor directly above the contaminated groundwater.

7.1.13 SAMPLING RESULTS FROM NEARBY STRUCTURES

When questions exist regarding vapors within a particular structure, sampling results may be evaluated from nearby structures to help resolve these questions. For example, it may not be possible to collect a substructure soil vapor sample from a particular structure. In such a case, substructure soil vapor from nearby structures (as well as other lines of evidence) may be considered in determining whether indoor air concentrations in a structure are potentially attributable to subsurface contamination.

7.1.14 MODELING

For initial site screening, the EPA's VISLs should be used. Modeling results using the currently available EPA Vapor Intrusion Model (EPA 2004, initially developed by Johnson and Ettinger) may be appropriate in limited circumstances. The current model likely either over or underestimates VI impacts and does not always provide a reliable prediction of actual conditions. The model should only be used where no reasonable alternative is available. Model results may not be considered as conclusive evidence regarding VI.

7.1.15 EVIDENCE OF BIODEGRADATION

Data regarding the fixed gasses (oxygen, carbon dioxide, methane, nitrogen, and hydrogen) in sub-slab and soil vapor samples may be needed to verify biodegradation of contaminants in the vadose zone. This information along with relative concentrations of various contaminants in one media compared to concentrations in other media may be useful to determine whether degradation of vapors may be occurring at a rate that may inhibit VI.

Compound specific isotopic analysis may be able to provide data to show whether these contaminants are being biodegraded versus attenuated by dilution, absorption, and other physical factors (ITRC, 2011).

7.1.16 AVERAGING SAMPLE RESULTS NOT ACCEPTABLE

Averaging of sub-slab soil vapor concentrations is not acceptable because averaging does not represent potential worst case, and averaging is not the most protective of human health. Decisions regarding VI should be made on reasonable maximum exposure concentrations. All the sub-slab data collected should be considered in VI decision making, but the highest sub-slab soil vapor concentration is typically used for regulatory decisions. Please verify the appropriate number of sub-slab samples needed with the DEQ technical contact.

7.1.17 PROFESSIONAL JUDGMENT

DEQ may consider any other information available for a site using professional judgment to determine whether VI is occurring.

7.1.18 UNCERTAINTY

Uncertainty is inherent in the VI investigation process. The higher the degree of uncertainty associated with a given VI investigation, the more conservative the risk management decision-

making should be in order to protect public health. The collection of additional data to address uncertainties is recommended.

7.2 DEQ Vapor Intrusion Decision-making Flowcharts

Appendix B provides VI decision-making flowcharts for use once indoor air and substructure sample results are available. There is one decision-making process for the first round of samples where many paths lead to resampling. The second flowchart is for the second round of samples and the paths lead to a given decision, typically either mitigation or no further VI action. These flowcharts pertain to the VI pathway only and are not meant to result in a comprehensive determination that no further remedial action is needed at a contaminated site. These flowcharts are meant to incorporate the decision-making process described above but are not necessarily inclusive of all factors that may be considered in site-specific decision making.

A note included on the flowcharts refers to significant differences. When a great deal of data is available, it may be possible to use statistics to determine whether differences between populations are significant. However, with VI data, one may be comparing one indoor air sample with another indoor air, ambient outdoor air, or substructure sample. In this case, the use of statistics may not be appropriate. In terms of the flowchart, “significant” typically means an order of magnitude or more. However, there may be situations where it is appropriate to conclude VI is occurring even when the difference is less than an order of magnitude. For example, where a sub-slab concentration is $15 \mu\text{g}/\text{m}^3$ and the associated indoor air concentration is $3 \mu\text{g}/\text{m}^3$, this information along with other available lines of evidence may lead to the conclusion that VI is occurring. The same conclusion might not be drawn where a sub-slab concentration is $3 \mu\text{g}/\text{m}^3$ and the indoor air concentration is $0.6 \mu\text{g}/\text{m}^3$. It is important to remember the determination of significance is only one piece of evidence among the multiple lines of evidence that are considered. Resampling may be very helpful in situations where the determination of significance is unclear.

