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ENVIRONMENT

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David L. South
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Washington State Department of Ecology
Toxics Cleanup Program, NWRO
3190 160th Avenue Southeast
Bellevue, Washington 98008-5452

Soil Vapor Investigation Work Plan, 2013
Former Unocal Edmonds Bulk Fuel Terminal
11720 Unoco Road
Edmonds, Washington 98020

Dear Mr. South:

On behalf of Chevron Environmental Management Company (Chevron), ARCADIS U.S., Inc. (ARCADIS) has prepared this Soil Vapor Investigation Work Plan (work plan) for the Lower Yard of the Former Unocal Edmonds Bulk Fuel Terminal (the Site). This Report is being submitted under Agreed Order (AO) No.DE 4460 which requires the Union Oil Company of California (Unocal), a wholly owned indirect subsidiary of the Chevron Corporation, to conduct additional Site characterization activities that will be used to evaluate vapor intrusion risk due to potential Site redevelopment and to support remedial strategy decisions at the Lower Yard during the Feasibility Study.

The soil vapor probe installation, sampling and data evaluation procedures proposed within this work plan will be completed in accordance with the Washington State Department of Ecology's (Ecology) *Draft Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action* (Ecology 2009), the Chevron *Soil Vapor and Indoor Air Sampling Technical Toolkit* (Version 1.8, Chevron 2013) included as **Appendix A** and the ARCADIS Standard Operating Procedure (SOP) for Soil Gas Sampling and Analysis Using United States Environmental Protection Agency (USEPA) Method TO-17 and TO-15 included as **Appendix B**.

Site Description

As defined in the Agreed Order, the Site consists of three areas, the Upper Yard, the Lower Yard and the Willow Creek Fish Hatchery (fish hatchery). The Lower Yard is currently in escrow for sale to the Washington State Department of Transportation (WSDOT) and is the focus of this investigation.

The Lower Yard is approximately 22 acres in area. ; The Site layout is shown on **Figure 1**. The Lower Yard is currently zoned master plan hillside mixed-use zone 2 (MP2), which would allow for use as mixed general residential and commercial uses, but which prohibits residential use on the ground floor of any building (ARCADIS 2013).

Site Geology and Hydrogeology

The current uppermost stratigraphic unit of the Lower Yard consists primarily of fill material with poorly graded coarse gravels with little to no fines. Remaining un-excavated areas are most likely fill material consisting of sand and gravel and sandy silts with gravel to a depth of 8 to 15 feet below ground surface (bgs).

As described in the Conceptual Site Model (CSM) report (ARCADIS 2013), historical groundwater elevations from 2008 through 2012 range from approximately 2 feet amsl to 15 feet amsl and generally decrease from south to north-northwest primarily towards Puget Sound and towards Edmonds Marsh (east). Depth to water values range from approximately 0.6 feet below top of casing (btoc) to 27 feet btoc (ARCADIS 2013).

Remaining Impacts

A trend analysis for data collected at 21 Site monitoring wells from October 2008 through June 2012 was presented in the CSM (ARCADIS 2013). Results indicated decreasing trends in total TPH and benzene concentrations at all locations evaluated, with the exception MW-510, where LNAPL has been historically present.

Remaining impacts to soil have been identified at the following areas:

- WSDOT Stormwater line: Eleven soil samples exceeded Site cleanup levels (CULs) and/or remediation levels (RELs) in two distinct areas adjacent to the WSDOT stormwater line (See Figure 1) at depths between 4 and 8 feet bgs with total petroleum hydrocarbons (TPH) concentrations ranging from 3,060 to 17,850 mg/kg. The impacted soils adjacent to the WSDOT stormwater line cover an area of approximately 0.31 acres, of the 22 total acres of the Lower Yard. Soils along the stormwater line, including those with CUL/REL exceedences, were unable to be excavated without compromising the integrity of the stormwater line.

- Detention Basin No. 2 Area (DB-2): Eleven soil samples exceeded Site CULs and/or RELs at depths from 4 feet to 14 feet bgs, with concentrations ranging from 4,413 to 220,400 mg/kg. Free-phase or residual LNAPL was encountered in eight of 17 borings at depths from 7 to 12 feet bgs The area surrounding DB-2, where impacted soils were encountered covers approximately 0.43 acres of the 22 total acres of the Lower Yard.

- Isolated soil samples from four locations exceeded Site CULs and/or RELs for TPH and/or carcinogenic polycyclic aromatic hydrocarbons (cPAHs):

    - During the installation of monitoring well MW-129R, a soil sample was collected at a depth of 7 feet bgs that contained a concentration of total TPH at 3,010 mg/kg.
    - During Phase I of the 2007/2008 Interim Action Investigation one soil sample in the Southwest Lower Yard, sample EX-B18-VV-1-6SW, had a total TPH concentration of 4,980 mg/kg at a depth of 6 feet bgs.
    - During Phase II of the 2007/2008 Interim Action Investigation one soil sample in the southeast Lower Yard, sample EX-BI-F-44-4, had a cPAH concentration of 0.212 mg/kg at a depth of 4 feet bgs.
    - During 2008 Site investigation activities a soil boring (SB-80) was installed southwest of the Point Edwards stormdrain line. The soil sample collected from this boring at a depth of 7.5 feet bgs contained concentrations of TPH at 4,660 mg/kg and cPAHs at 0.693 mg/kg, respectively.

The potential for soil vapor intrusion must be evaluated in areas of remaining impacts as part of the AO, and this work plan proposes collection of soil gas data to complete that evaluation. The potential chemicals of concern for remaining impacts at the Site include: benzene, cPAHs and TPH in the gasoline, diesel and heavy oil carbon ranges. Ecology does not currently have Method B CULs presented in the *Draft Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action* (Ecology 2009) for cPAHs and TPH in shallow soil gas. Benzene and specific aliphatic and aromatic TPH carbon ranges (C5-C8 aliphatic, C9-C12 aliphatic and C9-C10 aromatic) will be used for evaluation during this investigation.

Soil Vapor Probe Installation

ARCADIS proposes to install three permanent single level onsite soil vapor probes (VP-1, VP-2 and VP-3) to assess the potential for soil vapor at the Lower Yard adjacent to remaining impacts in soil and groundwater.

The vapor probe locations were selected as worst case scenarios for volatile organic compounds (Gasoline range hydrocarbons) and will be located in the vicinity of locations with maximum gasoline range hydrocarbon detection and/or areas of remaining impacts on the Site.

- Soil vapor probe VP-1 will be located in the vicinity of MW-525 (TPH-17,850 mg/Kg, TPH-G: 1,400 mg/Kg) and will evaluate potential soil vapor adjacent to the WSDOT stormwater line.

- Soil vapor probe VP-2 will be located in the vicinity of B-7 (TPH-111,400 mg/Kg, TPH-G: 1,400 mg/Kg) and will evaluate potential soil vapor adjacent to the drainage basin area 2 (DB-2) and adjacent to groundwater monitoring well MW-510 (LNAPL observed).

- Soil vapor probe VP-3 will be located adjacent to monitoring well MW-129R (TPH-3,010 mg/Kg, TPH-G: ND) and will evaluate potential soil vapor in the adjacent area.

A vapor probe in the location of Sample EX-B18-VV-1-6SW (TPH – 4,980 mg/Kg) in the southwest portion of the lower yard was considered but not selected due to two reasons: 1) Vicinity to the Burlington Northern Santa Fe (BNSF) active railroad tracks and 2) less likelihood of building a structure on the property boundary.

The soil vapor probe locations may be adjusted in the field based on accessibility, and with Ecology approval. Soil vapor probe locations are presented on **Figure 1** and soil vapor probe schematic is presented on **Figure 2**.

The depth to groundwater is approximately 6 feet bgs. In order to collect soil vapor samples from vadose zone (above the groundwater table), each vapor probe will contain one soil vapor probe set at 5 feet bgs or one foot above groundwater, whichever is encountered first. Vapor probes will be cleared to the respective target depth using hand auger and vacuum truck methods. When each respective boring has been advanced to its maximum depth of 5 feet bgs, a 6-inch long, 0.375-inch outer diameter stainless steel soil vapor screen will be set in a one-foot interval of standard sand pack, allowing approximately three-inches of sand above and below the screen. Teflon tubing (or equivalent) will be connected to the soil vapor screen and capped with a vapor-tight two-way valve or cap at the surface to eliminate the potential for barometric pressure fluctuations to induce vapor transport between the subsurface and the atmosphere. The two-way valve or cap will be installed in the closed position to allow equilibration of soil vapor concentrations to commence immediately after installation.

A one-foot interval of dry, granular bentonite will be placed above the sand pack followed by hydrated bentonite grout to within one-foot of the surface. Sand pack is used around the screened interval of each sample probe to allow soil vapor from the adjacent soil to reach the probes. Dry granular bentonite is used to ensure that the hydrated bentonite grout does not seal the vapor probe screen and inhibit the collection of soil vapor. The surface of each vapor probe location will be fitted with a concrete cap and a flush mounted, traffic rated well box with sufficient room to store the tubing lines and valves or caps.

Continuous soil samples will be collected from a hand auger at each proposed soil vapor probe location during advancement for field screening only. The collected intervals will be screened in the field using a photoionization detector (PID), and will be described by the supervising geologist using visual and manual methods of the Unified Soil Classification System (USCS).

Soil Vapor Sampling

Due to the introduction of atmospheric oxygen into the vadose zone during soil vapor probe installation, an equilibration time is required to allow the sand pack and tubing to equilibrate with the subsurface. A minimum of 48-hours will be allowed for equilibration before purging and sampling of the soil vapor probes.

To assure sampling train integrity a shut-in leak detection test will be implemented. One vapor tight two-way ball valve will be installed closest to the soil vapor port (port valve) and another vapor tight two-way ball valve will be installed on the opposite end of the sampling train as a purge valve (purge valve). While the port valve is left in the closed position, a laboratory provided syringe will be utilized to remove approximately 25 milliliters (ml) from the purge port inducing a vacuum of -8 inches of mercury (approximately -107 inches of water) within the sampling train. The purge valve will be closed and the vacuum within the sampling train will be monitored for a minimum of 2 minutes. If there is any observable loss in the vacuum within the sampling train after 2 minutes, fittings will be adjusted and the test repeated until the vacuum in the sampling train does not dissipate.

Purging will consist of removing approximately three volumes of stagnant soil vapor at a flow rate of ≤ 200 milliliters per minute (mL/min). The purge volume will be calculated based on the dimensions of the above-ground gauges, tubing, sampling equipment, below-ground tubing, soil vapor probe and sand pack annulus pore space. Purge volume calculation, field conditions, flow rate, pump specifics and other applicable information will be recorded by field personnel on soil vapor sample collection logs.

Purged air will be measured for oxygen, carbon dioxide and methane with a GEM2000 landfill meter. Purged air will also be measured with a PID (for volatile organic compounds) and a helium meter (for leaks).Fixed gas measurements will be compared to laboratory analytical results and support potential biodegradation evaluation. If methane is detected above the lower explosive limit (LEL), an alternative sorbent tube sampling method will be implemented.

A leak test will be conducted to ensure the integrity of the sampling system. The well head and entire sampling train (valves, tubing, gauges, manifold and sample canister) will be placed in an enclosure with pliable weather stripping along the base. A tracer check compound (helium) will be admitted into the enclosure. A helium concentration of between 10 and 20 percent (%) will be maintained in the enclosure as measured using a portable helium detector. Analysis for the tracer compound in the soil vapor sample will be used to assess if leakage occurred. The soil vapor samples will then be collected using 1-Liter batch certified SUMMA™ canisters (or an acceptable alternative) at a flow rate of ≤ 200 mL/min. Soil vapor sampling will be stopped when the canister vacuum has dropped to 5 inHg as measured by the vacuum gauge attached to the SUMMA Canister.

If methane is detected in purged soil vapor above the LEL, sorbent tube sampling methods will be implemented. Sorbent tube sampling will consist of connecting a laboratory provided sorbent tube to the sampling train. Soil vapor will then be actively drawn through the sorbent tube via laboratory provided syringe. The volume of soil vapor required for the sorbent sample will be pre-determined by the laboratory in order to meet appropriate reporting limits for data evaluation. Sorbent tube samples will be sealed with vapor tight caps on both ends and stored on ice. If sorbent tube sampling methods are utilized, sampling procedures will be conducted in accordance with the ARCADIS SOP (#112409) *Soil-Gas Sampling and Analysis Using USEPA Method TO-17 and TO-15*. Additionally, if sorbent tube sampling methods are utilized, fixed gas data will be obtained through field measurements only.

A duplicate sample collected in-line with its respective parent sample for each day of sampling and an equipment blank sample collected using a laboratory supplied air source will also be submitted to the laboratory for quality assurance purposes.

Purge volume calculation, field conditions, flow rate, VOC concentrations, pump specifics and other applicable information will be recorded by field personnel on soil vapor sample collection logs. The soil vapor samples will be shipped under appropriate chain of custody protocols to Eurofins Air Toxics Ltd. in Folsom, California for analysis of the following:

- Benzene and TPH-G (with specific carbon ranges: C5-C6 aliphatic hydrocarbons, greater than (>)C6-C8 aliphatic hydrocarbons, >C8-C10 aliphatic hydrocarbons, >C10-C12 aliphatic hydrocarbons, >C8-C10 aromatic hydrocarbons, >C10-C12 aromatic hydrocarbons) and naphthalene by Modified United States Environmental Protection Agency (USEPA) Method TO-15 or TO-17.

- Oxygen, carbon dioxide, methane and helium by Modified American Society for Testing and Materials (ASTM) Method D-1946.

If sorbent tube methods are utilized, TPH will not be analyzed as this compound is not directly comparable to Method B CULs presented in the Ecology *Draft Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action* (Ecology 2009).

Data Evaluation

Measured concentrations will be reported in micrograms per cubic meter (µg/m^3). TO-15 reporting limits will be calculated based on method detection limits and potential dilution. TO-17 reporting limits will be calculated based on detected concentrations and sample volume. Detected concentrations of constituents in soil vapor will be compared to health-based screening criteria. These screening criteria define levels that the regulatory agencies have deemed safe for human exposure under a vapor intrusion scenario. Soil vapor data will be compared with Method B soil gas screening levels presented in Table B-1 of the Ecology *Review DRAFT*

Guidance for Evaluation Soil Vapor Intrusion in Washington State: Investigation and Remedial Action (Ecology 2009). Ecology provides draft soil gas screening values for samples collected at depths less than 15 feet bgs and soil gas screening values for samples collected at 15 feet bgs or deeper.

Table 1 : Soil Vapor Data Screening Levels

Measured Concentration (µg/m^3)	Screening criteria (µg/m^3)
Benzene	3.2
Naphthalene	14
Σ(C5-C6AL)+(>C6-C8AL)	27,000
Σ(>C8-C10AL)+(>C10-C12AL)	1,400
Σ(C8-C10AR)+(>C10-C12AR)	1,800

It is recognized that petroleum hydrocarbon vapors rapidly biodegrade in the soil column when sufficient oxygen is present. Aerobic biodegradation consumes oxygen and generates carbon dioxide. Comparison of fixed gas concentrations relative to atmospheric levels will be discussed as a qualitative evaluation of the degree to which hydrocarbon vapors may be biodegrading at the Site.

The results of soil vapor investigation will be presented in the Draft Feasibility Study Report scheduled to be submitted to Ecology in December 2013. The soil vapor investigation event at the Site is scheduled for Fall 2013. Should you have any questions or if ARCADIS can be of further assistance, please contact Scott Zorn at (206) 726-4709.

