# APPENDIX G

# ASSESSMENT OF THE VAPOR INTRUSION PATHWAY

# FROM SUBSURFACE SOURCES TO INDOOR AIR

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## G1.0 OVERVIEW

Vapor intrusion is the migration of hazardous vapors from a subsurface source through the vadose zone and into indoor air. Subsurface sources of vapors generally include soil and/or groundwater that are impacted with a constituent that has sufficient volatility and toxicity and is present at sufficient concentrations to pose a possible inhalation risk within overlying buildings. Vapors migrating in the subsurface enter buildings by migrating through fractures and joints in the foundation including perforations due to utility conduits or other openings such as floor drains, sumps, etc. Vapor intrusion can occur in industrial and non-industrial land use settings and generally affects buildings that are considered to be enclosed structures. For the evaluation of vapor intrusion, an enclosed structure is defined as an occupied (or potentially occupied) [i.e., one or more receptors spend a significant portion of the day (or workday) within the enclosed structure] structure on a slab foundation (or on enclosed piers) that has a roof and walls on all sides which prevent the free exchange of indoor air with outdoor (ambient) air. Vapor intrusion is a potentially significant cause of exposure to volatile hazardous chemicals in indoor spaces. When vapor intrusion is significant, the concentrations of vapors in indoor air may reach levels that pose unacceptable health risks to building occupants. In addition, certain volatile chemicals (e.g., methane) can pose explosion hazards when they accumulate in confined spaces. RECAP requires that the vapor intrusion pathway be evaluated at sites were there is a subsurface vapor source near an enclosed structure.

## G2.0 CONSTITUENTS OF POTENTIAL CONCERN

For the vapor intrusion pathway, a chemical generally is considered to be "vapor-forming" if: 1) its molecular weight is less than 200 grams per mole (g/mol), and 2) vapor pressure is greater than 1 mm Hg, or Henry's law constant is greater than 1E-05 atm-$m^3$/mol (EPA 1991).

## G3.0 VAPOR INTRUSION PATHWAY

The vapor intrusion pathway is likely to be complete when:

- A subsurface source of vapor-forming chemicals is present;
- Subsurface vapor migration is capable of transporting hazardous vapors from the source to an enclosed structure;
- The enclosed structure is susceptible to soil gas entry; and
- Vapor-forming chemicals are present in the indoor environment (which can be confirmed by indoor air sampling and analysis for site-related vapor-forming chemicals that also are found in the subsurface environment).

Each of these conditions entails obtaining and weighing multiple lines of evidence. The various lines of evidence shall be considered and evaluated together in determining completeness of the vapor intrusion pathway. Lines of evidence to evaluate the vapor intrusion pathway may include, but are not limited to:

***Subsurface Vapor Sources***

- Site history and documentation of the source of the COC to demonstrate that vapor-forming chemicals have been released to the underlying and surrounding subsurface environment.
- Groundwater data to confirm the presence of a water-table aquifer as a source of vapors, if applicable, and establish its chemical and hydrogeologic characteristics.
- Soil gas data, soil sampling and/or NAPL sampling data to confirm the presence of a COC in the vadose zone as a source of vapors, if applicable, and establish its chemical and physical characteristics.
- Comparison of groundwater and soil gas concentrations to screening levels to evaluate the potential for a health concern if the vapor intrusion pathway is complete.

***Vapor Migration and Attenuation in the Vadose Zone***

- Soil gas survey data to confirm soil gas migration and attenuation along anticipated paths in the vadose zone between sources and buildings.
- Data on site geology and groundwater hydrology to support the interpretation of soil gas profiles, the characterization of gas permeability, and the identification of anticipated soil gas migration paths in the vadose zone or the identification and characterization of impeded migration.

- Vertical profiles of chemical vapors, electron acceptors for microbial transformations (e.g., oxygen), and biodegradation products (e.g., methane, vinyl chloride) to characterize attenuation due to biochemical processes.
- Utility corridor assessment to identify preferential pathways for subsurface vapor migration between sources and buildings

***Enclosed Structure Survey***

- Enclosed structure construction including utility conduits or other preferential pathways of soil gas entry, heating and cooling systems in use, and any segmentation of ventilation and air handling.
- Instrumental (e.g., PID) readings to locate and identify potential openings for soil gas entry into buildings.
- Grab samples of indoor air near openings for soil gas entry into buildings.

***Interior Assessment***

- Sub-slab soil gas data to assess COC concentrations potentially available for soil gas entry to the indoor air.
- Indoor air sampling data to assess the presence of subsurface COC in indoor air, estimate potential exposure levels to building occupants.
- Results of site-specific modeling.
- Background indoor air data.
- Comparative evaluations of indoor air and sub-slab soil gas data, including calculation and comparison of building-specific, empirical attenuation factors.

***Indoor and Outdoor Sources of Vapor-forming Chemicals Found in the Subsurface***

- Building-specific indoor sources of volatile chemicals.
- Concurrent outdoor air data to assess potential contributions of ambient air to indoor air concentrations.

***Additional Supporting Lines***

- Results of statistical analyses (e.g., data trends, contaminant ratios) to support data interpretation.

## G4.0 VAPOR INCLUSION ZONE

Vapor concentrations generally decrease with increasing distance from a subsurface vapor source and eventually at some distance the concentrations become negligible. The distance at which soil gas concentrations are negligible is a function of many site-specific factors which include, but may not be limited to, the chemical nature of the COC (e.g., chlorinated hydrocarbons, petroleum hydrocarbons, and other non-chlorinated volatile hydrocarbons), the COC concentration and spatial extent of the vapor source, the type of vapor source, the soil types in the vadose zone, the presence of physical barriers at the ground surface, and the presence of preferential migration pathways (e.g. sewer or utility bedding) in the subsurface. Other factors include the age of the chemical release and whether or not the release/vapor source is in declining conditions. Because these factors vary among sites, the distance beyond which enclosed structures will not be threatened by vapor intrusion is necessarily a site-specific determination. Site-specific vapor inclusion zones are subject to Department approval.