The term “habitable” is included on the second flowchart. Crawlspace, root cellars, and other very small subsurface levels of a structure are not considered habitable unless evidence exists that people do spend a reasonable amount of time on that level.

8.0 Mitigation and Property Development

Once a VI pathway is found to be complete and assuming DEQ has determined that action to interrupt the VI pathway is necessary, mitigation techniques need to be considered. Mitigation interrupts the VI pathway either by preventing contaminated soil vapors from entering the structure or by removing or treating the vapors that are inside the structure. These methods are used as a response to VI until the contaminant source causing VI to occur has been effectively remediated and the system is no longer needed to ensure protection of public health. Individual regulatory programs may have specific requirements for selecting remedial alternatives; please consult with the DEQ technical contact for the site to ensure the appropriate requirements are met.

The techniques for mitigating VI are similar to those used for mitigating methane and radon intrusion. The options available are different for existing and proposed structures and are discussed in detail below. The goal of this section is to provide readers with information on:

- various widely accepted mitigation techniques;
- installation and design of mitigation systems;
- post-mitigation testing;
- operation, maintenance, and monitoring (OM&M) of mitigation systems; and
- termination of mitigation system operations.

For more detailed information regarding the different mitigation strategies presented in this section, please refer to the 2009 California Environmental Protection Agency Department of Toxic Substances Control Vapor Intrusion Mitigation Advisory (DTSC, 2009) or the 2008 EPA Engineering Issue Indoor Air Vapor Intrusion Mitigation Approaches (EPA, 2008b) documents referenced at the end of this guidance document.

8.1 Methods of Mitigation

The appropriate method of mitigation may largely depend on the construction of a structure's foundation. However, most frequently this mitigation strategy will involve sealing any potential infiltration points and actively manipulating the pressure difference between the interior and exterior of the structure on a continuous basis. In circumstances where a structure may have more than one foundation design feature (such as a partial crawlspace and partial concrete basement), more than one method of mitigation may be necessary.

Mitigation systems that achieve depressurization of the sub-slab or subsurface beneath a structure relative to the structure's indoor air to prevent infiltration of soil vapor to indoor air are preferred. However, in certain circumstances there may be site-specific or structure-specific conditions under which alternative mitigation methods (such as indoor air treatment, heating, ventilating, and air conditioning (HVAC) modification, or increased ventilation) may be necessary. The DEQ technical contact should be consulted prior to the installation of any system.

It is critical to recognize that depressurization systems may compete with the proper venting of fireplaces, wood stoves, and other combustion or vented appliances (e.g. furnaces, clothes dryers, and water heaters), resulting in the accumulation of exhaust gases in the structure and the potential for carbon monoxide poisoning. Therefore, in structures with natural draft combustion appliances, the structure should be tested for backdrafting of the appliances. Backdrafting conditions should be considered and addressed as part of the process of selecting a mitigation technology.

8.1.1 EXISTING STRUCTURES

Options for mitigation of existing structures are more limited than those for a proposed structure. For an existing structure, a system should be designed based on the options and limitations presented by the standing structure. For example, it may not be cost effective to put a vapor barrier underneath an existing structure while a vapor barrier is easily incorporated into the construction of a new structure. The most common mitigation technique for existing construction is subsurface depressurization (EPA, 2008b).

Subsurface depressurization prevents soil vapors from entering a structure by creating a vacuum underneath the structure. Active subsurface depressurization systems use a fan to create an area of negative air pressure beneath a structure and outside of the foundation. This negative pressure, or vacuum, draws soil vapor from an extraction point underneath a structure into a vertical pipe that discharges the treated or untreated soil vapor to the atmosphere. For larger structures or structures where the subsurface soils limit the vacuum radius of influence, additional extraction points and/or fans may be necessary to effectively mitigate VI (EPA, 2008b). Information on the different subsurface techniques is provided below.