Sincerely,

for
Eric Epple
Geologist II

Scott Zorn
Principal Geologist

Copies:
Cc: Kim Jolitz, Chevron Environmental Management Company

Attachments:

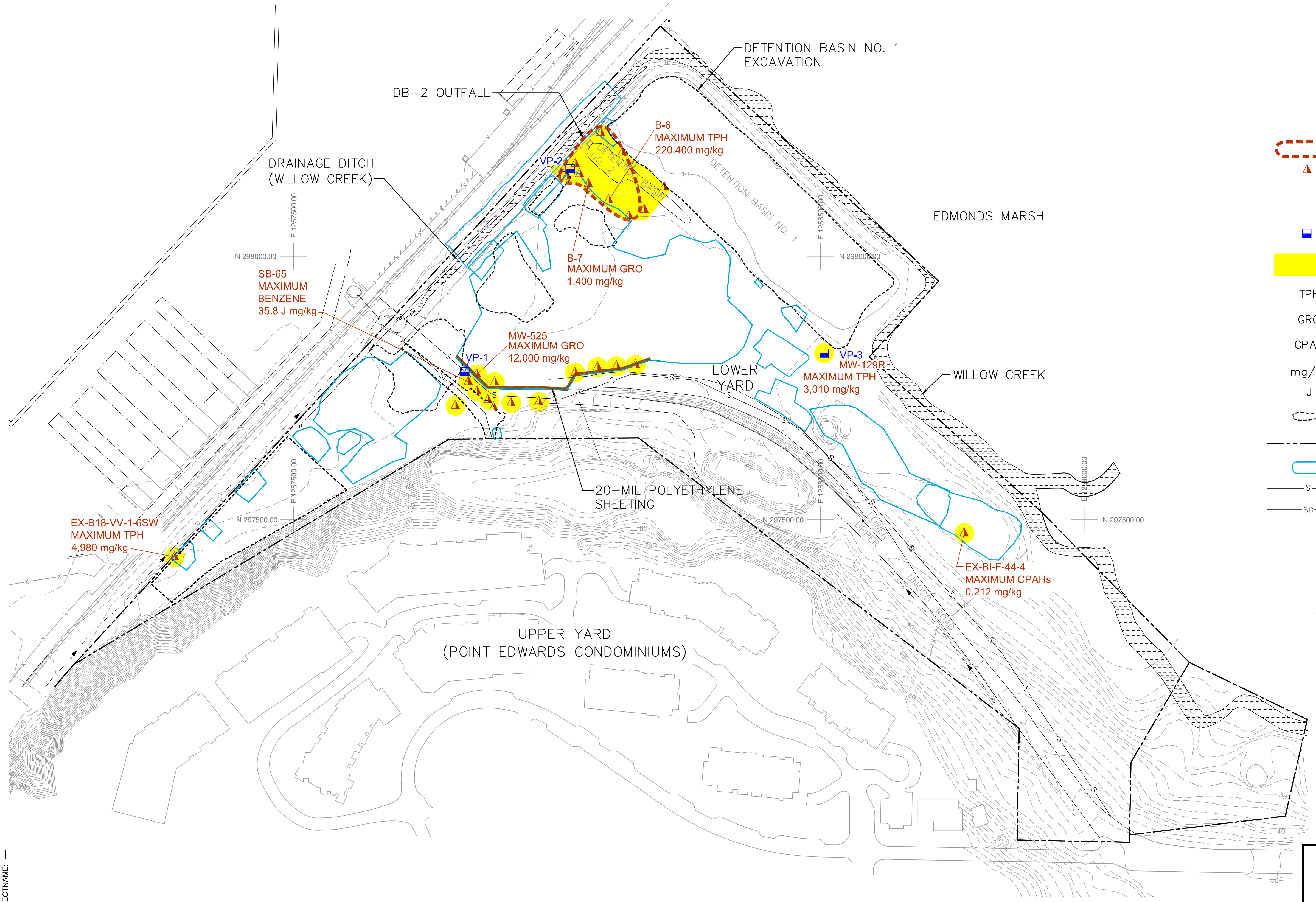
Table 1	Soil Vapor Data Screening Levels
Figure 1	Soil Vapor Probe Locations
Figure 2	Soil Vapor Probe Schematic
Appendix A	Chevron *Soil Vapor and Indoor Air Sampling Technical Toolkit v1.8*
Appendix B	ARCADIS SOP (#112409) *Soil-Gas Sampling and Analysis Using USEPA Method TO-17 and TO-15*

References:

ARCADIS, 2013. Former Unocal Edmonds Bulk Fuel Terminal. *Conceptual Site Model*. May 2013.

Ecology, 2009. *Draft Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action*. October 2009.

Figures



LEGEND:

⬭	ESTIMATED LNAPL BOUNDARY
▲	SOIL SAMPLE COLLECTION LOCATION WITH CONCENTRATIONS OF TOTAL TPH AND/OR CPAHS EXCEEDING APPLICABLE SITE CULs AND/OR RELs.
⬓	SOIL VAPOR PROBE
🟨	AREA WITH REMAINING SOIL IMPACTS EXCEEDING SITE CULs AND/OR RELs
TPH	TOTAL PETROLEUM HYDROCARBONS
GRO	GASOLINE RANGE HYDROCARBONS
CPAH	CARCINOGENIC POLYNUCLEAR AROMATIC HYDROCARBONS
mg/kg	MILLIGRAMS PER KILOGRAM
J	INDICATES AN ESTIMATED VALUE
⬭	2001 AND 2003 SOIL EXCAVATIONS BELOW GROUNDWATER TABLE
—·—·—	LOWER YARD PROPERTY BOUNDARY
▭	2007/2008 EXCAVATION BOUNDARIES
—S—	WSDOT STORM DRAIN LINE
—SD—	POINT EDWARDS STORM DRAIN LINE

NOTES:

1. 20–MIL POLYETHYLENE SHEETING INSTALLED UPON COMPLETION OF PHASE I EXCAVATION. SHEETING REACHES TO APPROXIMATELY 7.5 FEET ABOVE MEAN SEA LEVEL.
2. SOUTHEAST PORTION OF WSDOT STORM DRAIN LINE HAS NOT BEEN SURVEYED.

0 200' 400'
GRAPHIC SCALE

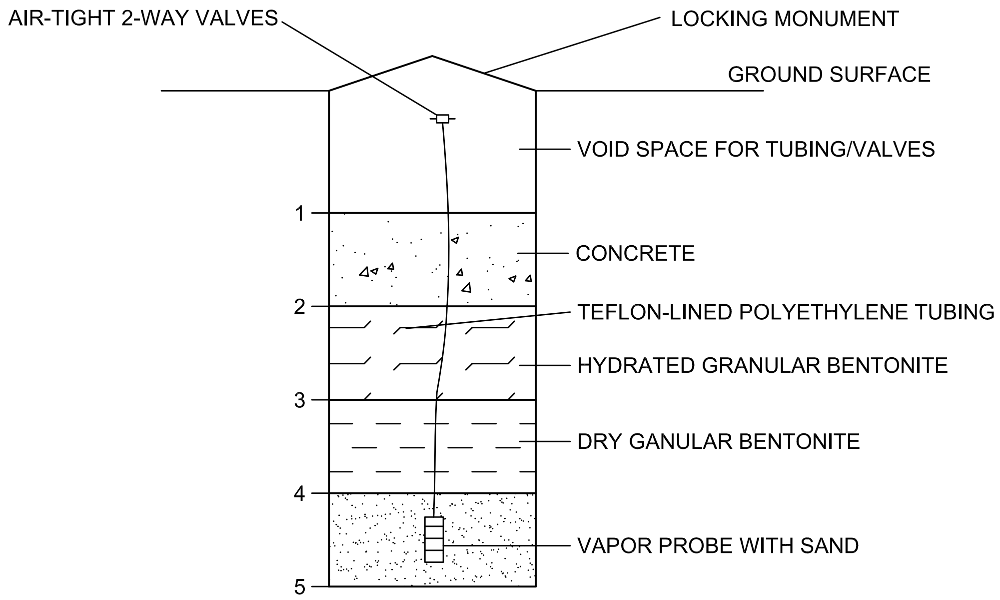
CHEVRON ENVIRONMENTAL MANAGEMENT COMPANY
FORMER UNOCAL EDMONDS TERMINAL, LOWER YARD
EDMONDS, WASHINGTON
SOIL VAPOR INVESTIGATION

SOIL VAPOR PROBE LOCATIONS

ARCADIS

FIGURE
1

CITY: SYRACUSE, NY DIV/GROUP: ENV/IM-DV DB: K. DAVIS, R. ALLEN, P. LISTER PM/TM: R. ANDRESEN TR: P. GHATPANDE LYR: ON=*;OFF=*REF*
G:\ENVCAD\SYRACUSE\ACT\B0045362\0004\00006\DWG\45362B13.dwg LAYOUT: 1 SAVED: 9/25/2013 8:19 AM ACADVER: 18.1S (LMS TECH) PAGESETUP: --- PLOTSTYLETABLE: PLTFULL.CTB PLOTTED: 9/25/2013 8:19 AM BY: LISTER, PAUL
XREFS: IMAGES: PROJECTNAME: ---
45362X02
45362XDL
45362X03



NOT TO SCALE

NOTE:

VAPOR PROBE IS CONSTRUCTED WITH A 6-INCH, 0.375-INCH OUTER DIAMETER STAINLESS STEEL SOIL VAPOR SCREEN.

CHEVRON ENVIRONMENTAL MANAGEMENT COMPANY
FORMER UNOCAL EDMONDS TERMINAL, LOWER YARD,
EDMONDS, WASHINGTON

SINGLE LEVEL SOIL VAPOR PROBE SCHEMATIC DIAGRAM

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FIGURE
2

CITY: (PETALUMA, CA), SYRACUSE, NY DIV/GROUP: ENV/REM-W/IM-DV DB: (J. HARRIS), P. LISTER PM: R. ANDRESEN TM: P. GHATPANDE TR: D. RASAR LYR: ON=*;OFF=*REF*
G:\ENVCAD\SYRACUSE\ACT\B0045362\0004\00006\DWG\45362T01.dwg LAYOUT: 2 SAVED: 9/23/2013 10:55 AM ACADVER: 18.1S (LMS TECH) PAGESETUP: SETUP1 PLOTSTYLETABLE: PLTFULL.CTB PLOTTED: 9/23/2013 10:55 AM BY: LISTER, PAUL
XREFS: IMAGES: PROJECTNAME: ---

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Appendix A

Chevron - Soil Vapor and
Indoor Air Sampling Technical
Toolkit (v1.8)

Soil Vapor & Indoor Air Sampling Technical Toolkit

Version 1.8

This work was funded by Chevron Environmental Management Company and performed by Chevron Energy Technology Company, Health, Environment and Safety Group, Environmental Unit.

Tom Peargin, Senior Staff Hydrogeologist
Ravi Kolhatkar, Staff Environmental Hydrogeologist
Hong (Emma) Luo, Environmental Hydrogeologist

Environmental Unit
Health, Environment and Safety Department
Chevron Energy Technology Company

March 20, 2013

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TABLES

1 INTRODUCTION

The Chevron (CVX) Soil Vapor Sampling Technical Toolkit provides technical guidance to suppliers conducting vapor migration pathway (VIP) investigations at petroleum hydrocarbon contaminated sites. The toolkit is a collation of identified "best practices" in planning and conducting soil vapor surveys. Maintaining consistency in best practices across the Chevron portfolio is a primary driver for this toolkit, as this will enhance the defensibility of the soil vapor data gathered at these sites. The toolkit is intended to remain "evergreen": that is, as new best practices are developed, the toolkit will be edited to incorporate those developments. In this manner the most up-to-date technologies and methods can be implemented in the field.

The toolkit is primarily focused on petroleum hydrocarbon impacted sites; that is, sites where biodegradation of vapor phase contaminants can play a role in attenuation. However, many elements of the toolkit can also be applied at sites where biodegradation of vapor phase contaminants is unlikely to occur (e.g., chlorinated solvent contaminated sites). The toolkit is organized into sections focusing on soil vapor sampling probes, soil vapor sampling, analytical techniques, and data reporting. Diagrams are included to provide further description of the processes and equipment discussed. Further technical information and advice is available by contacting the Chevron Energy Technology Co. VIP Team members:

Tom Peargin, Senior Staff Hydrogeologist, tpeargin@chevron.com, 925-842-5586
Ravi Kolhatkar, Staff Environmental Hydrogeologist, kolhatrv@chevron.com, 713-954-6082
Hong (Emma) Luo, Environmental Hydrogeologist , Emma.Hong.Luo@chevron.com, 713-954-6101

2 SOIL VAPOR PROBE INSTALLATION

All standard protocols required before initiating any drilling activities (e.g., regulatory permits, underground utility markings, clearances from overhead lines etc.) need to be followed when preparing the site for installation of soil vapor probes.

2.1 Permanent vs. Temporary Probes

Permanent soil vapor sampling probes are required for soil vapor surveys conducted for human health risk assessment to ensure that samples from a given location can be collected repeatedly. **Chevron recommends permanent probes to increase the accuracy and technical defensibility of samples used to assess human health risk.** Temporary probes (which are sampled only once) are suitable only for non-human health risk assessment soil vapor samples, such as in support of delineation of a vapor phase contaminant plume.

Permanent probes also facilitate repeated sampling rounds if this is deemed necessary to represent soil vapor concentrations during different seasons, during high and low water table conditions, or during periods of frozen ground. If a sample is only taken once at a particular point, the result could be misleading due to variable water table elevations, and the variation of NAPL/air interaction that comes with these seasonal changes.

2.2 Borehole Clearance

The use of air knife for borehole clearance is not recommended for direct emplacement of soil vapor sampling points at shallow depths (e.g., 5 ft). This is because air knife utilizes high pressure air and is expected to significantly disturb the soil vapor profile around the installation, and it could take weeks to months for the profile to re-equilibrate (API 2005). Instead, hand auguring is preferred for installing soil vapor sampling points at a shallow depth of 5 ft.

Air knife borehole clearance (typically performed to a depth of 8 ft) is acceptable for installation of deeper soil vapor sampling points (10 ft deep or greater). Following the borehole clearance, these deeper points could be installed using either direct push or hollow stem auger methods.

2.3 Water Table Elevation and Soil Vapor Sampling Probe Depth

Prior to installing permanent soil vapor probes it is critical to review the historical range of site groundwater elevation data to determine the proper depth for probe installation. Soil vapor sampling probes should ideally be installed so that the vapor sampling screen is situated 2 to 3 ft above the historical high groundwater elevation, which will reduce the likelihood that the probe will be submerged during periods of elevated groundwater, and will enable the probe to sample that interval of the subsurface with the potentially highest soil vapor volatile organic compound (VOC) concentrations.

The US EPA and most state regulatory guidance require a minimum of 5 ft depth for the shallowest soil vapor sampling probes. For sites with shallow water tables (high water table elevation is within 5-7 ft of the surface) it is acceptable to place the soil vapor sampling probe at a depth of 5 ft, even though this depth may cause the point to be submerged, or occluded with water from the capillary fringe during certain portions of the season. **Placing soil vapor sampling points at depths less than 5 ft. should be performed only on an exception basis and with approval of Chevron Project Manager**. **When approval has been granted to install a soil vapor sampling point shallower than 5 ft, it is critical to take extra care to ensure there are no leaks due to potential short-circuiting from the surface.**

2.4 Single vs. Multilevel Soil Vapor Sampling

Chevron recommends installation of multilevel probes in order to understand the source of soil vapors (impacted vadose zone soil vs. impacted groundwater) and to qualitatively evaluate the depth and degree of biodegradation of soil vapors in the vadose zone (using concentration versus depth profiles of VOCs, methane, oxygen and carbon dioxide). In addition, several VI guidance documents (e.g., CA DTSC, 2011) recommend multilevel probe installation, with the sample containing the highest concentration (regardless of depth) used for comparison to Tier I screening tables.

EPA and most state regulatory guidance documents state that soil vapor samples used for vapor intrusion screening should not be collected shallower than 5 ft depth. Agency guidance states that this is intended to minimize the potential for short-circuiting of atmospheric air into soil vapor samples. **See section 2.3 for sites where depth to groundwater is about 5 ft or less from the ground surface or less**. The deepest probe should be installed 2 to 3 ft above the historical high groundwater elevation, with shallower probes installed at defined intervals above the deepest probe (e.g., 5 ft intervals). For example, at a site where the seasonal high groundwater elevation is 18 ft below grade, probes could be emplaced at depths of 15, 10, and 5 ft below grade.