### G4.1 Chlorinated Hydrocarbons

Chlorinated hydrocarbons have limited potential to undergo biodegradation and therefore tend to have greater mobility within the vadose zone. In addition, chlorinated hydrocarbons, through microbial, chemical, and other mechanisms of degradation, over time yield chlorinated intermediates that may also serve as vapor sources. For these reasons, the evaluation of the vapor intrusion pathway for chlorinated hydrocarbons may be more complex than for non-chlorinated volatile constituents. It is the Department's preference that the vapor inclusion zone for chlorinated hydrocarbon releases be defined based on site-specific conditions. For initial investigation efforts or in the event it is not feasible to define a site-specific vapor inclusion zone, a default zone defined by lateral and vertical separation distances of 100 feet from the subsurface vapor source may be used for the evaluation of vapor intrusion pathway.

### G4.2 Petroleum Hydrocarbons

Petroleum hydrocarbons consist of mixtures of hundreds of constituents that are volatile, semi-volatile, and nonvolatile. The petroleum hydrocarbon components that may potentially represent a vapor intrusion risk include the lighter volatile hydrocarbon constituents and fractions such as benzene, toluene, ethylbenzene, xylenes, aliphatic hydrocarbon fractions $C_{>6}$-$C_8$, $C_{>8}$-$C_{10}$, and $C_{>10}$-$C_{12}$, and aromatic hydrocarbon fraction $C_{>8}$- $C_{10}$. Refer to Appendix D Table D-2 for a listing of the COC associated with various types of petroleum releases.

Biodegradation of petroleum hydrocarbons is recognized as one of the primary removal mechanisms of petroleum hydrocarbon contaminants from the environment. Petroleum

hydrocarbons can biodegrade aerobically and thereby reduce the potential for human exposure from petroleum vapor intrusion (PVI). Further, studies have shown that if at least five feet of clean (TPH ≤ 100 mg/kg), biologically active soil is present between the source of petroleum vapors and the lowest (deepest) point of the enclosed structure foundation and the soil contains sufficient oxygen (1-4% $O_2$) to attenuate vapors, then there is likely aerobic biodegradation occurring of the petroleum hydrocarbons. The oxygen content should be greater than 1% throughout the thickness of clean, biologically active soil necessary for aerobic biodegradation of petroleum hydrocarbon vapors emanating from the source. A soil vapor profile (unsaturated zone) characterized by decreasing $O_2$ and increasing $CO_2$ and $CH_4$ is indicative that aerobic biodegradation of petroleum hydrocarbons is occurring. For the purposes of defining clean soil and for application of the exclusion criteria, Total Petroleum Hydrocarbons (TPH) shall be defined as the sum of the concentrations (AOIC or CC) of the aliphatic and aromatic fractions detected within the AOI.

The vapor inclusion zone is bounded by the horizontal and vertical separation distances which are defined as follows:

<u>Horizontal Separation Distance</u> is defined as the horizontal distance from the enclosed structure to a distance equal to the vertical separation distance.

<u>Vertical Separation Distance</u> is defined as the thickness of clean (TPH ≤ 100 mg/kg), biologically active soil between the source of petroleum hydrocarbon vapors and the lowest (deepest) point of the enclosed structure foundation. The vertical separation distance shall consider seasonal fluctuations of groundwater. For characterizing gasoline releases, the TPH concentration shall be defined as the sum of the concentrations reported for the aliphatic hydrocarbon fractions $C_{>6}$-$C_8$, $C_{>8}$-$C_{10}$, and $C_{>10}$-$C_{12}$ and aromatic hydrocarbon fraction $C_{>8}$- $C_{10}$.

Based on the documented attenuation of petroleum hydrocarbons in the subsurface, vertical separation distances for evaluating the vapor intrusion pathway for petroleum hydrocarbon vapor sources have been recommended for defined concentrations of benzene and total petroleum hydrocarbons in soil and groundwater as follows:

### *G4.2.1 No LNAPL Present*

A. <u>Vertical Separation Distance < 6 Feet</u>
   Sites with a vertical separation distance of less than 6 feet between the source of the petroleum hydrocarbon vapors and the lowest point of the enclosed structure foundation shall be evaluated on a site-specific basis.

B. Vertical Separation Distance 6-15 Feet

- Evaluation Criteria:
  i. Groundwater: Benzene ≤ 5 mg/L and TPH ≤ 30 mg/L
  ii. Soil: Benzene ≤ 10 mg/kg and TPH ≤ 100 mg/kg
- If all of the evaluation criteria are met, then PVI shall not be evaluated for the enclosed structure.
- If any of the evaluation criteria are not met, then soil oxygen ($O_2$), carbon dioxide ($CO_2$), and methane ($CH_4$) percentages shall be obtained at 1 foot intervals until groundwater is encountered or to a depth of 6 feet. If the soil oxygen percentage in all of the intervals is 1% or greater, then PVI shall not be evaluated for the enclosed structure.

C. Vertical Separation Distance >15 Feet

- Evaluation Criteria:
  i. Groundwater: Benzene ≤ 5 mg/L and TPH ≤ 30 mg/L
  ii. Soil: Benzene ≤ 10 mg/kg and TPH ≤ 250 mg/kg
- If all of the evaluation criteria are met, then PVI shall not be evaluated for the enclosed structure.
- If any of the evaluation criteria are not met, then soil oxygen ($O_2$), carbon dioxide ($CO_2$), and methane ($CH_4$) percentages shall be obtained at 1 foot intervals until groundwater is encountered or to depth of the source. If the soil oxygen percentage in all of the intervals is 1% or greater, then PVI shall not be evaluated for the enclosed structure.