For any treatment system where, subsurface vapors are actively emitted to the atmosphere, DEQ will generally expect the treatment of the effluent vapors, at least initially, with an appropriate media such as granular activated carbon. Please refer to DEQ's Effluent Vapor Modeling Guidance (DEQ, 2020) for additional information on evaluating and demonstrating whether treatment of effluent vapors from remediation systems is necessary prior to effluent discharge to the atmosphere.

8.1.1.1 Sub-Slab Depressurization

Sub-slab depressurization (SSD) can be used in any structure where a concrete slab is present, either slab-on-grade or a basement with foundation. Sub-slab depressurization systems are designed to prevent contaminated soil vapors from entering the structure. A suction point, a 4.5 to 6 inch diameter hole, is created by drilling through the slab, and removing sufficient soil to create a pit 6 to 18 inches deep and 12 to 36 inches in diameter depending on soil conditions. After this sub-slab soil is removed from the suction point, a perforated PVC pipe is installed into the hole. Additional PVC pipe material is connected, and a fan is attached to the piping outside of the living spaces or in a closet or utility corridor. A vacuum is applied to the PVC pipe to extract soil vapor from beneath the slab. Cracks or holes in the structure slab should be sealed to maintain vacuum beneath the slab. Extracted soil vapor is vented to the atmosphere at a point that is above the eave of the roof, ten feet or more from ground level, ten feet or more from any window, door, or other opening into the structure located less than two feet below the exhaust point, and ten feet or more from any opening into an adjacent structure. The number of suction points necessary depends on the structure size, configuration, and the sub-slab material. Sub-slab depressurization systems create a measurable field of negative pressure beneath the entire structure slab for the effective interruption of a VI pathway (DTSC, 2009)

8.1.1.2 Sub-Membrane Depressurization

Sub-membrane depressurization (SMD) may be used for structures with an earthen floor such as in an unfinished earthen basement or a crawlspace. A soil vapor retarder consisting of plastic sheeting or other suitable membrane material is installed over the earthen floor and sealed against the structure, forming a barrier to prevent vapors from entering the structure. This membrane is installed in conjunction with a depressurization system similar to that used in the sub-slab system. A suction pit is installed beneath the membrane in the same fashion as that used in a sub-slab depressurization system. A negative pressure field is created under the barrier similar to that created by a sub-slab depressurization system. Piping may also be installed in various ways, such as a system of horizontal pipes laid underneath the barrier to create a larger extraction area in a large structure. The exhaust point of this system is located according to the same criteria as in a sub-slab depressurization system (DTSC, 2009).

8.1.1.3 Block Wall Depressurization

If a structure was built with a block wall as the foundation, block wall depressurization can be used. This mitigation method involves inserting piping into the void spaces in the blocks and attaching those pipes to a fan to create a negative pressure field in the wall. Openings at the top of the wall and any other cracks or openings in the wall should be sealed. This technique does not create a negative pressure under the slab and is usually used in conjunction with subsurface or sub-membrane depressurization. The exhaust point of this system should be located according to the same criteria as in a sub-slab depressurization system (NYSDOH, 2006).

8.1.1.4 Drain Tile Depressurization

If a structure has perforated drain tile installed around the outside of the structure footers to assist with drainage issues, drain tile depressurization can be used. The fan is attached to the drain tile system and a negative pressure is applied. If the drain tile is attached to a sump pit in the basement, the sump pit is sealed, and the vacuum is applied to the sump. If the drain tile is attached to an external collection point, then the vacuum is applied to the drain tile loop at an external location. The exhaust point of this system should be located according to the same criteria as in a sub-slab depressurization system (NYSDOH, 2006).

8.1.1.5 Site Remediation Technologies (Soil Vapor Extraction)

While mitigation techniques are used in conjunction with remedial activities at the site, certain remedial activities can be used to mitigate VI. Primarily, soil vapor extraction (SVE) systems can be designed in such a way to assist with the mitigation of VI. SVE systems use vertical and/or horizontal extraction points throughout a site to collect and remove contaminated soil vapor by using high flow rates to create a large vacuum. The system can be designed such that the radius of influence reaches underneath structures, or if a structure is outside of the contaminated subsurface but within the halo of contaminated soil vapor, SVE extraction points can be put in place to collect these vapors before they can reach the structure (NYSDOH, 2006).