2.5 Soil Vapor Probe Installation using Hollow-stem Augers

A conventional drill rig equipped with a hollow-stem auger should be used for permanent soil vapor probe installation. Use of methods such as rotosonic, air rotary, or mud rotary drilling methods can influence soil vapor sample results and/or alter the physical properties of the subsurface adjacent to the sampling probe, although they may be necessary due to stratigraphic limitations (e.g., cobbles). **If rotosonic, air rotary, or mud rotary drilling methods are deemed necessary they should be utilized only on an exception basis and with approval of the Chevron Project Manager**.

2.5.1 Soil Sample Collection

During drilling, soil cores should be collected for lithologic and stratigraphic description, and, **if required by CEMC project managers, for evaluation of soil porosity and moisture content (ASTM D2216) for potential vapor transport modeling**. Soil samples should be collected and preserved for off-site chemical and physical analyses. Sampling interval selection is site specific, based on stratigraphic heterogeneity and Chevron recommends continuous logging and taking soil sample at each lithology or planned screen interval. Chemical analyses are chosen based on the site contaminants, but typically would include TPHg and TPHd (EPA 8015B) and BTEX (EPA 8260B) for gasoline release sites. Undisturbed soil samples should be collected in stainless steel or brass liners and capped with Teflon® sheeting and plastic end caps and placed in re-sealable plastic bags. The liners should then be stored in iced coolers and transported to a certified laboratory under chain-of-custody documentation.

2.5.2 Soil Vapor Sampling Probe Construction

After the borehole is drilled to its maximum depth, the deepest soil vapor sampling probe is installed (Figure 1). Each sampling probe tip should be approximately 6 inches long, and of small diameter (¼-inch is typical) to minimize dead space within the probe. Screens constructed of stainless steel and PVC are acceptable, Each 6-inch-long screen tip is vertically centered in a 1-ft long interval containing standard sand pack, resulting in 3 inches of sand being above and below each screen. It is important to correctly size the sand pack for the probe screen diameter. Each sand pack is covered with a 1 ft interval of dry granular bentonite, which is then covered with ≥ 2 ft of hydrated granular bentonite slurry to the bottom of the next sand pack (i.e., the next sampling interval). The dry granular bentonite is emplaced immediately above the sand pack to ensure that hydrated granular bentonite slurry does not flow down to the probe screen and seal it off from the adjacent soil. Following the emplacement of 1 ft of dry granular bentonite immediately above the uppermost sampling interval (sand pack), the remainder of the borehole should be filled with hydrated granular bentonite slurry (mixed at the surface and poured in) and, at the top, a 1-ft cement cap. A flush-mounted, locked utility vault of sufficient size to contain the tubing lines should be set in the cement cap.

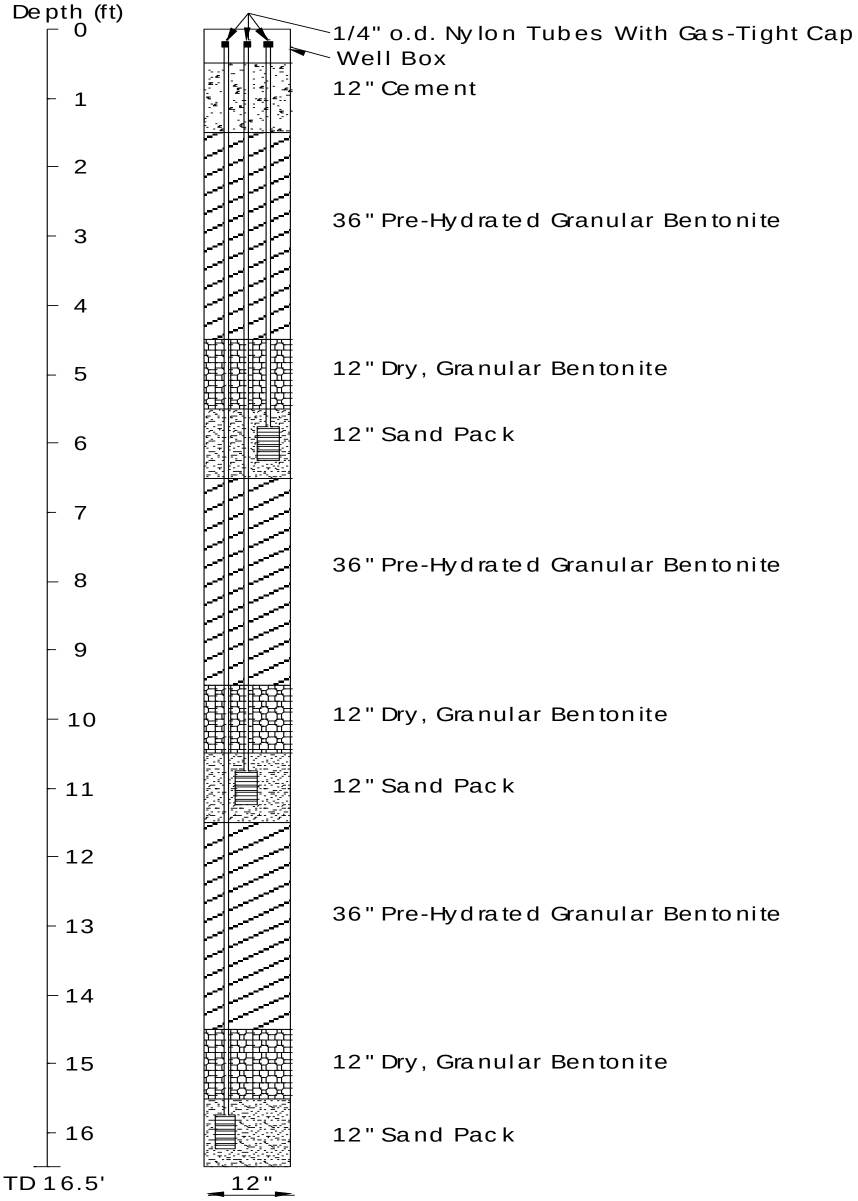


Figure 1. Augered, permanent multilevel soil vapor sampling probe (by Chuck Zuspan, ETC)

Probes should have screen and end caps fitted with a Swagelok® fitting connected to the upper end cap. Use chromatography-grade 316 stainless steel compression fittings to ensure that fitting materials are not a source of VOCs. Tubing should be ¼-inch outer diameter Teflon® or Nylon or stainless steel. Hose clamps, push-on barbed fittings, and other types of connectors should be avoided as they may not provide an air-tight seal. Two studies have been done to evaluate different types of tubing. Air Toxics (Hayes et. al, 2006) conducted tests of three tubing types (Teflon®, nylon, PEEK) that showed little difference in the tubing type with respect to cleanliness and inertness to the chemicals tested. Low-level blanks were detected in nylon, but the values were far below required soil-gas risk-based screening levels. An earlier study presented at a conference in 2004 (Ouellette, 2004) compared the adsorption of a hydrocarbon standard by five tubing types (Teflon®, nylon, polyethylene, vinyl and flexible Tygon®). Nylon and Teflon® showed insignificant adsorption (<10%), but the others showed higher adsorption, especially the flexible tubing, where losses of the tested hydrocarbon standard were up to 80 percent. **For this reason, flexible tubing materials such as Polyethylene, vinyl and Tygon® are not acceptable for use at Chevron sites**.

Also very important is where the tubing is stored and how it is handled. Any type of tubing will become contaminated and contribute to false positives if it is stored near volatile chemicals. For this reason, all tubing should be new, carefully stored, and blank tested (see QA/QC section).

Each of the tubing lines must be clearly and permanently marked at the land surface to denote its corresponding screened interval. Do not use markers. Each tube must be fitted with a gas-tight, Swagelok® valve or cap at the ground surface to eliminate the potential for atmospheric air getting into the tubing. If a cap is used, it must be removed before sampling, which creates an opportunity for atmospheric air entry to the probe, so the period between removing the cap and assembling the sampling train should be as brief as possible and purging (discussed later in this toolkit) is required before sampling.

2.6 Soil Vapor Sampling using Direct-push Techniques

Single or multilevel soil vapor sampling can be performed with a direct-push rig (e.g., Geoprobe®) in certain soil type (e.g. non-clayey soil). These rigs can install permanent soil vapor sampling probes, or can be used to collect soil vapor data during a direct-push where no permanent probe is installed. **Chevron requires human health risk assessments to be performed with data collected from permanent soil vapor sampling probes** but soil vapor samples collected from tubing during a single push (temporary direct-push, e.g. Post-Run Tubing System) can be useful to delineate areas of elevated soil vapor concentrations, and can help identify location and depth of permanent soil vapor sampling probes if needed (but not for human health risk assessment).

2.6.1 Temporary Direct-Push Soil Vapor Sampling (Post-Run Tubing System)

Soil vapor surveys using direct push techniques (non-permanent installations) are sometimes useful in determining the depth and extent of localized petroleum hydrocarbon vapors, especially when sourced from residual soil contamination in the vadose zone.

Once delineated, these data can be used to determine the location of permanently installed sampling probes for human health risk assessment.

Temporary direct-push soil vapor concentration data does not represent the most technically defensible sampling available, since it is difficult to insure that samples from temporary direct-push probes have not leaked to the surface (which might yield false-negative data), and the technique precludes collection of multiple samples over time to verify the presence or absence of temporal variation. **As a result, use of temporary direct-push soil vapor sample data in assessing human health risk should only be considered on an exception basis and with approval of Chevron Project Manager.**

The Post-Run Tubing (PRT) system involves the use of a drive point holder (located just above the drive point) that also serves as the soil vapor sampling probe (Figure 2). Both expendable and retrievable drive point/drive point holder systems are available. The PRT system allows for soil vapor samples to be obtained from multiple depths from a single borehole during a single sampling event. First, the drill rods and drive point/drive point holder are pushed to the shallowest designated depth. Then, an adapter connected to Teflon® or nylon (Nylaflow®) sampling tubing that extends to the ground surface is attached to the drive point holder. Leakage of atmospheric air through the drive rods into the drive point holder (the vapor sampling probe) is prevented by o-rings that are part of the adaptor assembly. After obtaining a soil vapor sample (described in Section 3), the adaptor/tubing assembly is removed, and the tubing is discarded. The drive point/drive point holder is then pushed deeper into the subsurface until the next designated sampling depth is reached. The adaptor/tubing assembly, with a new piece of tubing attached, is then connected to the drive point holder and the soil vapor sampling process is repeated. This process can be repeated over multiple depths, but if lower concentrations exist beneath high concentrations, the samples in the deeper interval may have a positive bias. With the expendable PRT system, the drive point/drive point holder assembly remains in the subsurface when the rods are withdrawn, while for the retrievable PRT system the entire apparatus is removed.

There is no sand pack or hydrated bentonite seal needed in the borehole annulus. However, there is potential for cross-contamination resulting from contaminants being pushed downward by the drilling rods. Avoid lateral movement of the drive rods during the push and sampling processes, and if the probe is deflected by cobbles, or wavering of the rig, it is preferable to remove the probe, and retry to obtain a linear unwavering entry to avoid leakage along the outer wall of the casing. To avoid potential surface leakage due to these difficulties, a surface seal of hydrated granular bentonite is recommended with the PRT system.

2.6.2 Permanent Direct-push Soil Vapor Sampling Probes

Direct-push techniques to install permanent soil vapor sampling probes involves use of a truck-mounted hydraulic ram to push hollow metal rods equipped with a drive point to a designated depth. Table 1 describes the advantages and disadvantages of using direct push techniques over hollow-stem auger for installing soil vapor probes.

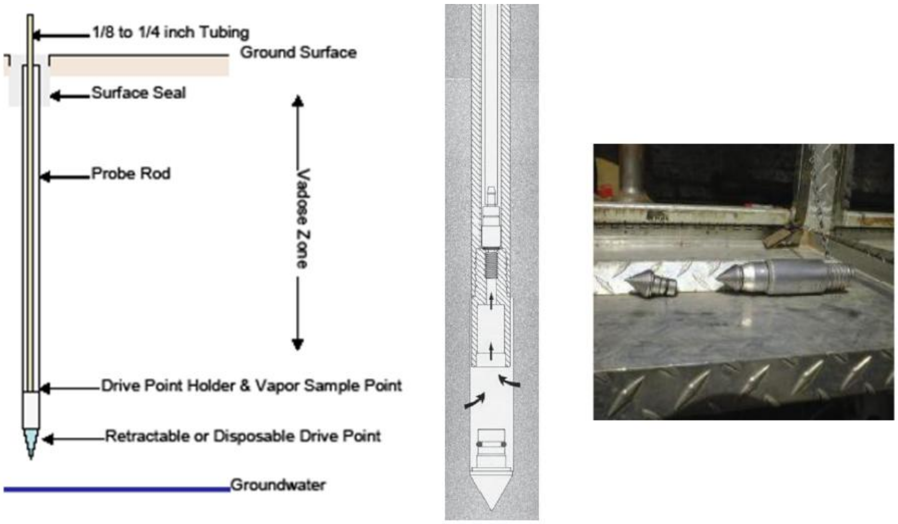


Figure 2. Direct-push soil vapor sampling probe (PRT; Geoprobe ®)

Pro Direct Push	Con Direct Push
• Usually quicker and cheaper to install and cause less disruption to subsurface, therefore requires far less equilibration time prior to sampling. • Optimal for shallow-depth (up to about 20 ft), or in conjunction with an on-site, mobile laboratory enabling real-time adjustments to the sampling program. • Allows soil vapor sample collection very close to the building minimizing concern about interpolation or extrapolation of data to conditions beneath the building	• Multi-level sampling requires larger footprint. • Likely to fail in some lithologies (e.g. soil with cobbles, calcified sediments etc). • Difficult to obtain soil samples for chemical and physical analyses. • Difficult to install sand packs and bentonite seals through direct push rods.

Table 1. Pros and Cons for direct-push technique over hollow-stem auger for probe installation.

The soil vapor sampling probes consist of an implant of tubular stainless steel screen with a length of 6 inches, outer diameter of ¼ inch, and typically a pore size of 0.0057 inches. Note that the implant is not retrievable and at site closure must be abandoned in place. The implant is connected to a Teflon® or nylon (Nylaflow®) sampling tube of sufficient length to reach the ground surface. A direct-push rig (i.e., Geoprobe®) is used to push a series of drive rods to a designated depth. When this depth is reached, the implant is slid down the bore of the drive rods and is attached to the drive point at the bottom. Then the drive rods are removed, leaving the implant and drive point in the subsurface (Figure 3).

As the drive rods are removed the borehole may collapse around the sampling probe. Also, as the drive rods are removed a sand pack can be installed around the implant, followed by a hydrated granular bentonite seal extending to the ground surface. A surface seal of hydrated granular bentonite is applied where the drive rods meet the ground surface.

One of the potential drawbacks of soil vapor sampling probe implants is the difficulty in installing a sand pack and hydrated granular bentonite seal through the drive rods as they are removed from the borehole. As a result, lateral movement of the sampling tubes and drive rods should be avoided to prevent atmospheric air from entering the soil vapor sample. Soil vapor probes installed using direct push technique as described above are acceptable for human health risk assessment.

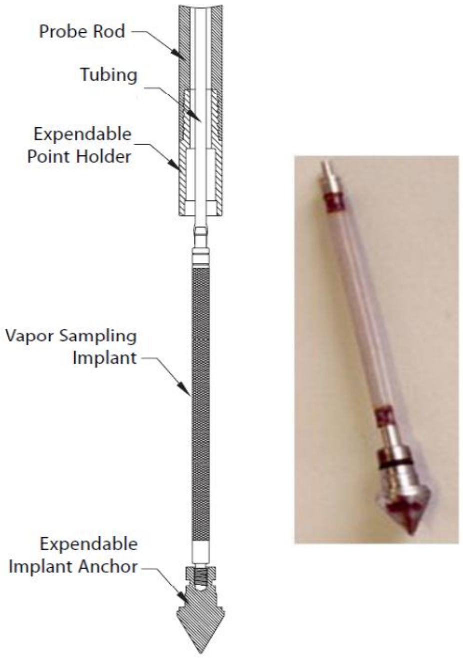


Figure 3. Direct-push soil vapor sampling probe (implant type; Geoprobe®).