### *G4.2.2 LNAPL Present*

Identification of LNAPL: LNAPL may not readily appear in soil borings or groundwater monitoring wells and can be difficult to identify during the site investigation. Visible evidence of LNAPL observed in soil borings or groundwater monitoring wells would include measurable accumulations of free product in monitoring wells, an oily sheen on the water, and saturation of bulk soil samples.

A. Vertical Separation Distance < 15 Feet

If the vertical separation distance is ≤ 15 feet and LNAPL is present in the soil and/or on the groundwater beneath the enclosed structure (as determined by soil borings or groundwater monitoring wells placed as close to the structure as possible), then PVI shall be evaluated for the enclosed structure.

B. Vertical Separation Distance >15 Feet

a. Evaluation Criteria: Soil: Benzene ≤ 10 mg/kg and TPH ≤ 250 mg/kg

b. If the benzene and TPH evaluation criteria are met, then PVI shall not be evaluated for the enclosed structure.
c. If the benzene and TPH evaluation criteria are not met, then soil oxygen ($O_2$), carbon dioxide ($CO_2$), and methane ($CH_4$) percentages shall be obtained at 1 foot intervals until groundwater is encountered or to depth of the source. If the soil oxygen percentage in all of the intervals is 1% or greater, then PVI shall not be evaluated for the enclosed structure.

It is expected that these vapor inclusion zones will be appropriate for the evaluation of the vapor intrusion pathway at most petroleum release sites. However, in the event that the Department determines these recommendations are not appropriate based on site-specific conditions (e.g. presence of preferential pathways), a site-specific vapor inclusion zone shall be identified and approved by the Department.

## G5.0 SAMPLING CONSIDERATIONS FOR THE VAPOR INTRUSION PATHWAY

At most sites, site investigation activities for the vapor intrusion pathway may include delineation of the horizontal and vertical extent of the subsurface vapor source, indoor air sampling (and concurrent ambient air sampling), sub-slab soil gas sampling, and/or groundwater sampling. Based on site-specific conditions, additional investigation efforts may include, but may not be limited to, near-source exterior soil gas sampling, characterization of the soil properties in the vadose zone, identification of potential preferential pathways for vapor migration in the vadose zone, a survey of the enclosed structure to identify potential points of vapor entry into the structure as well as other characteristics that may influence indoor air COC concentrations, consideration of background concentrations of COC in indoor air, and site-specific modeling.

For inactive enclosed structures, indoor air sampling is the Department preferred method for evaluating the presence of subsurface COC in indoor air; however, sub-slab soil gas or near source exterior soil gas sampling may be conducted and used in conjunction with other lines of evidence to evaluate the potential health risks associated with the vapor intrusion pathway

For active enclosed structures where there are ongoing commercial or industrial operations and the COC potentially involved in vapor intrusion is also released to indoor air due to ongoing operations, it may not be feasible to evaluate the significance of the vapor intrusion pathway using indoor air sampling. In this situation, it is recommended that sub-slab soil gas or exterior soil gas sampling be conducted and used in conjunction with other lines of evidence to evaluate the potential health risks associated with the vapor intrusion pathway.

## G6.0 SAMPLING PROTOCOLS FOR THE VAPOR INTRUSION PATHWAY

### G6.1 Ambient (Outdoor) Air Sampling

A minimum of one ambient (outdoor) air sample shall be collected during each indoor air sampling event. However, ambient air samples may be collected at multiple locations to minimize bias toward obvious sources of petroleum chemicals (e.g., vehicles, lawn mowers, oil storage tanks, service stations, industrial facilities). The results of the ambient air sample can be helpful in determining if an influence of outdoor air on the indoor air quality exists. The ambient air sample shall be collected at breathing zone height (3-5 feet above ground) and close to the area being evaluated but not affected by the subsurface vapor source. Thus, the canisters shall be placed in a secure outside location.

For residential structures, ambient air samples shall be collected from a representative upwind location away from wind obstructions. For non-residential structures, outdoor air samples shall be collected in locations upwind of the intakes of the building heating, ventilation and air conditioning (HVAC) systems. Outdoor air samples shall be collected for the same time periods as the indoor air samples and analyzed by the same method as indoor air samples.

### G6.2 Indoor Air Sampling

The descriptions of indoor air sampling procedures in this section are general in nature and reflect commonly accepted designs and methods followed by the EPA. The goal of the indoor air sampling is to collect a representative indoor air sample for the purpose of assessing the risk posed by contaminants present within a building. However, many commonly used consumer products contain some of the same target compounds of concern that are measured in indoor air samples (e.g., benzene from petroleum based products used in garages and PCE from dry-cleaned clothes). Therefore, the interpretation of indoor air sampling data in vapor intrusion assessments is complex. To reduce the potential for other sources of vapors in the enclosed structure, the occupants should comply with the following instructions starting at least 48-hours prior to and during the indoor air sampling event (NJDEP 2013):

- ✓ Operate the furnace and air conditioner as appropriate for the current weather conditions
- ✓ Do not use wood stoves, fireplaces or auxiliary heating equipment
- ✓ Do not smoke in the building
- ✓ Do not use air fresheners or odor eliminators
- ✓ Do not use paints or varnishes (up to a week in advance, if possible)
- ✓ Do not use cleaning products (e.g., bathroom cleaners, furniture polish, appliance cleaners, all-purpose cleaners, floor cleaners)