8.1.1.6 Indoor Air Purifiers

There is very little information regarding the use of air purification for vapor mitigation. Indoor air purification directly treats indoor air, including subsurface soil vapors that have migrated into the indoor air, by passing indoor air through a system that includes adsorbents, scrubbers, catalytic oxidation, or other air purification. The system can be retrofitted into currently installed HVAC systems or installed as a standalone system. These techniques may allow for the collection and treatment of vapors within the structure, though they remain largely unproven to date (DTSC, 2009).

8.1.1.7 Ventilation

Ventilation allows clean, outside air to enter into the structure and either creates a positive pressure in the structure or dilutes the concentrations of contaminated soil vapors present in indoor air.

Increased Passive Ventilation

If there are no air quality issues with the ambient outdoor air, the easiest method of ventilation is to open doors and windows to allow outside air into the structure. The effect will be temporary and once the windows and doors are closed the contaminated soil vapors may once again increase in concentration. Also, if only windows in the upper levels of the structure are opened then an increased stack effect may be created which may result in increased rates of VI (EPA, 2008b).

Crawlspace Ventilation

If a structure is constructed with an enclosed crawlspace, then vapors may build up inside this area. Passive ventilation can be increased by installing and opening vents on the crawlspace wall. Ventilation may be performed actively by installing a fan that circulates outside air into and out of the crawlspace (EPA, 2010). However, the temperature of the outside air should be considered if freezing of water or sewer pipes is a concern.

Heat Recovery Ventilation

In heat recovery systems, outside air is pulled into the structure through an outside collection point. This air is then passed through a heat exchanger and warmed with air that is leaving the structure (EPA, 2010). These systems may be an option for increasing the exchange of outside with inside air while being cognizant of heating costs.

8.1.1.8 Building Pressurization

Building pressurization is achieved by adjusting HVAC operation for the structure in such a way that a positive pressure is created inside of the structure which effectively pushes accumulated soil vapor below the structure around the outside of the structure foundation. It is necessary that the effect is achieved on the lower levels of the structure, primarily in levels that are in contact with soil. Building pressurization can be created with a forced-air HVAC system. For building pressurization to be achieved, these systems are continually operated. This technique is primarily used in commercial structures (DTSC, 2009).

8.1.1.9 Sealing Entryways

When soil vapor concentrations are very high or a concrete slab is relatively thin, soil vapor will diffuse directly through the concrete. However, in most cases, soil vapors diffuse primarily through cracks and other openings in a structure slab. To prevent VI, cracks and other openings, such as where utilities enter the structure, should be sealed. These openings include any exposed earth surface as well as sumps or other breaks in the foundation or slab. Sealing entryways is typically used in conjunction with other mitigation techniques (DTSC, 2009).

8.1.2 PROPOSED STRUCTURES

Proposed structures offer more options for VI mitigation because the mitigation system may be installed during the construction of the structure. The first mitigation strategy that should be considered for a proposed structure is site and location selection. If a structure is proposed for a site with subsurface soil vapor issues in one part of the site, efforts should be made to build away from this area of the site. If that is not possible, the mitigation techniques mentioned in existing structures can be effectively used in proposed structures. For sub-slab depressurization, additional horizontal piping can be placed underneath the slab to create a vacuum more effectively for structures with a large footprint. Some other options that are effective for proposed structures are discussed below.