3 NEAR-SLAB SOIL VAPOR SAMPLING

The proper collection of near-slab soil vapor samples is a critical step in producing reliable concentration data. A number of factors are important in ensuring the reliability of the data; each is discussed below. Note that some regulatory agencies have specific guidelines for soil vapor collection that may differ from those within the Chevron Sampling Toolkit. **Where possible, Chevron recommends following the Sampling Toolkit protocols unless specifically directed to do otherwise by local agencies.**

Prior to beginning a near-slab soil vapor sampling program, it is important to obtain the correct sampling equipment and to write a site-specific sampling plan. Written documentation of the equipment used and the sampling processes employed is critical.

Consistency in equipment and sampling processes between probe locations and between multiple sampling events is important in order to minimize potential discrepancies in soil vapor concentration data.

Chevron recommends that near-slab soil vapor probes be installed at a minimum two depths (when possible based on depth to groundwater) at each sampling location: one at a shallow depth (i.e. near ground surface, e.g. 5 ft bgs) and one at a deeper depth (i.e. close to groundwater capillary fringe). This is to help identify the likely source of soil vapors (from the groundwater or from contaminated soils in the vadose zone). Also, given the typical screening rationale for near slab soil vapor sampling, in general Chevron recommends conducting one round of near-slab soil vapor sampling (unless there is significant groundwater fluctuation at the site).

3.1 Sampling Equipment

Numerous types and combinations of tubing, connectors, valves, and pumps have been used for soil vapor sampling. The tubing, gauges, and pump (if any) should be connected by tubing that is flexible, air-tight, and has a low capacity for adsorption of VOC's. **Teflon® or Nylon tubing (marketed under the NylaFlow® name) with ¼-" OD is recommended. Tygon®, rubber, and Polyethylene tubing should not be used. Swagelok® type connectors/fittings (Figure 4) should be used for all connections between tubing and other sampling components to ensure that fitting materials are not a source of VOCs.** These connectors are air-tight and reliable. Hose clamps, push-on barbed fittings, and other types of connectors should be avoided as they may not provide an air-tight seal. The lack of an air-tight seal can allow air to enter the sample, thus diluting the vapor concentrations and compromising the integrity of the sample. Leak testing (discussed in Section 3.4) is used to ensure the integrity of soil vapor samples.

A vacuum must be created in order to draw the soil vapor to the ground surface. The vacuum can be created by a battery powered pump, a syringe, or a sampling container that is under a vacuum (such as a Summa™ canister, discussed below). **If a pump is used, it is important to ensure that the sample collection point is on the intake side of the pump.** This will prevent any contaminants present in the pump from being drawn

Figure 4. Swagelok® connectors (image from equipsales.com)

into the vapor sample. A typical soil vapor sampling train using a helium shroud (for leak detection) and a flow-calibrated pump (for purging) is shown in Figure 5.

Although a number of sampling containers have been used for soil vapor sample collection, including Summa$^{\text{TM}}$ canisters, Tedlar$^{®}$ bags, Cali-5-Bond$^{®}$ bags, syringes, and sorbent sampling tubes, at Chevron sites, **Summa$^{\text{TM}}$ canisters (Figure 6) are required for soil vapor samples, for they provide samples with the highest possible integrity when collected using the appropriate sampling protocol.** Tedlar$^{®}$ bags are not recommended, primarily because of the concerns about integrity of soil vapor samples beyond a holding time of 48 hours as well as presence of trace levels of VOCs in new Tedlar bags (Hartman, 2006). Soil vapor samples can be collected in syringes for on-site soil vapor analyses *only* where the sample is immediately injected into a gas chromatograph (GC).

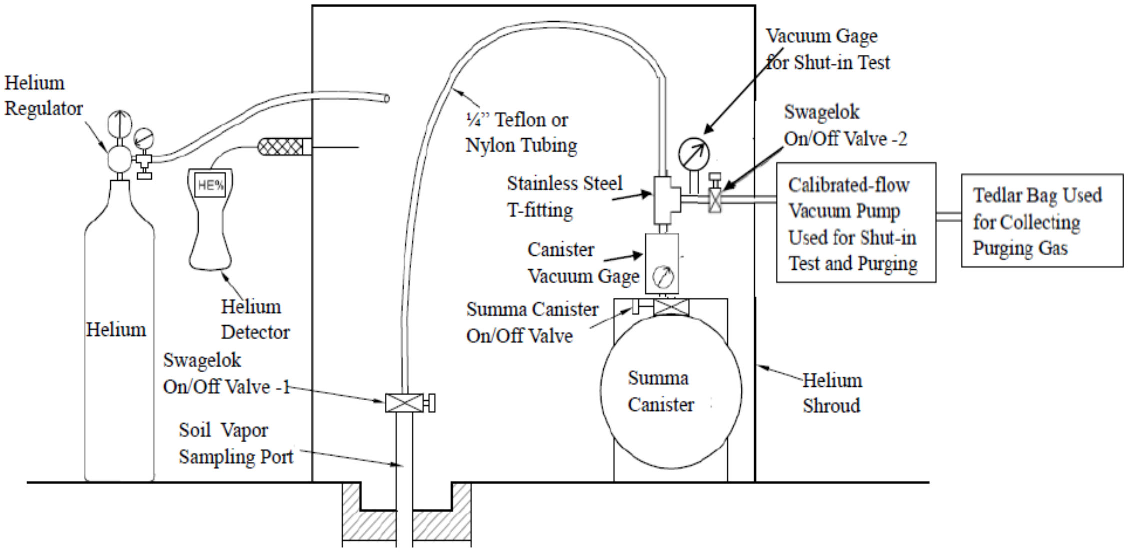


Figure 5. Picture of a sampling system for soil gas sampling train leak test, soil gas purging and sampling (Adapted from ARCADIS)

A Summa$^{\text{TM}}$ canister is a stainless steel, gas-tight, opaque and laboratory-certified clean sample container with a passivated internal surface. The passivation process utilizes electro polishing and chemical deactivation to create a chemically inert surface. Containers range in size from < 1 L to 15 L and are provided by the analytical laboratory. Canisters are typically certified clean at the 10 % level (i.e. every one out of 10 canisters is certified after cleaning) or at the 100 % level (i.e. every canister is certified after cleaning). The cleaning process is the same for both certification levels and utilizes dilution, heat, and high vacuum. The certification process utilizes EPA Method TO-15 (GC/MS) to ensure that VOC concentrations are <1 ppb$_{v}$. **It is acceptable to use canisters certified at the 10% level for soil vapor sampling activities. However, the use of 100 % certified canisters is required for sub-slab soil vapor, indoor air and ambient air sampling in order to minimize potential interferences in analyzing low**

VOC concentrations for human health risk assessment. The required size of the canister depends upon the laboratory's capabilities. **Before ordering canisters, contact the laboratory to inquire about what size canisters are required to meet the reporting levels necessary to meet site data quality objectives.**

After cleaning, the canister is evacuated until a vacuum of 29.9 in Hg is obtained. The canister will hold a vacuum of greater than 25 in Hg for more than 30 days. The maximum holding time for canisters following sample collection varies from state to state. Check the locally applicable regulations to determine the maximum holding time for the site in question. As discussed below, the soil vapor sample flows into the canister due to the pressure gradient between the vadose zone and the canister. A flow controller/particulate filter, provided by the laboratory, controls the vapor flow rate into the canister. Be aware that the flow controller may be defective and it is best practice to have some extra available.

Figure 6. 6 L Summa^{TM} canister with ¼" stainless steel bellows valve (image from Air Toxics Ltd.)

Regardless of the design of the sampling equipment, there are a number of important topics to address in order to obtain reliable soil vapor concentration data. These topics are discussed below.

3.2 Field Activities Prior to Sampling/Documentation

Written documentation of field conditions during sampling is required. This includes weather conditions (temperature, barometric pressure, wind direction and speed, humidity, degree of cloud cover); surface soil conditions (presence of standing water, wet soil, irrigation activities, etc.) and groundwater elevations. Some agencies are concerned that the rain will affect the validity of the sample (> 0.5 inch precipitation during 24-hour period as in California EPA, 2012). Under wet soil conditions, one should follow the state soil vapor sampling guidance for detailed requirements on soil gas sampling or consult with Chevron project manager if no such state guidance exists. Maintain detailed field records of all activities, conditions, and sampling processes, including names of field personnel, dates and times, etc. It is important to maintain consistency in sampling activities between sampling events (e.g., purging volume and purge rate, sampling volume, leak testing methods, equipment used). Carefully plan all sampling activities to maintain consistency between sampling events and to avoid errors that can affect soil vapor concentrations.

3.3 Equilibration Time

The installation of soil vapor sampling probes can introduce oxygen into anaerobic portions of the vadose zone. An equilibration time is required to account for the effects of soil vapor probe installation; this allows for equilibration of vapor component concentrations between the probe and subsurface (API 2005). Soil vapor samples should not be obtained until after the equilibration time is reached. **Probes installed using hollow stem or hand auger methods should be allowed at least 48 hours of equilibration time while probes installed using direct-push techniques should be allowed at least two hours of equilibrium time (California EPA, 2012).**

3.4 Evaluating Leaks in Sampling Train

Leakage of atmospheric air into the sampling equipment during sampling can compromise sample integrity and dilute measured soil vapor hydrocarbon concentrations, possibly to the point of an incorrect decision such as failing to identify a concentration of concern (i.e., a “false negative”). Contaminants in ambient air can also enter the sampling system and be interpreted as originating from diffusive transport from a subsurface source (i.e., a “false positive”). Air leakage can occur at the land surface into the probe and, more typically, through loose fittings in the above-ground sampling equipment.

Leakage of air into the below-ground sampling system is unlikely if the probe has been properly constructed and a proper bentonite or concrete surface seal (described earlier) has been emplaced. Temporary (direct-push) probes are most susceptible to leakage around the rods. Sub-slab soil vapor sampling probes also are susceptible to leakage of indoor air due to the difficulties of ensuring a proper seal between stainless steel probe and slab concrete. Sampling equipment must be thoroughly inspected to ensure tight fittings between all components. Be aware that leakage locations may not be obvious. Elevated O_2 concentrations in samples from deeper depths in multi-level probes may be indicative of leakage, but in some cases this alone would not provide definitive evidence for leakage. If O_2 concentrations remain high with increasing depth and petroleum hydrocarbon concentrations are also high, this is evidence that leakage is likely to be occuring. **To minimize the potential for leakage, the soil vapor sampling rate should be kept at < 200 mL/min per EPA guidance (Section 3.6).** Repair or replacement of the sampling probe may be necessary if it is determined that leakage through the probe is occurring. Refer to state or regional guidance to determine if a prescribed course of action applies for probe replacement.

After the soil vapor sampling ports and probes are constructed and installed and soil vapor has equilibrated, leaks in the sampling train should be tested, including a complete shut-in test and system leak test.

3.4.1 Shut-in Test

After the soil vapor probe construction, soil vapor sampling probe installation, and sufficient time for the soil vapor to reach equilibrium, a shut-in test should be conducted to check for leaks in the above-ground sampling system. The equipment set-up for shut-in test is also shown in Figure 5. In this case, the helium shroud and the Tedlar bag may not be needed. To conduct a shut-in test, assemble the above-ground valves, lines and fittings downstream from the top of the probe as shown in Figure 5. The Swagelok valve-1 and Summa Canister valve are kept closed, evacuate the system to a minimum measured vacuum of about 100 inches of water using a purge pump and close Swagelok valve-2. Observe the vacuum gauge connected to the system with a “T”-fitting for at least one minute or longer. If there is any observable loss of vacuum, adjust the fittings until the vacuum in the sample train does not noticeably dissipate. After the shut-in test is validated, the sampling train should not be altered. The vacuum gauge should be calibrated and sensitive enough to indicate a water pressure change of 0.5 inches. If the shut-in test failed, then specific measures are needed such as tightening all the fittings and repeating the test until it is validated before proceeding to the next test.

3.4.2 Leak Test

3.4.2.1 Leak test tracer

A tracer is used to test for an ambient air leakage into the sampling system. Numerous tracer compounds have been referenced in regulatory and industry guidance documents, including isopropanol, isobutene, propane, butane, helium, and sulphur hexaflouride. **Chevron does not recommend use of isopropanol** because, due to its high vapor pressure, even a small leak will result in laboratory dilutions that will compromise the data quality objectives (i.e. reporting limits higher than screening levels). **Chevron does not recommend use of isobutene, propane, or butane** as leak detection tracers because their purity cannot be easily verified, resulting in a likelihood of low level impurities such as BTEX compounds. **Chevron does not recommend use of sulphur hexaflouride** because it has a very high greenhouse gas potential, and therefore difficult to acquire and use as a tracer compound. **Chevron does not recommend use of Freon** because it is not possible to determine the degree of leakage that has taken place and there is a possibility that Freon is present in the soil gas due to ubiquitous use of Freon as coolant for air conditioning units. **Chevron recommends use of laboratory grade helium as a leak detection tracer gas where practical to do so, based on accessibility.** Helium is readily available, has low toxicity, does not disrupt analytical measurements, will not be found at fuel contaminated sites, and has a high purity. Small volume bottles of helium can be purchased at party stores but contain industrial grade helium, which may contain organic compounds as impurities. **Lab grade helium is recommended**, and will require time for the sampling crew to acquire through the analytical laboratory or an alternate source. A possible drawback of helium is that its small molecular size may cause it to permeate the sampling materials more readily than larger VOC molecules (Hartman, 2006). Of all the tracer compounds described in various regulatory guidance documents, only the leak detection method using helium gas provides a quantitative estimate of leakage rate. **If lab-grade helium supply is scarce (as has been recently reported), Chevron recommends using 1,1-difluroethane (1,1-DFA) as an alternative leak tracer gas, with prior concurrence from EMC project manager and ETC.**

Small amounts of sample train leakage may be permissible, subject to regulatory standards and analytical limits applicable to the site. **For sites located in California, Chevron follows the CAEPA guidance (CAEPA, 2012) and recommends a maximum leak percentage of 5% be used to determine sample validity. For sites located outside California, Chevron recommends a maximum leak percentage of 10% be used to determine sample validity**. This is consistent with the VI guidance in New Jersey (NJDEP 2012). The presence of any leakage should be recorded, as should all techniques used in the leak testing process. Maintain consistency of the leak testing process over multiple sampling events.

Where multi-level soil vapor probes are intended to acquire soil vapor concentrations to be used either as a basis for an attenuation factor screening step, or as a source term for Johnson & Ettinger modeling, leakage of as much as 10% may allow back calculation of an adjusted soil vapor concentration. However, this may not be possible if the overall compounds of interest concentrations are low, and the reporting limits have been increased above acceptable screening values due to the necessity to dilute the sample to avoid loading the GC column with tracer gas. In such cases, the probes must be re-sampled.

3.4.2.2 Leak test using helium as a tracer

The New York State Department of Health (NYSDOH, 2006) has prepared guidance for using helium as a tracer gas, suggests construction of a shroud around the sampling probe but not the sampling train. To test the integrity of the whole sampling train, **Chevron recommends building a shroud to cover the entire sampling train (probe to Summa canister) in order to detect possible leaks in all fittings and tubing of the sampling system (Figure 5 and Figure 7).** This enables detection of helium ingress into the sampling train and can be used to estimate the leakage rate as shown at the end of this section. The shroud should be filled with helium before purging the sampling point. It is important to ensure that the pressure in the shroud is close to atmospheric pressure, so that normal sampling conditions exist (NYSDOH, 2006). **Introducing helium from a pressurized cylinder for several seconds will generally be sufficient to create concentrations in the shroud up to 10% by volume or higher. The helium concentration in the shroud should be monitored and maintained relatively stable at the target concentration, i.e. 10% or higher (CAEPA, 2012) during the course of soil vapor sampling.** This can be done with a helium detector connected to a port on the shroud. Portable detectors are available for rental. It is required that the selected portable detector have a minimum helium detection limit of 0.5% by volume.