- ✓ Do not use cosmetics, including hair spray, nail polish remover, perfume, etc.
- ✓ Avoid bringing freshly dry cleaned clothes into the building
- ✓ Do not engage in hobbies indoors that use solvents
- ✓ Do not apply pesticides
- ✓ Do not store containers of gasoline, oil or petroleum based or other solvents within the building or attached garages (except for fuel oil tanks)
- ✓ Do not operate or store automobiles in an attached garage
- ✓ Do not operate gasoline powered equipment within the building, attached garage or around the immediate perimeter of the building

Indoor air samples are typically collected under conditions representative of the normal use of the structure. It may be useful to collect a sample directly from a point of suspected vapor entry to better understand the site specific conditions. If collecting a combination of indoor air samples, outdoor air samples, and sub-slab soil vapor samples for a project, it is suggested the indoor and outdoor air samples are collected first, followed by collection of the sub-slab soil vapor samples. It is not recommended to collect sub-slab samples simultaneously with the indoor air samples because the installation and purging of the sub-slab probes may introduce site constituents of concern (COC) into the indoor air.

### *G6.2.1 Indoor Air Sampling Methods*

The most common method for collecting indoor air samples is by a passivated canister. The sampling canister is a passivated or specially lined inert container that is sent to the field under vacuum and is certified clean and leak free. The canister fills with air at a fixed flow rate over a pre-set period of time with use of a flow controller that is calibrated and set in the laboratory. Initial and final vacuums are recorded for each canister. The main advantages of canister sample collection are the capability of analyzing multiple samples from the same canister and the ease of deployment and retrieval.

Passivated canisters shall be certified clean by the laboratory prior to sampling. This certification shall be done on an individual canister basis.

The vacuum in the stainless steel canister shall be verified before and after the sample collection. Canisters with dedicated vacuum gauges facilitate this effort and are strongly recommended. The laboratory is required to record the vacuum in the canister upon shipment. In turn, the canister's initial vacuum shall be verified at the site prior to collecting a sample. If the measured vacuum at the site is $\geq$ 10% lower than the initial lab reading, the canister shall not be utilized for sampling. The potential for vacuum loss during transit negates the usability of the data generated from the defective canister or regulator.

The canister must be retrieved prior to being completely filled (with some residual vacuum remaining) to ensure the proper collection period. For indoor air samples, a residual vacuum shall exist in the canister upon completion of the sampling event. Since the sample is designed to be collected over a designated period of time (i.e., 8 – 24 hours), the residual vacuum ensures that the sample was collected over that time period. If no vacuum remains, the usability of the data is questionable. When the results are used to determine the pathway is incomplete (no exceedances in the indoor air), a residual vacuum in the canister is critical.

### *G6.2.2 Initial Building Survey*

An important first step in any indoor air sampling program is a building survey to assess potential indoor and background sources of volatile organic compounds (VOC). It is recommended that a survey checklist be used to document information on the building conditions, products/chemicals used or stored in the building, and other potential sources of indoor air contamination (refer to RECAP VI Form 1 at the end of this appendix). As part of the building survey, potential preferential vapor intrusion pathways shall also be identified. Utility corridors can act as contaminant migration pathways allowing VOC to travel long distances. Any foundation penetrations such as water, sewer, gas, electric and telecommunication lines, as well as sumps shall be documented during the initial building survey. To be active these pathways need to provide a direct connection between the contaminated vapors and the building being investigated. Depending on the target compounds, screening for VOC using direct reading instruments, such as a PID or combustible gas meter may be useful. These may be used for locating potential points of vapor entry, locating indoor VOC sources, or identifying acute exposure or potentially explosive situations.

### *G6.2.3 Indoor Air Sample Locations*

The number of indoor air samples collected is dependent upon the size, layout, and use of the building; however, for most properties it is recommended that indoor air samples are collected from a minimum of two locations. Where samples are collected from a small apartment/home, one indoor air sample may be sufficient. Larger dwellings may require additional indoor air samples. Multi-family residential units and commercial or retail buildings will require a more careful review of the building features and typically warrant multiple sample locations.

The sampling plan shall take into account the different exposure scenarios (e.g., day care, residences, office, commercial facilities, medical facilities) that exist within the building and any sensitive populations that may be exposed to the contaminated vapors. For multi-storied residential buildings, initial samples are typically collected on the lowest occupied floor as they are likely to be most prone to vapor intrusion. Collect additional samples from upper floors based upon professional judgment. Adjust the number of samples based on the building-specific

features and conditions. The sample inlet port is typically placed at the breathing zone height (3-5 feet from the floor) of the primary living or working area. Samples shall be collected away from windows, doors, and heater/AC vents.

### *G6.2.4 Indoor Air Sample Duration*

In general, indoor air samples at residential and commercial properties shall be collected over a 24-hour period. However, at some properties, the sampling period may be shortened to 8-hours to correspond to the average workday or the timeframe the building or floor of interest is occupied on a daily basis. Sampling times less than 8-hours shall be technically justified and proper consideration given to future use changes. Longer duration samples may be appropriate if significant variability in VOC concentrations is suspected.

### *G6.2.5 Indoor Air Sampling Analytical Methods and Holding Time*

Indoor air samples shall be analyzed by the following:

1. Volatile constituents: EPA Method TO-14, TO-15, TO-17;
2. Semi-volatile constituents: EPA Method TO-10, TO-13;
3. Petroleum hydrocarbons: Massachusetts Department of Environmental Protection Volatile Petroleum Hydrocarbons (VPH) Method (aliphatic hydrocarbon fractions $C_{>6}$-$C_8$, $C_{>8}$-$C_{10}$, and $C_{>10}$-$C_{12}$, and aromatic hydrocarbon fraction $C_{>8}$- $C_{10}$);
4. Fixed Gases [oxygen ($O_2$), carbon dioxide ($CO_2$), and methane ($CH_4$)]: portable meter, ASTM D-1946-90, or EPA Method 3C; or
5. Other methods upon Departmental approval.