8.1.2.1 Sub-Soil Venting

Sub-soil venting can potentially be used for existing structures but is best utilized in new construction. This technique is similar to sub-slab depressurization except that no fan is necessary. Instead, the system uses thermal and wind effects to draw contaminated vapors from the sub-slab or sub-membrane area which dilutes the vapors that diffuse into the lower levels of the structure. Sand or pea-gravel is usually placed underneath the slab to enhance the lateral movement of the soil vapor underneath the structure to a collection system of lateral piping that then passes the vapor to the outside of the slab to a vent pipe that travels up the side of the structure and discharges above roof level according to the same criteria as in a sub-slab depressurization system. A sub-soil venting system can be designed and installed in such a way that it can be used as a sub-slab depressurization system with the addition of a fan (EPA, 2010). The design of the system needs to account for the possibility of downdrafting during cold temperatures.

8.1.2.2 Sub-Slab Liners

Liners are installed underneath a structure to provide a barrier that pushes the vapors to the outside of the structure footprint without allowing them to enter through the slab. These liners do not completely prevent VI due to ease of tears, punctures, and improperly installed seals. In areas with VI issues, a sub-slab liner can be used in conjunction with other mitigation techniques (DTSC, 2009).

8.1.2.3 Podium Structure

Structures that are built with a ground level that is open and well vented may not encounter VI issues due to the amount of ventilation achieved beneath the lowest living level of the structure. This can be achieved by building structures on top of stilts or similar construction materials. It is possible with this type of structure that vapors can travel up utilities or other conduits such as elevator shafts or stairwells from the slab to the floors that are used for living or working space, so podium style structures should be built with well-sealed utilities or entrance ways to decrease the potential for VI (DTSC, 2009).

8.2 Installation and Design of Mitigation Systems

This section provides additional detail regarding procedures for specific mitigation techniques once a mitigation method has been selected.

8.2.1 GENERAL RECOMMENDATIONS

Mitigation systems are designed and installed by a professional engineer or environmental professional. In many cases, radon mitigation contractors may also be qualified to install vapor mitigation systems.

The mitigation system design should take into account the desired system outcome as well as any possible effects on indoor air quality, ambient outdoor air quality, and potential impact to air exchanges inside the structure, including potential back-drafting of combustion devices. Because of the potential for backdrafting of combustible devices, any mitigated structure with combustion devices needs to be tested for backdrafting to prevent the potential for carbon monoxide to accumulate in the structure.

For any treatment system where subsurface vapors are actively emitted to the atmosphere, effluent vapors, at least initially, should generally be treated with an appropriate media such as granular activated carbon. Please refer to DEQ's Effluent Vapor Modeling Guidance (DEQ, 2020) for additional information on evaluating and demonstrating whether treatment of effluent vapors from remediation systems is necessary prior to effluent discharge to the atmosphere.

Typically, the responsible party (RP) at the site is responsible for arranging design and installation activities. All design and installation activities should be documented and reported to DEQ. Once a mitigation system is installed, an information package should be given to the structure's owner and tenants, if applicable, to facilitate their understanding of the system's OM&M.

8.2.2 SELECTING A TECHNOLOGY

Before a technology can be selected, the extent of VI and the objective of mitigation should be fully understood. Determining the extent of VI is discussed in Sections 2 and 3. The objective of mitigation is to reduce concentrations of contaminants present in indoor air to cleanup levels determined protective of public health as detailed in this guidance. Mitigation options are evaluated based on this information and site-specific criteria.

Site-specific considerations include existing or proposed building construction, soil type, and depth to groundwater. Sandy soils or gravels that have larger void spaces will be more effective for soil venting and depressurization than clay, which may limit the radius of influence of a SSD or SMD system's extraction point. If groundwater levels are too close to the base of the slab, then extraction systems can pull water into the system, which limits their effectiveness. Often, mitigation systems can be designed to take into account this type of site-specific criteria.

Building construction information to evaluate when choosing a technology includes the structure use, size, foundation type, HVAC system, and structure ventilation. All of this information should be used to determine which mitigation technologies will be the most effective methods to reach desired indoor air levels.

8.2.3 SYSTEM SPECIFIC RECOMMENDATIONS

The following sub-sections detail basic design and installation guidance for mitigation systems.