The following guidance on constructing the helium shroud is adapted from the EPRI Reference Handbook for Site-Specific Assessment of Subsurface Vapor Intrusion to Indoor Air (EPRI, 2005). The shroud can be in the form of a clear plastic container (e.g. large Tupperware™ or Rubbermaid® container or a tent made of clear plastic sheet large enough to surround the soil vapor probe and valves and fittings at the top of the probe as in Figure 5 and Figure 7. The shroud will typically have three ports, one for helium addition, one port for monitoring helium concentration inside the shroud and another port for the ¼-inch Nylon tubing coming out of the shroud for the vacuum pump located outside the shroud.

Chevron recommends using one Summa canister under a helium shroud for leak-test (helium checking in the soil gas sample) and soil vapor sampling (chemical analysis in the soil vapor sample) simultaneously. A separate Summa Canister is not needed for leak-test. Figure 5 illustrates conducting a simultaneous leak-test and soil vapor sampling from a sub-slab soil vapor sampling point. In this case, the Tedlar bag may not needed and the Swagelok valve 2 remains closed. Turn on the Summa canister valve to collect a soil vapor sample for analysis of helium and chemicals in the lab. To access the sampling train, the shroud can be lifted and the canister valves opened. The shroud can then be placed back again on the ground/floor and filled with helium within a half-minute or less. The samples typically take at least 5 minutes to fill, so the first few seconds of no helium in the shroud is not problematic as long as the helium concentration in the shroud is maintained relatively stable at the target concentration.

The analytical laboratory should be notified that helium is to be used as a leak detection tracer prior to sampling. The integrity of the soil vapor samples can be assessed by estimating the % leakage as follows.

$$\%leakage = \frac{\text{helium concentration in the soil vapor sample (ug/m}^3\text{)}}{\text{average helium concentration measured inside the shroud (ug/m}^3\text{)}} \times 100$$

3.5 Purging

The US EPA conducted a comparison of chlorinated hydrocarbon soil vapor concentrations collected utilizing a broad range of purge volumes (0.5 to 100L) at a site with relatively coarse-grained soils and found no significant differences based on the purge volumes (DiGiulio et al 2006b). McAlary and Creamer (2006) performed similar experiments at a Chevron research site for high concentration petroleum hydrocarbon vapors and also observed no effect in sample concentration as a function of purge volume. While it is not clear to what degree purging may affect sample concentration, all regulatory guidance requires stagnant air in the sampling tubes be removed prior to sample collection. This is believed to ensure that the soil vapor sample is representative of actual soil vapor concentrations.

Field notes containing information about the above-ground sampling equipment and below-ground tubing length and inner diameter should be used to calculate the “dead volume" to be purged. The "dead volume" should also include the borehole sand pack. The volume of a sample container, such as a Summa^{TM} canister (which is not used during purging), should not be included in this calculation. **Check to make sure that all connections, fittings, etc. are tightly fit in the sampling equipment prior to purging**.

Figure 7. Helium shroud used for leak-testing soil vapor sampling train.

Figure 5 also shows the equipment set-up recommended by Chevron when purging a soil vapor sampling port. In some cases, the regulatory agency requires one to develop the number of purging volumes. In that case, as shown in Figure 5, a battery powered, flow-calibrated pump and a Tedlar bag can be used to purge the system and determine the number of required purge volumes. The purging gas collected by the Tedlar bag is analyzed on site for chemical concentrations till the concentrations become stabilized. From the volume of gas purged which is measured by the flow-calibrated pump, the number of purging volume can be determined and recorded and then the soil vapor sampling can proceed. If the number of purging volumes is not required, Tedlar bag only serves as a collector of purging gas to protect the environment from potential adverse impact from the contaminants in the soil vapor.

The maximum flow rate for purging should not exceed the flow rate limit used for subsequent sampling (< 200 mL/min). Guidance documents from different agencies recommend different purge volumes, ranging from 1 to 10 purge volumes (CSDDEH, 2002; API, 2004, CAEPA, 2012). **Chevron recommends that 3 volumes be purged unless otherwise required by applicable guidance.** The purge test data (calculated purge volume, purging rate, and duration of purging) should be recorded for each soil vapor sampling point. It is important to ensure that the same purge volumes and rates are used at a given probe for each sampling event.

For fine-grained soils large sample volumes are often not possible or difficult to collect. Also, if large sample volumes are attempted, the chances of leakage in the sampling train increase. A larger sample volume also increases the uncertainty about the location of soil vapor sampled. Given these uncertainties, it is best to minimize the "dead volume" that needs to be purged in the sampling train.

3.6 Sample collection

There are numerous combinations of tubing, connectors, pumps, and sampling containers that have been used for soil vapor sample collection. As noted above, the design of the sampling equipment should be such that the dead volume is minimized in order to keep the necessary purge volume small. In all cases, a vacuum is used to draw soil vapor from the subsurface to the sample container. Note that equipment must be decontaminated prior to sampling, shut-in test should be performed before purging and sampling, and leak-testing should be performed during the sampling process. An example of the equipment arrangement used for soil vapor purging (with a flow-calibrated pump) and sampling (with Summa^{TM} canister) is shown previously in Figure 5. In Figure 5, to collect a sample, Swagelok valve 1 and the Summa canister valve should be open and Swagelok valve 2 should be closed. The soil vapor sample collected will be analyzed for helium (for leak test), COCs and fixed gases.

The exact procedure used in obtaining a soil vapor sample will vary as a function of the equipment used, but the following considerations are important to ensure that a high quality sample is collected.

3.6.1 Vacuum And Flow Rate Considerations

The vacuum and resulting sampling flow rate should be minimized in order to limit enhanced volatilization of VOCs from water and soil into the soil vapor sample. Consistency in vacuum and sample flow rates should be maintained between sampling probes and over multiple sampling events. The vacuum and flow rate should be documented in the field notes. A flow rate between 100 ml/min and 200 ml/min and a vacuum less than 100 inches of water (approx. 7.3 in Hg at 4^{o}C) should be maintained during purging and sampling (California EPA, 2012).

The Summa^{TM} canister system utilizes a flow controller to control the flow rate. The flow controller contains a critical orifice flow restrictor intended to maintain a relatively constant flow rate over a 0.5 to 8 hour period, even though the vacuum in the canister is decreasing over that time (which would otherwise cause the flow rate to concurrently decrease). A vacuum gauge is built in to the flow controller to monitor sampling progress. The laboratory (e.g., Eurofins Air Toxics Inc.) sets up the flow controller for the flow rate specified. Table 2 shows the range of flow rates for given sampling time intervals. A particulate filter is built into the flow controller device which serves to prevent particulates from fouling the flow controller or entering the Summa^{TM} canister. The recommended sampling time interval for soil vapor samples is approximately 30 minutes, but in any case the flow rate should not exceed 200 mL/min.

Sampling Interval (hrs)	0.5	1	2	4	8	12	24
6 L Canister	167	83.3	41.7	20.8	11.5	7.6	3.5
1 L Canister	26.6	13.3	6.7				

Table 2. Flow rates (mL/min) for given sampling time intervals using the flow controller (from Eurofins Air Toxics Inc.)

3.6.2 Other Sampling Considerations

Once the above listed topics have been addressed, after making certain that all connections between the Summa^{TM} canister, flow controller, and all other portions of the sampling equipment are tight, and arrangements have been made with the analytical laboratory regarding sample shipment and analysis, soil vapor sampling can commence. Sampling of all probes should preferably be completed within a one day time period, with a maximum collection period of one week. Sample collection from a purged soil vapor probe should begin as soon as possible once purging is completed. Leak-testing should be performed concurrently with sampling as described above. To begin sampling, open the valve on the Summa^{TM} canister. As the canister fills, observe the vacuum gauge on the flow controller to ensure that the vacuum in the canister is decreasing over time. If the flow controller is working correctly, the planned sampling completion time will be reached when the canister vacuum has decreased to 5 in Hg. Note that low permeability soils characterized by low soil vapor flow rates may require sampling to cease before the canister vacuum has decreased to 5 in Hg.

Quality control (QC) of soil vapor samples must be addressed through the collection of equipment blanks and field duplicates. An equipment blank should be collected at the site during sampling activities by collecting a sample of clean air or nitrogen through the probe materials before installation in the ground. Analysis of the equipment blank can provide information on the cleanliness of new materials and/or the effectiveness of decontamination procedures used in the field. Clean stainless steel, Nylon or Teflon® tubing and a certified regulator should be used. Only 100% certified canisters (the sample canister and the source canister/cylinder, if applicable) should be used to collect equipment blank. **Trip blanks were previously recommended, however with the use of 100% certified Summa^{TM} canisters, trip blanks are not necessary**.

At least one duplicate sample should be obtained each day of sampling, or from at least 10 % of the samples obtained. A duplicate sample should be collected by using a splitter (such as a T fitting) located between the flow controller and sample canisters, with separate sampling tubes connecting the splitter to two Summa^{TM} canisters as shown in Figure 8. The flow controller must be set such that the flow rate from the sampling probe is < 200 mL/min; this will double the required sampling time since two canisters are being filled simultaneously.

After sample collection, canisters must not be chilled since contaminants may condense in the canister at low temperatures. Make certain that all samples are correctly and clearly labeled. Follow standard chain-of-custody procedures, including noting the final canister vacuum and serial numbers of the canisters and flow controllers. The laboratory checks the vacuum on receipt to ensure that there were no leaks during shipment. See Section 3.1 for canister maximum holding time information. Document all procedures, sampling times, conditions, problems, etc

If the initial assessment of subsurface soil vapors indicates potential for vapor intrusion to indoor air, further characterization will usually require entry into the affected building(s) to conduct sub-slab vapor sampling and concurrent indoor and ambient outdoor air sampling as described in the following sections. EMC environmental attorneys will be able to help in getting the necessary access agreements before these sampling activities commence.

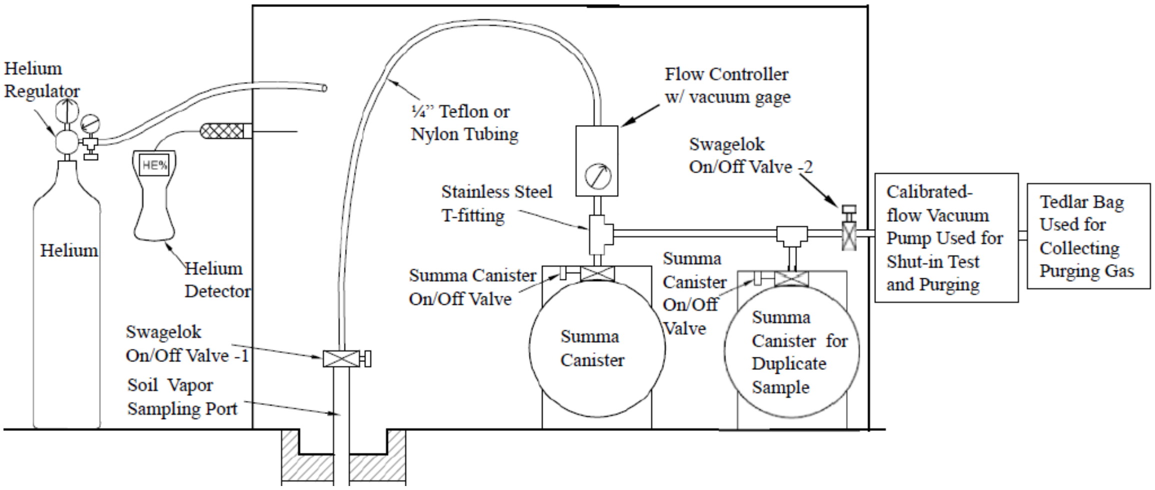


Figure 8. Soil vapor sampling train using two Summa canisters for a sample and a duplicate sample (Adapted from ENSR)

4 SUB-SLAB VAPOR SAMPLING

4.1 Sub-slab soil vapor probe installation

Sub-slab vapor sampling probes allow for collection of soil vapor data from directly beneath the slab from a layer of granular fill material that is highly permeable and well-drained for structural purposes. These samples are useful to evaluate a possible relationship to indoor air samples and are recommended if indoor sampling is deemed necessary. It is critical to obtain building construction details as much as possible (i.e., slab thickness, depth and type, presence of vapor barrier, location of utility trenching etc) to appropriately locate sub-slab vapor sampling locations. **Sub-slab sampling may not be possible when groundwater or a partially saturated capillary fringe is present directly below the slab.** Do not drill through the slab if it is suspected that the penetration could allow groundwater to enter the building during high water table conditions. Also, it is important to determine prior to drilling if the slab has a vapor barrier; if so, **make sure the vapor barrier is not punctuated during the drilling**. **Drilling through tension slabs is not recommended.** Tension slabs contain embedded steel cables that have been pulled tight after the concrete has cured. The tension in the cables strengthens the slab and helps prevent cracking. The slab can be damaged if a cable is cut during drilling.

Petroleum hydrocarbons are amenable to aerobic biodegradation. Therefore, a conservative approach supports obtaining soil vapor samples at the center of the slab where lowest oxygen concentrations in soil are likely to occur (California EPA 2011) and away from utility conduits,. **At least two probes should be placed, for foundation area**

up to 5000 ft^2 with one located in the center of the slab, and the other in the likely direction of potential subsurface impacts, (California EPA, 2005, 2011). US EPA recommends several probes for single-family dwellings to assess spatial variability (e.g., 3 to 5; DiGiulio, 2006a).

Prior to drilling holes in a slab, identify and mark utilities coming into the building from the outside (e.g., gas, water, sewer, electrical lines) and determine any internal locations where utilities penetrate the slab (e.g., furnace, water heater, circuit breaker box, water or sewer lines). **Avoid installing sub-slab monitoring points where the utilities penetrate the slab as these may be potential entry points for downward oxygen migration through the slab. Also, avoid installing sub-slab points along straight-line points where utility trenches may have been installed beneath the slab during building construction.**

Prior to fabrication of sub-slab vapor probes, remove carpeting from the drilling location, if present. This can be done by cutting a small ½ inch square flap that can be glued back down after the probe is installed. Obtain any available information (e.g., from the owner, construction plans) to determine the thickness of the slab. **Do not drill a pilot hole to assess the thickness of a slab.** As illustrated in Figure 9, use a rotary hammer drill to create a “shallow” (e.g., 2.5 cm or 1 inch deep) “outer” hole (e.g., 2.2 cm or 7/8 inch diameter) that partially penetrates the slab. Do not completely penetrate the slab with the shallow hole. Use a small portable vacuum cleaner to remove cuttings from the hole. Removal of cuttings in this manner in a non-penetrated slab will not compromise soil vapor samples because of lack of pneumatic communication between sub-slab material and the vacuum cleaner.

Next, use the rotary hammer drill to create a smaller diameter “inner” hole (e.g., 0.8 cm or 5/16 inch diameter) through the remainder of the slab and some depth (e.g., 7 to 8 cm or 3 inch) into sub-slab material. Drilling into sub-slab material will create an open cavity which will prevent obstruction of probes by small pieces of gravel.

The basic design of a sub-slab vapor probe is illustrated in Figure 10. Once the thickness of the slab is known, tubing should be cut to ensure that the probe tubing does not reach the bottom of the hole (to avoid obstruction of the probe with sub-slab material). **Chevron prefer use of stainless steel tubing materials although recent data comparing the performance of Teflon® and Nylon tubing with stainless steel tubing suggest that it would be appropriate to use these materials for constructing the sub-slab vapor probes too (Hartman 2008).** An advantage in using Nylon and Teflon® tubing is that there will likely be fewer sealing difficulties between the probe and concrete. If using stainless steel, construct sub-slab vapor probes from small diameter (e.g., 0.64 cm or ¼ inch outer diameter (OD) x 0.46 cm or 0.18 inch inner diameter (ID)) chromatography grade 316 stainless steel tubing and stainless-steel compression to thread fittings (e.g., 0.64 cm or ¼ inch OD x 0.32 cm or ⅛ inch (ID) Swagelok® or NPT female thread connectors) as illustrated in Figure 10. **Use stainless-steel to ensure that construction materials are not a source of VOCs.** Brass fittings (tubing, nipples and couplings) readily available at hardware stores are machined using cutting oils and could be a potential source of trace level VOCs and as such are not recommended to be used for constructing sub-slab vapor probes. In addition, use of Teflon® tape is recommended on any NPT threaded joints to ensure a good seal and to reduce the torque needed install and remove the probe plug, thus reducing the stress on the cement bond.