The indoor air samples collected in passivated canisters shall not be chilled during storage and shall be analyzed within 14 days by a laboratory accredited with the Louisiana Environmental Laboratory Accreditation Program (LELAP).

### *G6.2.6 Indoor Air Sample Frequency*

Sampling frequency shall be determined by Department based on the site objectives of the study, the nature of the contaminants, geological and hydrogeological conditions, and land use. In many circumstances, a single round of indoor/ambient air samples shall be adequate to determine whether the vapor intrusion pathway is complete. However, in some cases, seasonal variability in vapor concentrations may necessitate collecting more than one set of indoor air samples from a building and an ambient air sample. Many studies have shown indoor air temporal variations to be less than a factor of 10, so if initial results are 10 times below applicable screening levels, a second sampling round may not be necessary.

## G6.3 Soil Gas Sampling

The descriptions of soil gas sampling procedures in this section are general in nature and reflect commonly accepted designs and methods followed by the EPA. Soil gas samples are commonly collected to evaluate the potential for vapor intrusion into enclosed structures. Site-specific conditions that may influence soil gas concentrations include meteorological conditions and hydrogeological conditions. During the soil gas sampling event, ambient meteorological conditions shall be collected that could influence soil gas sampling results.

### *G6.3.1 Soil Gas Sampling Methods*

Vapor migration results from two processes, diffusion and advection. Diffusion is the process whereby net transport of vapors occurs from a source area of higher concentration to an area of lower concentration. Diffusion can lead to vapor migration into buildings directly through a dirt floor, a crawlspace, cracks in the concrete slab, or through utility openings in the concrete slab and foundation.

Advection is the movement of soil gas in response to pressure differentials. When the pressure inside the building is lower than the pressure in the subsurface, vapors are drawn into the building. On the other hand, when the pressure inside the building is greater than the pressure in the subsurface, air within the building may be forced into the subsurface causing some degree of re-oxygenation. Heating and cooling systems can create differential pressures inside the building.

For active enclosed structures where there are ongoing commercial or industrial operations, the Department recommended methods to evaluate the vapor intrusion pathway are sub-slab or near source exterior soil gas sampling. Soil gas samples for volatile constituents are commonly collected in passivated canisters, on adsorbent tubes, gs-tight vials, or Tedlar® bags. Soil gas sample collection by other methods shall receive Department approval.

Passivated canisters shall be certified clean by the laboratory prior to sampling. Certification shall be done on an individual canister basis. For adsorbent tubes, gs-tight vials, or Tedlar® bags, batch certification is sufficient.

Soil gas probe installation methods may include hand equipment (hand auger, hammer drill, rotary hammer, etc.), hydraulically advance probes, or other approved equipment. Sampling points shall consist of small diameter tubing extending from the sampling zone to the surface equipped with an appropriate screen (sampling tip or other approved material). Use of small diameter (e.g. 1/8 inch) tubing is encouraged to reduce purge volume and prevent

leakage/breakthrough. Materials of construction shall not adversely affect sample integrity and may include such materials as stainless steel, nylon, or Teflon®. Sampling points shall be provided with an annular seal to prevent vertical contaminant migration, infiltration, and atmospheric intrusion during sampling. It is generally considered to be good practice to only use dedicated connectors and tubing (from the soil gas well to the sampling media) for each location and to order the sampling of soil gas from areas where lower concentrations are expected to areas where higher concentrations are expected (where possible). This minimizes the potential for cross-contamination and interference/bias/drift in field instruments that may be used.

If a passivated canister is used, the vacuum in the stainless steel canister shall be verified before and after the sample collection. The laboratory is required to record the vacuum in the canister upon shipment. In turn, the canister's initial vacuum shall be verified at the site prior to collecting a sample. If the measured vacuum at the site is $\geq$ 10% lower than the initial lab reading, the canister shall not be utilized for sampling. The potential for pressure loss during transit negates the usability of the data generated from the defective canister or regulator. The post-sampling vacuum in the canister shall be recorded; however, it is not necessary to maintain residual vacuum in the canisters for soil gas samples.

Leakage of atmospheric air into the samples shall be checked using an appropriate tracer gas to determine sample reliability. In addition, a tight seal between the sample point and slab or soil shall be verified via leak check to prevent indoor air or ambient air from mixing with the soil gas sample. Prior to collecting a soil gas sample, a leak test on the soil gas probe and all fittings of the sampling train shall be conducted. The leak test serves as a quality control measure to evaluate the potential for dilution of a sample from ambient air. Commonly used tracer gases are isopropanol and helium with each having its own advantages and disadvantages.

One leak test method employs a shroud placed over the soil gas probe and the sample train. An inert tracer gas (such as helium) is released into the shroud with a target concentration of 10 - 20%. With the canister valve closed, collect a soil gas sample using a Tedlar® bag. A leak is occurring when the helium concentration is greater than 10% of the concentration within the shroud. In this case, the leak must be fixed and the leak check repeated.

Another leak test method is to conduct a shut-in test of the sampling train at each sampling location during each sampling event to verify aboveground fittings do not contain leaks. A shut-in test consists of assembling the above-ground apparatus (valves, lines, and fittings downstream of the top of the probe), and evacuating the lines to a measured vacuum of about 100 inches of water, then shutting the vacuum in with closed valves on opposite ends of the sample train. The vacuum gauge is observed for at least 1 minute, and if there was any observable loss of vacuum, the fittings shall be adjusted as needed until the vacuum in the above-ground portion of the sample train does not noticeably dissipate.