8.2.3.1 Sealing

To improve the effectiveness of depressurization and ventilation systems and to limit the flow of subsurface vapors into the structure, materials that prevent air leakage should be used to seal any cracks, void spaces, or other openings between the structure and the subsurface. Materials such as joint sealant, compatible caulking, mortar, grout, expanding foam, gaskets, etc. are often effective in sealing. Some sealants may contain volatile organic compounds; in some situations, this may be a consideration in choosing an appropriate sealing material (EPA, 2008b).

8.2.3.2 Soil Vapor Retarder or Membrane

- A minimum of 6 millimeter (or 3 millimeter cross-laminated) polyethylene or equivalent flexible sheeting material should be used.
- The sheet should cover the entire footprint and be sealed at the seams (with a minimum of a 12-inch overlap) and penetrations, around the perimeter of interior piers and to the foundation walls.
- Enough of the membrane should be used so it will not be pulled away from the walls when the depressurization system is operational and the sheet is drawn down.
- If a membrane is installed in areas that may have foot traffic, consideration should be given to also installing a wearing surface such as sand or stone over the top of the membrane to protect its integrity. A layer of sand may also be placed beneath the membrane to prevent penetrations by rocks or sharp objects beneath the membrane (NYDOH, 2006).

8.2.3.3 Depressurization Systems

- Systems should be designed to avoid the creation of other health, safety, or environmental hazards to structure occupants (e.g. backdrafting of natural draft combustion devices).
- The systems should be designed to minimize soil VI effectively while minimizing excess energy usage, to avoid compromising moisture and temperature controls and other comfort features, and to minimize noise.
- To evaluate the potential effectiveness of a SSD before it is installed, a diagnostic test (also known as a communication test) should be performed to measure the ability of a suction field and air flow to extend through the material beneath the slab. This test may be performed by applying suction at the anticipated location of the suction point, or by applying suction at a central location. The ability to achieve a negative pressure differential beneath the entire slab should be evaluated by drilling small diameter holes through the slab at the corners of the foundation and measuring the pressure differential with a micromanometer or comparable instrument. Depending on test results, multiple suction points or a more powerful fan may be necessary to achieve complete depressurization of the sub-slab.
- The vent fan and discharge piping should not be located in or below a livable or occupied area of the structure to avoid entry of extracted subsurface vapors into the structure in the event of a fan or pipe leak.
- To avoid entry of extracted subsurface vapors into the structure, the vent pipe's exhaust should be:
 - above the eave of the roof
 - at least 10 feet above ground level
 - at least 10 feet away from any opening that is less than 2 feet below the exhaust point, and
 - 10 feet from any adjoining or adjacent structures, or HVAC intakes or supply registers
- Rain caps, if used, should be installed so as not to increase the potential for extracted subsurface vapors to enter the structure.
- The components of the depressurization system should be labeled clearly.
- A warning device or indicator such as a liquid gauge or sound alarm should be installed to alert structure occupants if the system stops working properly. Structure occupants should be made aware of the warning device or indicator, how to read/understand it, and what to do if it indicates the system is not operating properly.
- Sealing should be used in combination with a depressurization system (NYSDOH, 2006).

8.2.3.4 HVAC systems

If it is not possible to install a depressurization system or if a depressurization system does not prevent VI, HVAC systems should be evaluated. HVAC systems should be designed, installed, and operated to avoid depressurization of basements and other areas in contact with the soil (NYSDOH, 2006).

8.2.3.5 Ventilation

- Ventilation systems should be designed to avoid the creation of other health, safety, or environmental hazards to structure occupants (e.g. backdrafting of natural combustion appliances).
- The discharge point of a ventilation system should be located so as not to cause ventilated air to re-enter the structure, have an adverse impact on ambient outdoor air, or enter the indoor air of adjacent structures.
- Sealing should be used in combination with enhanced ventilation (NYSDOH, 2006).