Set the sub-slab vapor probe in the hole. As illustrated in Figure 10, the top of the probe should be completed flush with the slab and have recessed stainless steel plugs so as not interfere with day-to-day use of the building. **The seal between the stainless steel sub-slab probe and the concrete floor is a common source of leakage.** Modeling clay or cement is typically used for surface seals. Unfortunately, there are few sealants that are non-adsorptive, do not give off vapors, and adhere well to both concrete and metal surfaces. Hydrating (swelling) cement adheres reasonably well to concrete, but not as well to metal tubing, so it is not unusual for the tubing to spin while fittings are being attached. Attaching all fittings before the probe is installed may minimize stresses on the seal. Mix a quick-drying Portland cement which is “VOC free” with water (e.g. hydro-cement available at building supply stores) which expands upon drying to ensure a tight seal) to form a slurry, Inject or push the slurry into the annular space between the probe and outside of the “outer” hole. Allow the cement to cure for at least 24 hours prior to sampling.

4.2 Sub-slab soil vapor sampling train tests, purging and sampling

After sub-slab soil vapor sampling probes are installed and soil vapor reaches equilibrium, a shut-in test should be done before purging and sampling. The procedures of shut-in test and leak test while sampling are the same as described in section 3 and as shown in Figure 5 and Figure 7.

After shut-in test, the probe is ready for purging and sampling. Please refer to section 3 for procedures of purging and sampling. **For sub-slab soil vapor sampling, 1 L 100 % certified Summa™ canisters are preferred in order to minimize the volume of soil vapor collected.** Collecting a smaller sub-slab sample will minimize the duration of inconvenience to the building occupants by minimizing the amount of time the helium shroud has to be monitored.

5 INDOOR AND AMBIENT (OUTDOOR) AIR SAMPLING

In some situations, it may be necessary to conduct indoor air and ambient air sampling to assess the potential for vapor intrusion to indoor air from subsurface contamination. **It is recommended to collect these concurrently with the sub-slab soil vapor samples.** Indoor air samples may contain BTEX and other VOCs within the concentration ranges commonly seen as background values measured at sites where no subsurface petroleum hydrocarbon contamination is known to be present. Unfortunately, these background VOC concentrations are also within (or even greater than) the range of risk-based concentrations (RBC) assuming a cancer risk range of 1E-06 to 1E-04 or hazard quotient of 1 (Figure 11, from Dawson & McAlary, 2009). There are many sources of background contamination inside buildings. Materials and substances commonly found in commercial and residential settings, such as paints, paint thinners, gasoline-powered machinery, building materials, cleaning products, dry cleaned clothing, and cigarette smoke, can potentially contribute to VOC detections in indoor air testing. Table 3 shows a list of common household petroleum – related VOC sources (NJDEP 2005). In urban areas, outdoor air also often contains background concentrations of VOCs that exceed risk-based indoor air target levels. **Therefore, outdoor ambient air samples should be collected whenever indoor air samples are collected to characterize the contribution from outdoor air.** It is not recommended to collect indoor air samples from buildings outside the assessed footprint of VOCs in the subsurface in an attempt to characterize the contribution from indoor sources, because consumer products, building materials and occupant habits vary from building to building.

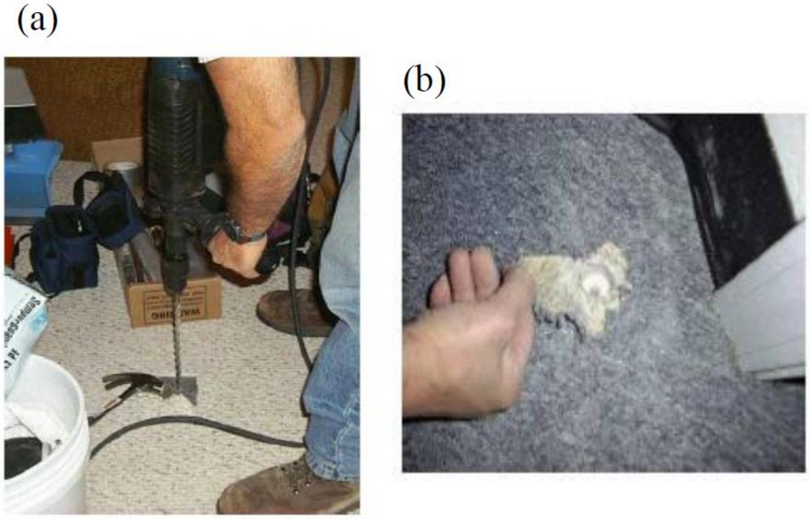


Figure 9. (a)Drilling through a slab, and (b) inner and outer holes (EPA).

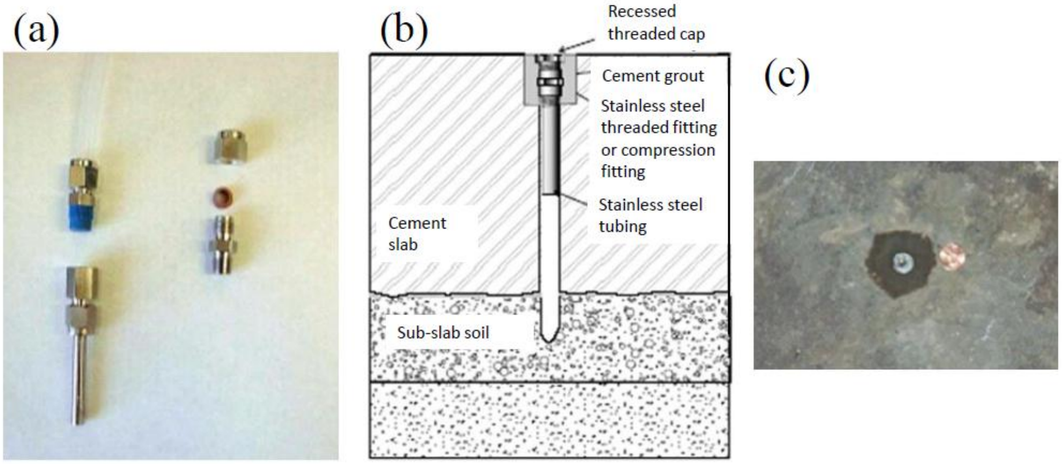


Figure 10. (a) Stainless steel sub-slab vapor probe components; (b) general schematic of sub-slab vapor probe and (c) completed sub-slab vapor probe. (EPA)

5.1 Indoor Air Sampling

Given the multitude of sources for VOCs in indoor air and that for some VOCs, the background indoor air concentrations could exceed the risk-based concentrations, it is critical to carefully plan any sampling event. Specifically for benzene in urban environments, indoor air sampling is not considered to be a first choice assessment option for residential structures unless the State has raised the acceptable indoor air benzene values above ambient levels. **This toolkit makes recommendations on the key elements of the plan. The project team should also consult appropriate state guidance for detailed information on indoor air sampling strategies, building inspection/surveys and household products inventory forms** (e.g., NYSDOH 2005, 2006, MADEP 2002, California EPA 2011, ITRC 2007).

Indoor air sampling may require multiple visits to the subject building(s). A pre-sampling site visit should be arranged at least 24 hours in advance of the sampling (NYSDOH 2005, MADEP 2002, California EPA 2011). This is used to interview the occupants and doing a building survey to gather the following information.

- Contact information for the occupants and owner
- Type of building construction
- Foundation characteristics
- Heating, Ventilating and Air Conditioning (HVAC) system details
- Water wells and sewage disposal

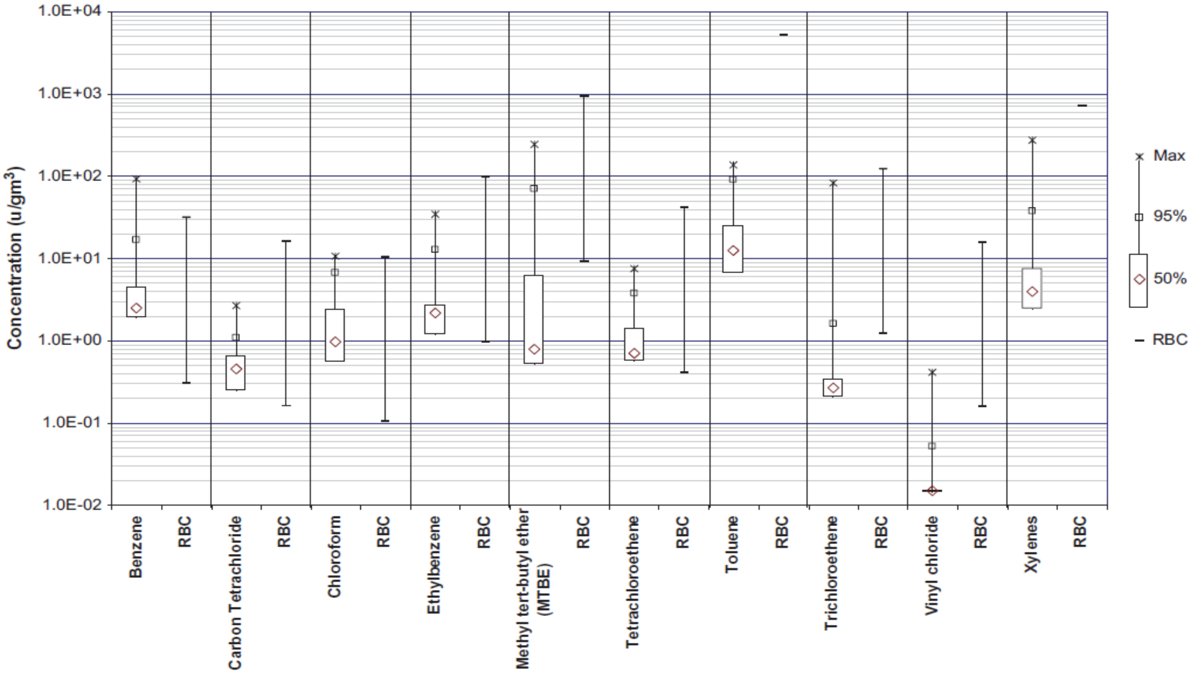


Figure 11. VOC concentrations in background indoor air compared to RBC.

- Potential indoor sources of VOC vapors, particularly those containing hydrocarbons, such as fuels, combustion products, cleaners, solvents and lubricants containing petroleum distillates and tobacco products. It is advisable to remove consumer products that contain VOCs or SVOCs from the building and any attached garage or shed at the time of the pre-sampling survey. Any unavoidable exceptions should be documented (including appropriate photographs) and highlighted with the results of the indoor air analysis.
- Plan view showing the sampling location(s) and pertinent information on floor layout including chemical storage areas, garages, doorways, stairways, basement sumps, plumbing and electrical conduits, elevator shafts etc.
- Potential outdoor sources of VOCs in ambient outdoor air. This will include a diagram of the area surrounding the building(s) being sampled showing potential sources such as service stations, repair shops, retail shops, landfills etc.

Indoor air sampling should be done in an environment that is representative of normal building use. Heating and air conditioning systems should be operated normally for the season and time of day. **Use 6 L 100% certified Summa™ canisters placed in the center of the room on the lowest floor at 3 to 5 ft above floor level to provide a sample representative of the breathing zone.** In order to mimic the anticipated daily exposure by inhalation, the **sampling duration for commercial/industrial buildings is 8 hours and for residential building is 24 hours (California EPA 2011).** Upon deployment of the sampling equipment, the Building Survey Form is updated to include the location of the sampling equipment, time, date, identification number, and environmental conditions.

As far as possible, the following activities should be avoided during the indoor air sampling event. Any unavoidable exceptions should be documented and highlighted with the results of the indoor air analysis:

- Allowing containers of gasoline or oil within the building or garage area, except for heating fuel oil tanks.
- Cleaning, waxing or polishing of furniture or floors (if cleaning is needed, use water only).
- Smoking cigars, cigarettes or pipes.
- Using air fresheners or odor eliminators.
- Using materials containing VOCs (dry markers, white out, glues, etc.).
- Using cosmetics including hairspray, nail polish, nail polish removers, perfume, and cologne.
- Applying pesticides.

5.2 Outdoor Ambient Air Sampling

Chevron recommends collecting ambient air samples at the same time the indoor air samples are collected. This will provide information about outside influences on indoor air quality. The outdoor ambient air sample will identify vapors from automotive fuels and exhaust, point sources such as gasoline stations, stack emissions and possible unique situations (paving crews, forest fires etc). **Use 6 L 100% certified Summa canisters**

placed 3-5 ft above grade at an upwind location protected from the elements (wind, rain, snow or ice) on the upwind side of the building (5-15 ft away). It is recommended that ambient air sampling begin at least 1 hour prior to indoor air sampling and should continue at least 30 minutes prior to the end of the indoor air sampling period.

6 ANALYTICAL TECHNIQUES

The analytical methods used are specific to the components analyzed and the reporting limits required to meet the data quality objectives. For example, reporting limits for fixed gases such as O_2, CO_2, N_2, and CH_4 of about 1% v/v are sufficient for interpretation; whereas VOCs such as benzene often have target concentrations in the low $\mu g/m^3$ range or lower, although this varies considerably between States. **Analytical reporting limits for indoor air samples should be lower than the risk-based target indoor air concentration, unless it is technically impracticable.** Analytical reporting limits for soil vapor samples could be higher because soil vapor concentrations attenuate upon entry to indoor air to varying degree. These could be estimated as a ratio of the indoor air target concentration to a conservative attenuation factor for the location of soil vapor sample (e.g., 1 for crawl space, 0.05 for sub-slab vapor and 0.002 for a deeper soil vapor sample in CAEPA 2011 VI guidance). Confer with the laboratory and applicable guidance to ensure that the necessary detection limits are met.

Before sampling and analysis begins, refer to applicable state and/or regional guidance and regulations to ensure that all requirements are complied with in sampling and analysis, including the number of analytes, analytical methods, reporting limits, and any requirement for state certification of the analytical laboratory. Maintain consistency of analytical methods between sampling events, as this can help reduce uncertainties in data results and interpretation. Table 4 provides a summary of required analytes for different samples and recommended analytical methods used for several common analytes during vapor intrusion investigations (adapted from API 2005).

Prior to sampling and analysis, the specific chemical components of concern at the site should be identified. These components commonly consist of the VOCs and SVOCs that have been identified as chemicals of interest at the site. In addition, some regulatory agencies have specified which chemicals of interest must be included in the list of analytes.

Prior to analysis, it is important to verify that a calibration for the chemicals of interest, or at a minimum calibration for the classes of chemicals of interest, has been developed. The mass spectrometer (MS) yields different response factors for different classes of compounds. **The tracer compound (helium) used during leak testing should also be included in the list of laboratory analyses for soil vapor samples. A laboratory-modified version of ASTM method D1946 may be needed because helium is not listed as an analyte in the method.** The analytical method used should be capable of quantifying these components at a concentration such that the subsurface vapor to indoor air exposure pathway can be adequately evaluated.