Sample collection shall be by an active whole-air sampling method. Unless otherwise approved, a minimum of three dead volumes shall be purged prior to sample collection. Samples shall be collected in low volume passivated canisters (generally <1 liter), Tedlar® bags, or other method-specific containers.

Soil classifications shall be performed at all soil gas sampling locations and shall describe the soil type at each sampling interval.

### *G6.3.2 Oxygen ($O_2$), Carbon Dioxide ($CO_2$), and Methane ($CH_4$) Measurements for the Assessment of Petroleum Hydrocarbon Vapor Attenuation*

Studies have shown that if at least five feet of clean (TPH-GRO ≤ 100 mg/kg), biologically active soil is present between the source of petroleum vapors and the lowest (deepest) point of the enclosed structure foundation and the soil contains sufficient oxygen (1-4% $O_2$) to attenuate vapors, then there is likely aerobic biodegradation occurring of the petroleum hydrocarbons.

Soil oxygen ($O_2$), carbon dioxide ($CO_2$), and methane ($CH_4$) percentages by volume shall be obtained at 1 foot intervals to a depth of six feet to establish a vertical profile to determine if biodegradable conditions exist. If the soil oxygen percentage in any of the intervals are 1% by volume or greater, then it can be assumed that sufficient soil oxygen exists to aerobically biodegrade the petroleum hydrocarbons.

Petroleum hydrocarbons are readily degraded to carbon dioxide by soil microbes in the presence of oxygen. There are no established screening criteria for carbon dioxide; however, the percentage by volume shall be recorded as an indicator of aerobic biodegradation.

Methane is the lightest of all hydrocarbons and is a colorless, odorless, tasteless, flammable gas that is produced as a result of the microbial or thermal alteration of organic matter and is widely distributed in nature. The principle health and safety concerns for methane are its explosive, flammable, and asphyxiant properties. Since methane is a simple asphyxiant, acting by displacement of oxygen, no threshold limit value (TLV), permissible exposure limit (PEL), or recommended exposure limit value (REL) has been established. However, migrating methane gas can pose serious public health and safety risks, principally fire and explosion. Methane is combustible at concentrations of 5 -15% by volume in air. Therefore, the percentage by volume of methane shall be recorded as a public health and safety precaution.

### *G6.3.3 Soil Gas Sampling Locations*

The two recommended locations for soil gas sampling are sub-slab (below the foundation slab) or near source exterior (immediately adjacent to the foundation wall nearest the vapor source). Different conditions may exist that affect the migration of vapors outside of the building as compared to beneath the building slab. Therefore, the preferred location is sub-slab especially for chlorinated hydrocarbons; however, if this is not accessible, then the near source exterior location shall be selected.

Sub-slab soil gas samples shall be collected as close as possible to the exterior wall nearest the vapor source. At least one additional sample shall be collected from an interior location near the center of the slab. Samples taken from beneath the slab shall be obtained by drilling directly through the slab and collected approximately 1 to 2 inches beneath the building slab. If possible, locate the sub-slab sampling points away from floor drains, sumps and any other openings in the slab.

Near source exterior soil gas samples shall be taken immediately adjacent to the foundation wall nearest the vapor source. It is recommended that exterior soil gas samples be collected from a minimum of two sides of the building in question. Location of the exterior soil gas samples will be in part dictated by the existing conditions around the building perimeter (e.g., other buildings, landscaping, access issues, etc.). The depth and volume of the soil gas sample shall be adequate to prevent the leakage of atmospheric air into the sample. Near source exterior location samples shall be collected at multiple depths to provide a vertical soil gas profile. Based on site geology and peak water table elevation, a minimum of two intervals shall be sampled beginning at 1 foot beneath the building slab (e.g., 2 feet and 4 feet, etc.) for petroleum vapor sources. For chlorinated vapor sources, the vertical soil gas profile shall be established until groundwater is encountered or to depth of 10 feet below the building slab, whichever is deeper. In addition to the exterior soil gas sampling for petroleum vapors, soil oxygen ($O_2$), carbon dioxide ($CO_2$), and methane ($CH_4$) percentages by volume shall be obtained at 1 foot intervals to a depth of six feet to establish a vertical profile to determine if biodegradable conditions exist.

### *G6.3.4 Soil Gas Sampling Equilibration Time and Flow Rate*

When soil gas probes are installed, the in-situ soil vapor can be displaced and a period of time is necessary for the soil vapor to re-equilibrate. An EPA study indicated the equilibration time ranged from 15 minutes to 8 hours depending on the method of soil gas probe installation. Soil gas samples may be collected immediately after soil gas probe installation provided the samples are collected through the probe rod with internal tubing attached prior to probe emplacement.

Prior to sample collection, adequate soil vapor shall be withdrawn to purge the probe and collection system of all ambient air or purge gas (e.g., 3 purge volumes). An EPA study measured soil vapor concentrations over different flow rates ranging from 100 mL/min to 5,000 mL/min in soil vapor probes and found no significant difference in measured soil vapor concentration. This suggests that flow rate does not appear to be an important variable on soil vapor concentrations. However, the Department recommends using a low flow rate of less than 200 mL/min. If vacuum is applied at the probe it shall be less than 100 inches of water (~8 inches of Hg).