8.2.3.6 SVE Systems Used to Mitigate Soil Vapor Intrusion

- The systems should be designed to avoid the creation of other health, safety, or environmental hazards to structure occupants (e.g. backdrafting of natural draft combustion appliances).
- To avoid reentry of soil vapor into the structure(s), the exhaust point should be located away from the openings of structures and HVAC air intakes. Depending upon concentrations of volatile chemicals in subsurface vapors and the expected mass removal rate of the system, treatment (e.g. granular activated carbon) of the SVE system effluent may be necessary to minimize ambient outdoor air impact.
- The SVE system's radius of influence should adequately address structures requiring mitigation, as well as subsurface contaminant sources requiring mitigation. The SVE system radius of influence should extend completely beneath the footprint of any structure requiring mitigation (NYSDOH, 2006).

8.3 Post-Mitigation Confirmation Testing

Once a mitigation system is installed, its effectiveness and proper installation should be confirmed. The RP is responsible for conducting post-mitigation testing. Objectives of post-mitigation confirmation are provided in the following subsections.

8.3.1 DEPRESSURIZATION MITIGATION SYSTEMS (INCLUDING SSD AND SMD SYSTEMS)

- Cracks or leaks in the slab or membrane should be identified and sealed. While the mitigation system is operating, smoke tubes may be used to check for leaks through concrete cracks, floor joints, and at the suction point.
- Once a depressurization system is installed, it should be tested to ensure its operation does not compete with the proper venting of fireplaces, wood stoves, and other combustion or vented appliances (e.g. furnaces, clothes dryers, and water heaters), Backdrafting conditions should be recognized and addressed before installation of the system, and corrected before the depressurization system is placed in operation.
- The distance that a pressure change is induced in the sub-slab area (i.e. pressure field extension test) should be evaluated. Similar to a communication test, the pressure field extension test is conducted by operating the depressurization system and monitoring the pressure differential between the indoor air and the sub-slab soil vapor at the furthest points

of the slab with a digital micromanometer or comparable instrument. The pressure field extension test needs to demonstrate complete depressurization of the structure footprint. In SMD systems, this may be verified visually by observing the membrane forced downward while the system is operating. The pressure field extension test should be performed immediately after system installation, following modifications to the system, or during routine system inspections.

- Proper operation of the warning device or indicator should be confirmed.
- Post-mitigation indoor and ambient outdoor air sampling should be conducted 30 days after the installation of the mitigation system according to the plan approved by DEQ (NYSDOH, 2006).

8.3.2 HVAC MODIFICATIONS

- The structure should be evaluated for a positive pressure condition (verify pressure differential between sub-slab and indoor air using a digital micromanometer or similar device).
- Backdrafting conditions should be evaluated and corrected (as discussed above).
- Proper operation of the warning device or indicator should be confirmed.
- Post-mitigation indoor and ambient outdoor air sampling should be conducted (see above) (NYSDOH, 2006).

8.3.3 VENTILATION

- Any leaks or cracks between the ventilated area and the livable spaces not previously found during mitigation system design/installation should be identified and sealed. Leaks between the ventilated area and livable spaces may be identified through the use of smoke tubes.
- Backdrafting conditions should be evaluated and corrected (as discussed above).
- Proper operation of the warning device or indicator should be confirmed.
- Post-mitigation indoor and ambient outdoor air sampling should be conducted (see above) (NYSDOH, 2006).

8.3.4 SVE SYSTEMS USED TO MITIGATE SOIL VI

- Backdrafting conditions should be evaluated and corrected (as discussed above).
- The pressure differential between the subsurface and indoor air environment should be evaluated in a similar fashion as discussed for depressurization systems. The SVE system should demonstrate that a vacuum is being created beneath the entire structure.
- Proper operation of the warning device or indicator should be confirmed.
- Post-mitigation indoor and ambient outdoor air sampling should be conducted (see above) (NYSDOH, 2006).

8.4 Operation, Maintenance, and Monitoring of Mitigation Systems

When mitigation systems are installed at a site, the OM&M for the mitigation systems should be included in a site-specific mitigation system management plan. The RP conducts OM&M activities and develops the management plan. Recommendations for minimum OM&M activities associated with specific mitigation methods are provided below.