Chemical	Common Household Sources
Acetone	Rubber cement, cleaning fluids, scented candles and nail polish remover
Benzene	Automobile exhaust, gasoline, cigarette smoke, scented candles, scatter rugs and carpet glue
1,3-Butadiene	Automobile exhaust and residential wood combustion
2-Butanone (MEK)	Automobile exhaust, printing inks, fragrance/flavoring agent in candy and perfume, paint, glue, cleaning agents and cigarette smoke
Ethylbenzene	Paint, paint thinners, insecticides, wood office furniture, scented candles and gasoline
Formaldehyde	Building materials (particle board), furniture, insulation and cigarette smoke
n-Heptane	Gasoline, nail polishes, wood office furniture and petroleum products
n- Hexane	Gasoline, rubber cement, typing correction fluid and aerosols in perfumes
Methyl isobutyl ketone (MIBK)	Paints, varnishes, dry cleaning preparations, naturally found in oranges, grapes and vinegar
Methyl tert butyl ether (MTBE)	Gasoline (oxygenating agent)
Naphthalene	Cigarette smoke, automobile exhaust, residential wood combustion, insecticides and moth balls
Styrene	Cigarette smoke, automobile exhaust, fiberglass, rubber and epoxy adhesives, occurs naturally in various fruits, vegetables, nuts and meats
Tertiary butyl alcohol (TBA)	Gasoline (oxygenating agent)
Toluene	Gasoline, automobile exhaust, polishes, nail polish, synthetic fragrances, paint, scented candles, paint thinner, adhesives and cigarette smoke
1, 2, 4-Trimethylbenzene	Gasoline and automobile exhaust
1, 3, 5–Trimethylbenzene	Gasoline and automobile exhaust
2 ,2, 4-Trimethylpentane	Gasoline and automobile exhaust
Xylenes, total	Water sealer, gasoline, automobile exhaust, markers, paint, floor polish and cigarette smoke

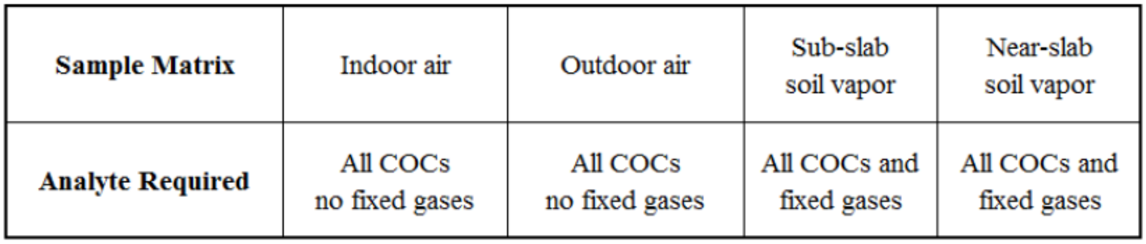
Table 3 Common household sources of petroleum hydrocarbons in background indoor air (Adapted from NJDEP, 2005)

6.1 VOCs/SVOCs

Gas chromatography/mass spectrometer (GC/MS) methods are recommended for all VOC and SVOC analyses. In the past we have recommended using EPA method TO-15 for analyzing VOC and SVOC concentrations in all types of VI investigations, however, a number of studies (Hayes et al 2005, Picker 2005 and Digiulio et al 2006a) have compared analytical results using methods TO-15 and 8260B. These data indicate that both give equivalent results down to levels as low as 10 μg/m^3. TO methods and hardware are designed for measuring low VOC levels in ambient air and not for high concentrations likely to be seen in soil vapor samples (which can exceed 100000 μg/m^3). **It is recommended that method 8260B be used for analyzing soil vapor samples and TO-15 be used for analyzing sub-slab vapor, indoor air and outdoor ambient air samples.** High concentrations in soil vapor samples can lead to system carryover, large dilutions and contaminated Summa^{TM} canisters increasing the potential for false positives, elevated reporting levels and problems associated with managing canisters (Hartman 2006).

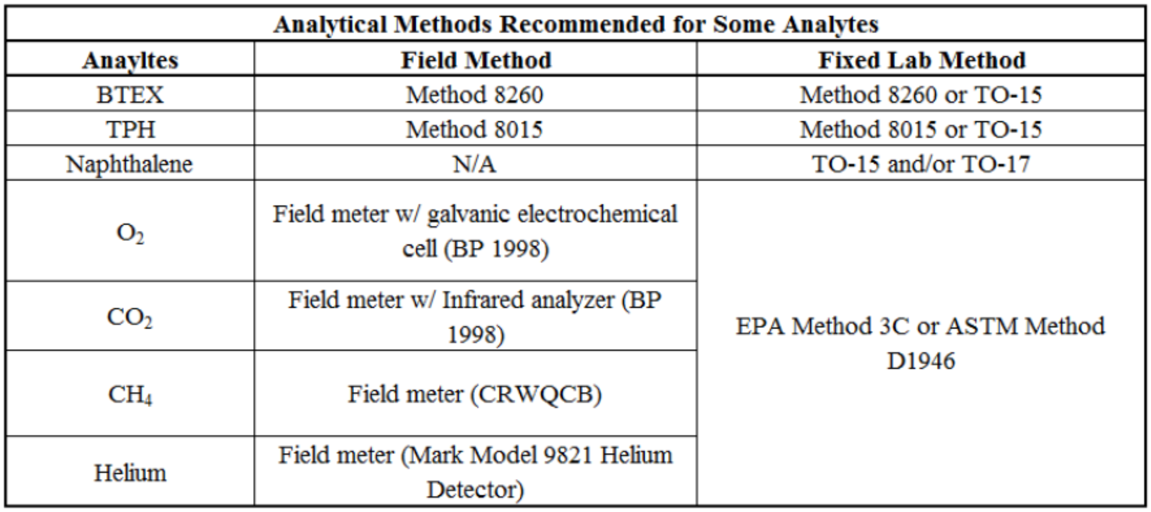
Naphthalene must be analyzed in all cases, and when using TO-15 (for sub-slab vapor, indoor air or outdoor ambient air), the laboratory must be notified of this request prior to ordering the Summa^{TM} canisters from the laboratory. In method

(a)



Sample Matrix	Indoor air	Outdoor air	Sub-slab soil vapor	Near-slab soil vapor
Analyte Required	All COCs no fixed gases	All COCs no fixed gases	All COCs and fixed gases	All COCs and fixed gases

(b)



Analytical Methods Recommended for Some Analytes		
Anaytes	**Field Method**	**Fixed Lab Method**
BTEX	Method 8260	Method 8260 or TO-15
TPH	Method 8015	Method 8015 or TO-15
Naphthalene	N/A	TO-15 and/or TO-17
O_2	Field meter w/ galvanic electrochemical cell (BP 1998)	EPA Method 3C or ASTM Method D1946
CO_2	Field meter w/ Infrared analyzer (BP 1998)	
CH_4	Field meter (CRWQCB)	
Helium	Field meter (Mark Model 9821 Helium Detector)	

Table 4 **(a) Required analytes for different samples and (b) recommended analytical methods used for several common analytes (Adapted from API 2005).**

TO-15 the detector (i.e. MS) can be operated in either the full scan mode (for standard method detection limit of 1 to 5 μg/m^3), or selected ion monitoring (SIM) mode to improve the method detection limit (< 1 μg/m^3) for a selected set of analytes. Sub-slab **soil vapor samples should not be analyzed in the SIM mode for two reasons:** One, it is not necessary as the risk-based soil vapor screening levels are generally higher than 5 μg/m^3 (Hartman 2006) and two, there is a potential for interference from the natural organic matter in the soil (EPRI 2005). **At this point, Chevron recommends using TO-15 method to do naphthalene sample collection and the lab conducting analysis should utilize certain procedures specified Appendix E in CAEPA's "Advisory Active Soil Gas Investigation" (CAEPA, 2012). Chevron does not recommend using TO-17 method due to the lack of the universal acceptance by most regulatory agencies.** Should the TO-17 method be required by the local agency, a detailed description of how soil vapor samples are to be collected in the field should be included with clear explanatory text and illustrative figures in work plan documents.

6.2 Fixed Gases

ASTM Method D1946, a gas chromatography/thermal conductivity detector (GC/TCD) method, is recommended for analysis of fixed gases, including O_2 and CO_2. For CH_4, ASTM Method D1946 can also be used, with a flame ionization detector (FID) in place of a TCD.

6.3 Data reporting

Soil vapor concentrations are reported in units of μg/L, μg/m^3, ppm$_v$, and ppb$_v$. Unlike concentration units for groundwater, these units are not directly interchangeable. The molecular weight (MW) of the compound in question is a factor in the conversion from units of parts per billion (ppb$_v$) to mass per unit volume (μg/m^3) as follows (API 2005) assuming temperature at 273 K and pressure at 1 atm.:

$$concentration(\mu g/m^3) = concentration(ppb_v) \times 0.04 \times MW$$

USEPA website also provides a useful conversion spreadsheet at:
http://www.epa.gov/athens/learn2model/part-two/onsite/ia_unit_conversion.html

Data are usually reported in table format, which is adequate for understanding and interpreting soil vapor concentrations over time and space. However, depth profiles for multi-level soil vapor sampling probes can be used in order to visualize changes in VOC concentrations and respiration/fixed gases over a given depth interval (as in Figure 12 particularly for assessing biodegradation of petroleum hydrocarbon vapors). Figure 12 shows the vertical soil vapor profiles for benzene vapors sourced from the smear zone or dissolved groundwater plume and oxygen suggesting that downward diffusion of oxygen from surface may have contributed to the significant attenuation of benzene over a 10-ft depth interval due to the aerobic biodegradation of benzene diffusing upward. On the other hand, if higher soil vapor concentrations are detected in the shallower probes than in the deeper probes, it is usually an indication of soil vapors sourced from hydrocarbon impacted soil in the vadose zone. Plotting data in visual formats often enhances the message that the text is providing.

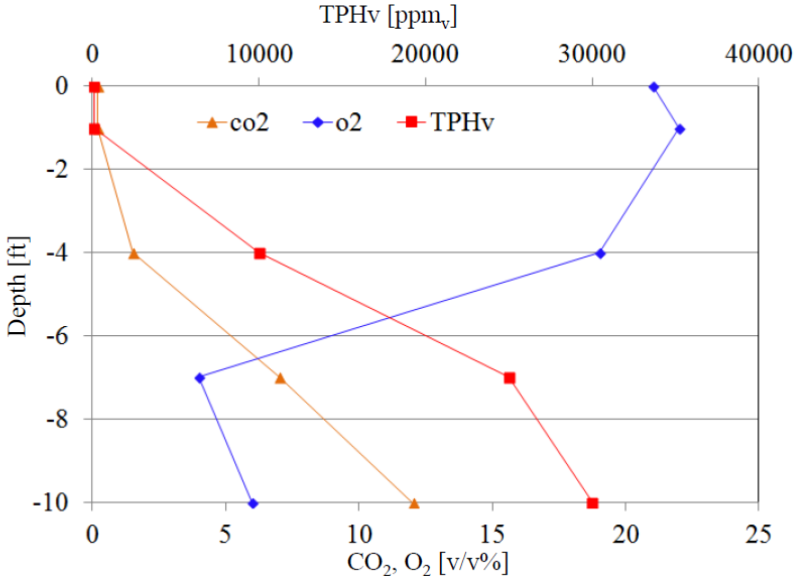


Figure 12. Vertical profile of TPHv, O_2, and CO_2.

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This website includes general information on vapor intrusion, along with information on VI guidiance documents from different states, and documents on different aspects of VI.

Appendix B

ARCADIS SOP (#112409) – Soil-Gas Sampling and Analysis Using USEPA Method TO-17 and TO-15

ARCADIS
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Soil-Gas Sampling and Analysis Using USEPA Method TO-17 and TO-15

SOP #112409

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Approval Signatures

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I. Scope and Application

This document describes the procedures to collect subsurface soil-gas samples from sub-slab sampling ports and soil vapor monitoring points for the analysis of volatile organic compounds (VOCs) including volatile polyaromatic hydrocarbons (PAHs) by United States Environmental Protection Agency (USEPA) Method TO-17 (TO-17) and USEPA Method TO-15.

The TO-17 method uses a glass or stainless steel tube packed with a sorbent material. Sorbents of increasing strength and composition are packed within the tube. The specific sorbent material packed within each tube is selected based on the target compounds and desired reporting limits. A measured volume of soil-gas is passed through the tube during sample collection.

The TO-15 method uses 1-liter 3-liter or 6-liter SUMMA® passivated stainless steel canister. An evacuated SUMMA canister (less than 28 inches of mercury [Hg]) will provide a recoverable whole-gas sample of approximately 5 liters when allowed to fill to a vacuum of approximately 6 inches of Hg. The whole-air sample is then analyzed for VOCs using a quadrupole or ion-trap gas chromatograph/mass spectrometer (GS/MS) system to provide compound detection limits of 0.5 parts per billion volume (ppbv). Optionally the canister sample can also be analyzed for fixed gasses such as Helium, Carbon dioxide and oxygen. .

Following sample collection the TO-17 tube and TO-15 canister is sent to the laboratory where the sampling media is analyzed for the target compounds.

The following sections list the necessary equipment and provide detailed instructions for the collection of soil-gas samples for analysis using TO-17 and TO-15.

Soil vapor samples can be collected from sub-slab sample probes or soil-vapor ports. Refer to the appropriate standard operating procedure (SOP) from the ARCADIS SOP library for a description of construction methods.

II. Personnel Qualifications

ARCADIS field sampling personnel will have current health and safety training, including 40-hour HAZWOPER training, site supervisor training, site-specific training, first-aid, and cardiopulmonary resuscitation (CPR), as needed. ARCADIS field sampling personnel will be well versed in the relevant standard operating procedures (SOPs) and possess the required skills and experience necessary to successfully complete the desired field work. ARCADIS personnel responsible for leading soil-gas sample collection activities must have previous soil-gas sampling experience.

III. Health and Safety Considerations

All sampling personnel should review the appropriate health and safety plan (HASP) and job loss analysis (JLA) prior to beginning work to be aware of all potential hazards associated with the job site and the specific task. Field sampling equipment must be carefully handled to minimize the potential for injury and the spread of hazardous substances. For sub-slab vapor probe installation, drilling with an electric concrete impact drill should be done only by personnel with prior experience using such a piece of equipment and with the appropriate health and safety measures in place as presented in the JLA

IV Equipment List

The equipment required for collect soil-gas samples for analysis using method TO-15 and TO-17 is presented below:

- Appropriate personal protective equipment (PPE; as presented in the site specific HASP and the JLA)

- TO-17 tubes pre-packed by the laboratory with the desired sorbent. Specific sorbents will be recommended by the laboratory considering the target compound list and the necessary reporting limits;

- TO-17 sample flow rate calibration tubes (provided by the laboratory);

- Stainless steel SUMMA® canisters (1-liter, 3-liter, or 6-liter; order at least 5% extra, if feasible) (batch certified canisters or individual certified canisters as required by the project)

- Flow controllers with in-line particulate filters and vacuum gauges; flow controllers are pre-calibrated to specified sample duration (e.g., 30 minutes, 8 hours, 24 hours) or flow rate (e.g., 200 milliliters per minute [mL/min]); confirm with the laboratory that the flow controller comes with an in-line particulate filter and pressure gauge (order at least 5% extra, if feasible). Flow rate should be selected based on expected soil type (see below).

- Two decontaminated Swagelok or stainless-steel or comparable two-way ball or needle valve (sized to match sample tubing).

- 1/4-inch outer diameter (OD) tubing (Teflon® or Teflon-lined polyethylene);

- Stainless steel or comparable Swagelok® or equivalent compression fittings for 1/4-inch OD tubing;

- Stainless steel “T” fitting (if sample train will be assembled with an inline vacuum gauge a four-way fitting will be needed);
- Three Stainless steel duplicate “T” fittings ;
- 2 Portable vacuum pumps capable of producing very low flow rates (e.g., 10 to 200 mL/min) with vacuum gauge;
- Vacuum gauge if monitoring vacuum reading during sample collection is necessary and portable vacuum pump is not equipped with a vacuum gauge;
- Rotameter or an electric flow sensor if vacuum pump does not have a flow gauge (Bios DryCal or equivalent);
- Tracer gas testing supplies (refer to Adminstering Tracer Gas SOP #41699);
- Photoionization Detector (PID) (with a lamp of 11.7 eV);
- Appropriate-sized open-end wrench (typically 9/16-inch, 1/2-inch , and 3/4-inch);
- 2 Tedlar bags;
- Portable weather meter, if appropriate;
- Chain-of-custody (COC) form;
- Sample collection log;
- Gel ice; and
- Field notebook.

V. Cautions

The following cautions and field tips should be reviewed and considered prior to collecting soil-gas samples.