### *G6.3.5 Soil Gas Sampling Analytical Methods and Holding Time*

Soil gas samples shall be analyzed by the following:

1. Volatile constituents: EPA Method TO-14, TO-15, TO-17; EPA SW-846 Method 8260;
2. Semi-volatile constituents: EPA Method TO-10, TO-13;
3. Petroleum hydrocarbons: Massachusetts Department of Environmental Protection Volatile Petroleum Hydrocarbons (VPH) Method (aliphatic hydrocarbon fractions $C_{>6}$-$C_8$, $C_{>8}$-$C_{10}$, and $C_{>10}$-$C_{12}$, and aromatic hydrocarbon fraction $C_{>8}$- $C_{10}$)
4. Fixed Gases [oxygen ($O_2$), carbon dioxide ($CO_2$), and methane ($CH_4$)]: portable meter, ASTM D-1946-90, or EPA Method 3C; or
5. Other methods upon Departmental approval.

The soil gas samples collected in passivated canisters shall not be chilled during storage and shall be analyzed within 14 days by a laboratory accredited with the Louisiana Environmental Laboratory Accreditation Program (LELAP).

The soil gas samples collected in Tedlar® bags shall not be chilled during storage and shall be analyzed within 3 days by a laboratory accredited with the Louisiana Environmental Laboratory Accreditation Program (LELAP) or transferred into a passivated canister.

### *G6.3.6 Soil Gas Sampling Frequency*

Typically, one soil gas sampling event is adequate to evaluate the vapor intrusion pathway. However, site specific conditions, environmental data, or ambient conditions (eg. seasonal groundwater fluctuation, weather conditions, etc.) may necessitate a second sampling event.

## G7.0 DATA INTERPRETATION

### G7.1 Indoor Air Data

Indoor air data shall be compared to the indoor air standard ($IA_{ni}$ or $IA_i$) (refer to Table G-1):

**$IA_{ni}$** The $IA_{ni}$ represents a constituent concentration in indoor air that is protective of human health for non-industrial land use (residential). The exposure pathway addressed by the $IA_{ni}$ is the inhalation of volatile emissions.

**$IA_i$** The $IA_i$ represents a constituent concentration in indoor air that is protective of human health for industrial/commercial land use. The exposure pathway addressed by the $IA_i$ is the inhalation of volatile emissions.

The IA shall be based on: (1) the IA in Table G-1; if a COC is not listed in Table G-1, refer to the Louisiana Toxic Air Pollutant Ambient Air Standards in Table 51.2 of LAC 33:III.5112. If the COC is a noncarcinogen, identify the 8-hour average ambient air standard as the IA. If the COC is a carcinogen, identify the annual average ambient air standard as the IA. If a COC is not listed in Table 51.2, a risk-based IA for the appropriate land use shall be calculated; (2) Under MO-1 and MO-2, a risk-based value calculated using default exposure assumptions for the appropriate land use scenario; (3) Under MO-3, a risk-based value calculated using site-specific exposure data; or (4) other risk-based value determined to be acceptable for site-specific conditions and approved by the Department. If multiple COC are present, the IA shall be adjusted to account for additive health effects as warranted based on site-specific conditions.

If a calculated IA is below the analytical quantitation limit, then the analytical quantitation limit shall be identified as the IA. The analytical quantitation limit identified for application as an IA shall be the lowest quantitation limit available by routine analysis and shall be approved by the Department prior to use. If the IA is below a Department-approved background concentration, the background concentration shall be shall be identified as the IA. For a non-detect result, the SQL shall be compared to IA to document that the SQL is less than or equal to the IA prior to eliminating the constituent from further evaluation under the RECAP.

<u>Methods for the calculation of a risk-based indoor air concentration (IA)</u>:

**Nonindustrial/Residential Land Use - Noncarcinogenic health effects ($IA_{ni}$)**

$$\left(\mu g/m^3\right) = \frac{THQ \times AT_r \left(\frac{365\ days}{year} \times ED_r\ (30\ years)\right) \times \left(\frac{1000\ \mu g}{mg}\right)}{EF_r \left(\frac{350\ days}{year}\right) \times ED_r\ (30\ years) \times ET_{ra} \left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times \frac{1}{RfC\left(mg/m^3\right)}}$$

**Nonindustrial/Residential Land Use - Carcinogenic health effects ($IA_{ni}$)**

$$\left(\mu g/m^3\right) = \frac{TR \times AT_r \left(\frac{365\ days}{year} \times LT\ (70\ years)\right)}{EF_r \left(\frac{350\ days}{year}\right) \times ED_r\ (30\ years) \times ET_{ra} \left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IUR \left(\mu g/m^3\right)^{-1}}$$

**Nonindustrial/Residential Land Use – Vinyl Chloride - Carcinogenic health effects ($IA_{ni}$)**

$$\left(\mu g/m^3\right) = \frac{TR}{IUR \left(\mu g/m^3\right)^{-1} + \left(\frac{IUR \left(\mu g/m^3\right)^{-1} \times EF_r \left(\frac{350\ days}{year}\right) \times ED_r\ (30\ years) \times ET_{ra} \left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right)}{AT_r \left(\frac{365\ days}{year} \times LT\ (70\ years)\right)}\right)}$$

**Nonindustrial/Residential Land Use – Carcinogenic - Mutagenic ($IA_{ni}$)**

$$\left(\mu g/m^3\right) = \frac{TR \times AT_r \left(\frac{365\ days}{year} \times LT\ (70\ years)\right)}{EF_r \left(\frac{350\ days}{year}\right) \times ET_{ra} \left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times \left(\left(ED_{0\text{-}2}\ (yrs) \times IUR \left(\mu g/m^3\right)^{-1} \times 10\right) + \left(ED_{2\text{-}6}\ (yrs) \times IUR \left(\mu g/m^3\right)^{-1} \times 3\right) + \left(ED_{6\text{-}16}\ (yrs) \times IUR \left(\mu g/m^3\right)^{-1} \times 3\right) + \left(ED_{16\text{-}30}\ (yrs) \times IUR \left(\mu g/m^3\right)^{-1} \times 1\right)\right)}$$