Typically, mitigation systems should be monitored quarterly for the first year of operation, semi-annually for the second year of operation, and annually thereafter. Monitoring of systems should include a visual inspection of the complete system (including the fan, piping, extraction point, warning device, soil vapor retarder membrane, etc.), verification of complete depressurization of the sub-slab (if applicable), identification and repair of any leaks in the structure slab or the mitigation system itself, and inspection of the exhaust or discharge point to verify no air intakes have been located nearby.

The OM&M plan should also include a schedule for testing and sampling the effectiveness of any effluent treatment component of the system (granular activated carbon units, etc.), as well as a description of triggers for change-out and replacement of the treatment media.

Any appropriate preventative maintenance (e.g. replacing fans), repairs, or adjustments should be made to the system to ensure its continued effectiveness at mitigating exposures related to VI.

If significant changes are made to the system or if the system's performance is unacceptable, the system may need to be redesigned and restarted. In this scenario, the post-mitigation testing activities described in Section 8.3 may need to be repeated. Also, additional indoor air sampling may be needed.

8.5 Termination of Mitigation Systems Operations

At some point, operation of a mitigation system may no longer be needed. Mitigation systems should not be turned off until all relevant factors are considered. These factors may include, but are not limited to:

- If subsurface sources of volatile chemical contamination have been remediated based upon an evaluation of appropriate post-remedial sampling results;
- If residual contamination, if any, in subsurface vapors is not expected to affect indoor air quality significantly based upon soil vapor and sub-slab vapor sampling results;
- If residual contamination, if any, in subsurface vapors is not affecting indoor air quality when active mitigation systems are turned off based upon indoor air, ambient outdoor air, and sub-slab vapor sampling results; and
- If there is no “rebound” effect for which additional mitigation efforts would be appropriately observed when the mitigation system is turned off for prolonged periods of time. This determination may be based upon indoor air, ambient outdoor air, and sub-slab vapor sampling from the structure over a time period determined by site-specific conditions.

Given the prevalence of radon throughout Montana, consideration should be given to leaving the system in place and transferring responsibility of its operation to the property owner in order to prevent exposure to radon gas intrusion. This action should be done with the permission of the property owner and after the property owner is aware of their responsibilities in operating, monitoring, and maintaining the system for this specific purpose.

The decision-making process for determining when it is acceptable to turn off a mitigation system will be likely be site-specific due to the variability between sites, buildings, and situations.

8.6 Institutional Controls

An institutional control may be established within the limits of the area of potential VI impacts to address future use of the overlying land. Depending on the degree of contamination and other site-specific factors, current (and potentially future) structures or environmental media may be monitored to assess any VI risk. Building construction can incorporate remedial designs to eliminate or address the VI pathway. Engineering controls may be appropriate based on the results of the remedial investigation, current or future land use and site conditions. Refer to EPA (2015a) for an extensive discussion of VI-related ICs.

8.6.1 PROPERTY DEVELOPMENT AND LAND USE CONTROL

When VI mitigation at a structure is necessary, the need for mitigation should be included in an institutional control (e.g., Covenant to Restrict Use of Property or Environmental Restriction). It may include other institutional controls with prescribed notifications, prohibitions, restrictions and requirements that are utilized to ensure OM&M and disclosure of the risks, restrictions, and requirements to future buyers and occupants. The following provisions may be included in the covenant:

- Notice of the existing conditions known to the environmental agency that may cause potential unacceptable risk from VI;
- Prohibition against specific uses of the property;
- Prohibition against interference with the VI mitigation system;
- Prohibition against activities that will disturb impacted soil;
- Notification of structure modifications;
- Right of access to the property for the RP and DEQ to inspect, monitor, and perform other activities relative to the VI mitigation system; and
- Right of access to the property for the party responsible for implementing the OM&M activities relative to the VI mitigation system.

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