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

- Care should be taken to ensure that the appropriate sorbent is used in the TO-17 tube preparation. Sorbent should be selected in consultation with the analytical laboratory and in consideration of the target compound list, the necessary reporting limits and the expected range of concentrations in field samples. The expected range of concentrations in field samples may be estimated from previous site data, release history and professional judgment informed by the conceptual site model.

- Flow rates for sample collection with TO-17 sorbent tubes should be determined well in advance of field work in consultation with the laboratory.

- A Shipping Determination must be performed, by DOT-trained personnel, for all environmental samples that are to be shipped, as well as some types of environmental equipment/supplies that are to be shipped.

- At the sampling location, keep the tubes in their storage and transportation container to equilibrate with ambient temperature prior to attaching to the sample train.

- Always use clean gloves when handling sampling tubes.

- Seal clean, blank sorbent tubes and sampled tubes using inert, Swagelok®-type fittings and PTFE ferrules. Wrap capped tubes individually in uncoated aluminum foil. Use clean, sealable glass jars or metal cans containing a small packet of activated charcoal or activated charcoal/silica gel for storage and transportation of multiple tubes. This activated charcoal is not analyzed, but serves as a protection for the analytical sorbent tube. Store the multi-tube storage container in a clean environment at 4ºC.

- Keep the sample tubes inside the storage container during transportation and only remove them at the monitoring location after the tubes have reached ambient temperature. Store sampled tubes in a refrigerator at 4ºC inside the multi-tube container until ready for analysis.

- The purge flow rate of 100 ml/min should be suitable for a variety of silt and sand conditions but will not be achievable in some clays without excessive vacuum. A low vacuum (<10” of mercury) should be maintained. Record the measured flow rate and vacuum pressure during sample collection.

The cutoff value for vacuum differs in the literature from 10" of water column (ITRC 2007) to 136" of water column or 10" of mercury (http://www.dtsc.ca.gov/lawsregspolicies/policies/SiteCleanup/upload/SMBR_ADV_activesoilgasinvst.pdf). A detailed discussion of the achievable flow rates in various permeability materials can be found in Nicholson 2007. Related issues of contaminant partitioning are summarized in ASTM D5314-92. Passive sampling approaches can be considered as an alternative for clay soils. However most passive sampling approaches are not currently capable of quantitative estimation of soil gas concentration.

- It is important to record the canister pressure, start and stop times and ID on a proper field sampling form. You should observe and record the time/pressure at a mid-point in the sample duration. It is a good practice to lightly tap the pressure gauge with your finger before reading it to make sure it isn't stuck.

- Ensure that there is still measureable vacuum in the SUMMA® after sampling. Sometimes the gauges sent from labs have offset errors, or they stick.

- When sampling carefully consider elevation. If your site is over 2,000' above sea level or the difference in elevation between your site and your lab is more than 2,000' then pressure effects will be significant. If you take your samples at a high elevation they will contain less air for a given ending pressure reading. High elevation samples analyzed at low elevation will result in more dilution at the lab, which could affect reporting limits. Conversely low elevation samples when received at high elevation may appear to not have much vacuum left in them. http://www.uigi.com/Atmos_pressure.html.

- If possible, have equipment shipped a two or three days before the sampling date so that all materials can be checked. Order replacements if needed.

- Requesting extra canisters and extra sorbent tubes from the laboratory should also be considered to ensure that you have enough equipment on site in case of an equipment failure.

- Shallow exterior soil-gas sampling should not proceed within 5 days following a significant rain event (1/2-inch of rainfall or more).

VI. Procedure

Soil-Gas Sample Preparation

Selection of Sorbent and Sampling Volume (to be completed prior to sampling event)

1. Identify the necessary final reporting limit for the target compound(s) in accordance with the project quality assurance plan and/or in consultation with the data end user.

2. Identify the necessary method reporting limit(s). The laboratory will be helpful in providing this information as it is typically specific to the sensitivity of the instrumentation.

3. The minimum sampling volume is the volume of soil-gas sample that must be drawn through the sorbent in order to achieve the desired final reporting limit. Calculate the minimum sampling volume using the following equation:

$$Minimum\ Sampling\ Volume\ (L) = \frac{Final\ Reporting\ Limit\ (\mu g)}{Action\ Level\ (\mu g/m^3)} \times \frac{1{,}000\ L}{m^3}$$

Where:

L = liters

µg = microgram

m = meter

4. If a timed sample duration is specified in the work plan, calculate the minimum flow rate. The minimum flow rate is the flow rate necessary to achieve the minimum sampling volume using the following formula:

$$Minimum\ Flow\ Rate\ (L/min) = \frac{Minimum\ Sampling\ Volume\ (L)}{Sample\ Duration\ (min)}$$

Where:

min = minutes

Then compare the minimum flow rate calculated to the requirements for maximum soil gas sampling without excessive danger of short circuiting, normally stated as 0.2 liters/minute, although it can be lower in tight soils. Soil vapor sampling flow rates should not exceed 200 ml/min.

5. Compare the minimum sampling volume to the safe sampling volume (SSV) for the sorbents selected. SSV for specific sorbents can be provide by the manufacture or the laboratory, being used (Table 1 and Appendix 1 in Method TO-17). Ensure that the compound will not breakthrough when sampling the volume calculated above.

Soil-Gas Sample Collection

Calibration of the sample pump prior to assembly of sampling train

1. Attach the sample flow rate calibration tube provided by the laboratory to the inlet of the sample pump using a section of tubing. Attach the flow calibrator to the inlet of the sample flow rate calibration tube. The sample flow rate calibration tube should be clearly marked by the laboratory with an arrow indicating flow direction (or as otherwise specified by the laboratory).

2. Turn on the sample pump and adjust the flow rate on the sample pump to achieve the desired minimum flow rate (calculated above) as measured by the flow calibrator.

3. Repeat until each sampling pump has been properly calibrated to its appropriate flow rate.

Assembly of combined TO-17 and TO-15 sampling train

1. Record the following information in the field notebook, if appropriate (contact the local airport or other suitable information source [e.g., site-specific measurements, weatherunderground.com] to obtain the information):

   a. wind speed and direction;

   b. ambient temperature;

   c. barometric pressure; and

   d. relative humidity.

2. If samples are being collected from temporary or permanent soil vapor points simply remove the cap or plug and proceed to step 3. When collecting samples from a sub-slab port remove the cap or plug from the sampling port. Connect a short piece of Teflon or Teflon-lined tubing to the sampling port using a Swagelok or equivalent stainless-steel or comparable compression fitting.

3. Connect the Teflon or Teflon-lined tubing to a stainless steel T fitting using a Swagelok or equivalent stainless-steel or comparableompression fitting.

4. Remove the brass cap from the SUMMA® canister and connect the flow controller with in-line particulate filter and vacuum gauge to the SUMMA® canister. Do not open the valve on the SUMMA® canister. Record in the field notebook and COC form the flow controller number with the appropriate SUMMA® canister number.

5. Connect the flow controller to the stainless steel T fitting using a Swagelok or equivalent stainless-steel or comparable compression fitting. The TO-15 leg of the combined sampling train is now complete.

6. Attach a length of Teflon or Teflon-lined tubing to the free end of the stainless steel T fitting using a Swagelok or equivalent stainless-steel or comparble compression fitting.

7. Complete the remainder of the sampling train as depicted in Figure 1.

Purge Sampling Assembly and Sampling Point Prior to Sample Collection.

1. Ensure the two-way valve next to the flow rate calibration tube is open and the two way valve next to the TO-17 sampling tubes is closed. Purge three volumes of air from the vapor probe and sampling line using the portable pump. Measure organic vapor levels with the PID. Lower flow rates may be necessary in silt or clay to avoid excessive vacuum. Vacuum reading greater than 136 inches of water column are clearly excessive. Other available sources cite a cutoff of greater than 10 inches of water column.

2. Check the seal established around the soil vapor probe and the sampling train fittings by using a tracer gas (e.g., helium) or other method established in applicable regulatory guidance documents. [Note: Refer to ARCADIS SOP "Administering Tracer Gas," adapted from NYSDOH 2005, for procedures on tracer gas use.]

3. When three volumes of air have been purged from the vapor probe and sampling line stop the purge pump and close the valve next to the flow rate calibration tube.

TO-15 Sample Collection

1. Open the SUMMA® canister valve to initiate sample collection. Record on the sample log (attached) the time sampling began and the canister pressure.

   If the initial vacuum pressure registered is not between -30 and -25 inches of Hg, then the SUMMA® canister is not appropriate for use and another canister should be used.

2. Take a photograph of the SUMMA® canister and surrounding area (unless photography is restricted by the property owner).

3. Check the SUMMA canister approximately half way through the sample duration and note progress on sample logs.

TO-15 Sample Termination

1. Arrive at the SUMMA® canister location at least 10 to 15 minutes prior to the end of the sampling interval.

2. Record the final vacuum pressure. Stop collecting the sample by closing the SUMMA® canister valves. The canister should have a minimum amount of vacuum (approximately 6 inches of Hg or slightly greater).

3. Record the date and time of valve closing in the field notebook, sample collection log, and COC form.

TO-17 Sample Collection

1. Record in the field notebook and COC form the tube number on the TO-17 tube.

2. Open the two-way valve next to the TO-17 tubes

3. Turn on the sample pump to begin sample collection. Use a stopwatch to ensure accuracy in pumping time. Record in the field notebook and the field sample log the time sampling began and the flow rate from each of the sample pumps.

Termination of Sample Collection

1. Stop the sample pumps after the desired volume of soil-gas has passed through the sorbent, and close the two-way valves next to the TO-17 sample tubes.

2. Record the stop time.

3. Detach the Tedlar bag from each sample pump and measure the helium concentration in the soil-gas collected by the Tedlar bag. Record any detections in the field book and sample collection log.

4. Open the two-way valve to permit flow through the flow rate calibration tube. Reconnect each of the sampling pumps and measure the flow rate. Record the post-sampling flow rates in the field log book and the sample collection logs. The post-sampling flow rate should match within 10% of the pre-sample flow rate. Average the pre-sampling and post-sampling flow rate and record in the field log book, and the sample collection log.

5. Calculate the sample volume using the average of the pre-sample and post-sample flow rate. Record the sample volume in the field log book, the sample collection log, and on the COC.

6. Package the tubes according to laboratory protocol on gel ice and ship to the laboratory for analysis.

VII. Waste Management

The waste materials generated during sampling activities should be minimal. PPE, such as gloves and other disposable equipment (i.e., tubing), will be collected by field personnel for proper disposal.

VIII. Data Recording and Management

Measurements will be recorded in the field notebook at the time of measurement with notations of the project name, sample date, sample start and finish time, sample location (e.g., GPS coordinates, distance from permanent structure), tube type and number and sample volume. Field sampling logs and COC records will be transmitted to the Project Manager.

IX. Quality Assurance

Duplicate samples should be collected in the field as a quality assurance step. Generally, duplicates are taken of 10% of samples, but project specific requirements should take precedence. Duplicate soil gas samples should be collected via a split sample train, allowing the primary and duplicate sample to be collected from the soil-gas probe simultaneously.

Quality assurance planning for method TO-17 should take careful note of the method requirement for distributed volume pairs. Although in some circumstances this requirement may be waived, this does constitute a deviation from the method as written. It is wise to discuss this decision with clients and/or regulators before sampling.

Soil-gas sample analysis will be performed using USEPA TO-17 methodology for a site specific constituent list defined in the work plan. Constituent lists and reporting limits must be discussed with the laboratory prior to mobilizing for sampling. Quality assurance parameters should be confirmed with the laboratory prior to sampling. Field quality assurance parameters should be defined in the site-specific work plan. A trip blank sample should accompany each shipment of soil-gas samples to the laboratory for analysis. Trip blanks assess potential sample contamination resulting from the transportation and storing of samples. Soil-gas sample analysis will generally be performed using USEPA TO-15 methodology or a project specific constituent list. Method TO-15 uses a quadrupole or ion-trap GC/MS with a capillary column to provide optimum detection limits (typically 0.5-ppbv for most VOCs).

X. References

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CITY: PETALUMA, CA DIV/GROUP: ENV DB: J. HARRIS LD:--- PIC:--- PM:(Reqd) TM:(Opt) LYR:(Opt)ON=*;OFF=*REF*
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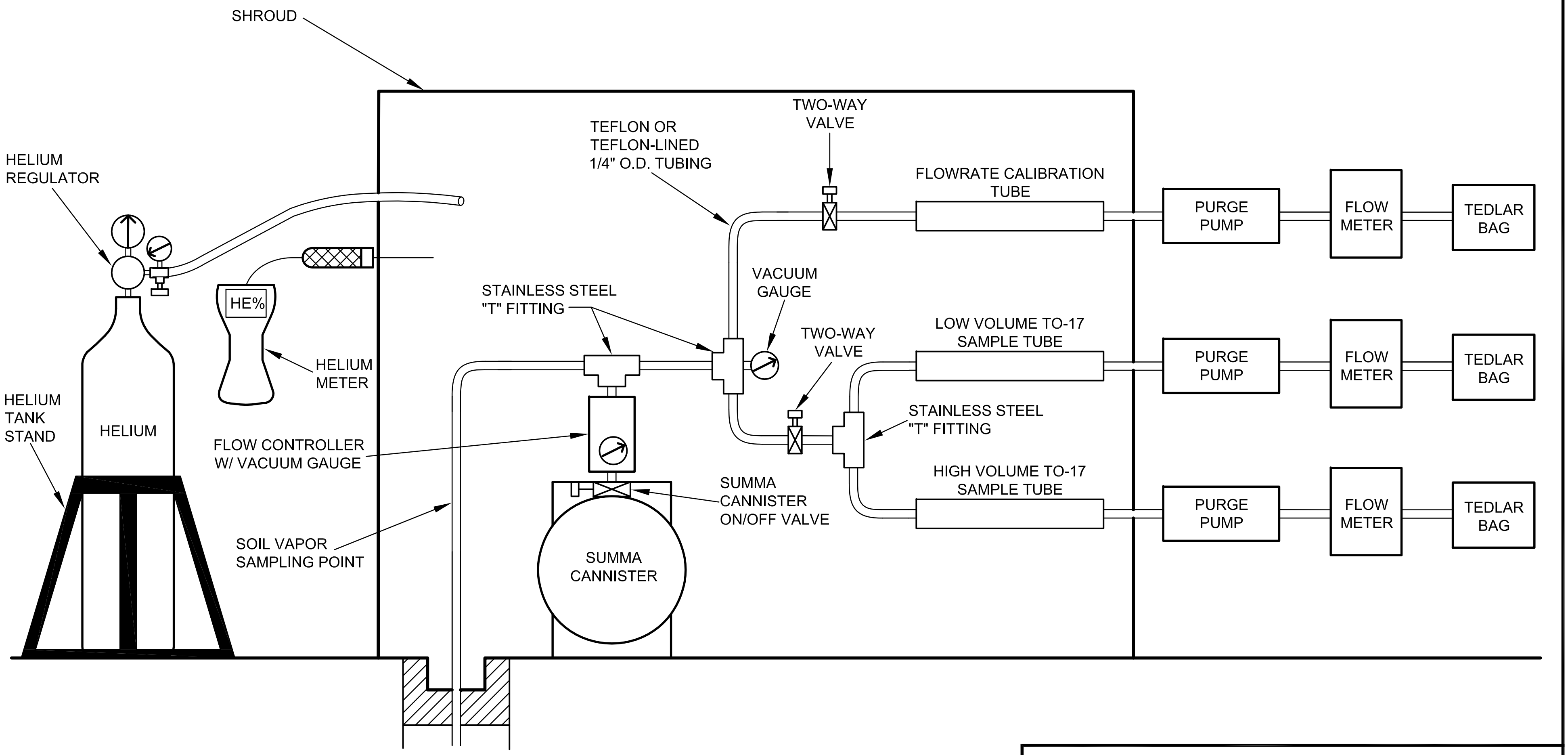

SOIL VAPOR SAMPLING EQUIPMENT ARRANGEMENT

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FIGURE
1