**Industrial Land Use – Noncarcinogenic health effects ($IA_i$)**

$$\left(\mu g/m^3\right) = \frac{THQ \times AT_w \left(\frac{365\ days}{year} \times ED_w\ (25\ years)\right) \times \left(\frac{1000\ \mu g}{mg}\right)}{EF_w \left(\frac{250\ days}{year}\right) \times ED_w\ (25\ years) \times ET_w \left(\frac{8\ hr}{24\ hr}\right) \times \frac{1}{RfC \left(mg/m^3\right)}}$$

**Industrial Land Use – Carcinogenic health effects ($IA_i$)**

$$\left(\mu g/m^3\right) = \frac{TR \times AT_w \left(\frac{365\ days}{year} \times LT\ (70\ years)\right)}{EF_w \left(\frac{250\ days}{year}\right) \times ED_w\ (25\ years) \times ET_w \left(\frac{8\ hr}{24\ hr}\right) \times IUR \left(\mu g/m^3\right)^{-1}}$$

Where:

| Parameter | Definition | Input value | Reference |
|---|---|---|---|
| RfC | Chronic Inhalation Reference Concentration ($mg/m^3$) | Contaminant-specific | EPA Superfund hierarchy |
| IUR | Chronic Inhalation Unit Risk $(\mu g/m^3)^{-1}$ | Contaminant-specific | EPA Superfund hierarchy |
| TR | target risk | $1 \times 10^{-6}$ | EPA 1991;EPA 1996; EPA 2012 |
| THQ | target hazard quotient | 1 | EPA 1991; EPA 1996; EPA 2012 |
| $AT_r$ | Averaging time - resident (days/year) | 365 | U.S. EPA 1989 |
| $AT_w$ | Averaging time - composite worker (days/year) | 365 | U.S. EPA 1989 |
| LT | Lifetime (years) | 70 | U.S. EPA 1989 |
| $EF_r$ | Resident Exposure Frequency (days/yr) | 350 | U.S. EPA 1991a |
| $EF_w$ | Worker Exposure Frequency (days/yr) | 250 | U.S. EPA 1991a |
| $ED_r$ | Resident Exposure Duration (yr) | 30 | U.S. EPA 1991a |
| $ED_c$ | Resident Exposure Duration - child (yr) | 6 | U.S. EPA 1991a |
| $ED_a$ | Resident Exposure Duration - adult (yr) | 24 | U.S. EPA 1991a |
| $ED_w$ | Worker Exposure Duration - (yr) | 25 | U.S. EPA 1991a |
| $ED_{0-2}$ | Exposure Duration - age segment 0-2 (yr) | Site-specific | Site-specific |
| $ED_{2-6}$ | Exposure Duration - age segment 2-6 (yr) | Site-specific | Site-specific |
| $ED_{6-16}$ | Exposure Duration - age segment 6-16 (yr) | Site-specific | Site-specific |
| $ED_{16-30}$ | Exposure Duration - age segment 16-30 (yr) | Site-specific | Site-specific |
| $ET_{ra}$ | Resident Air Exposure Time (hours/day) | 24 | The whole day |
| $ET_w$ | Worker Air Exposure Time (hr/hr) | 8 | The work day |

## G7.2 Sub-Slab Soil Gas

Compare the sub-slab soil gas results to the sub-slab soil gas standard ($SSSG_{ni}$ and $SSSG_i$) in Table G-2.

**$SSSG_i$** – The sub-slab soil gas standard defines the acceptable constituent concentration in soil gas for the evaluation of the vapor intrusion pathway for industrial/commercial land

use. The $SSSG_i$ was derived by applying an alpha (α) of 0.03 to the $IA_i$. The $SSSG_i$ is applicable to soil gas collected beneath the slab of the enclosed structure.

**$SSSG_{ni}$** The sub-slab soil gas standard defines the acceptable constituent concentration in soil gas for the evaluation of the vapor intrusion pathway for non-industrial land use (residential). The $SSSG_{ni}$ was derived by applying an alpha (α) of 0.03 to the $IA_{ni}$. The $SSSG_{ni}$ is applicable to soil gas collected beneath the slab of the enclosed structure.

If a volatile COC is not listed in Table G-2, determine the acceptable indoor air concentration (IA) as detailed in Section 7.1 and apply an alpha factor of 0.03.

## G7.3 Exterior Soil Gas

Compare the exterior soil gas results to the exterior soil gas standard ($ESG_{ni}$ and $ESG_i$) in the Table G-3.

**$ESG_{ni}$** – The exterior soil gas standard defines the acceptable constituent concentration in soil gas for the evaluation of the vapor intrusion pathway for non-industrial land use (residential). For petroleum hydrocarbon components, the $ESG_{ni}$ was derived by applying an alpha (α) of 0.003 to the $IA_{ni}$. For all other constituents, the $ESG_{ni}$ was derived by applying alpha of 0.03 to the $IA_{ni}$. The $ESG_{ni}$ is applicable to soil gas collected exterior to the enclosed structure.

**$ESG_i$** – The exterior soil gas standard defines the acceptable constituent concentration in soil gas for the evaluation of the vapor intrusion pathway for industrial/commercial land use. For petroleum hydrocarbon components, the $ESG_i$ was derived by applying an alpha (α) of 0.003 to the $IA_i$. For all other constituents, the $ESG_i$ was derived by applying alpha of 0.03 to the $IA_i$. The $ESG_i$ is applicable to soil gas collected exterior to the enclosed structure.

If a volatile COC is not listed in Table G-3, determine the acceptable indoor air concentration (IA) as detailed in Section G7.1 and apply an alpha factor of 0.003 for petroleum hydrocarbon constituents or an alpha factor of 0.03 for non-petroleum constituents.

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