

placed on the floor. If there is concern for damage or disturbance of the canister in high use areas, the canister may be moved from these areas but away from doors, windows, and vents. For multi-storied residential buildings, one sample should be collected in the basement level or first floor (if slab-on-grade construction). Crawl spaces that are not ventilated can be sampled to determine if contaminant vapors are present that could potentially impact indoor air.

6.3.4 Sample collection period

Residential indoor air samples are typically collected over a 24-hour period. However, in certain situations (e.g., commercial or industrial settings), it may be more appropriate to sample over an 8-hour period. During the sampling period, exterior doors and windows should generally be kept closed. Heating/ventilation/air conditioning (HVAC) systems should be operated normally to be representative of actual living conditions. HVAC operation should be noted and considered when evaluating whether additional tests are required (e.g. during different seasons). Indoor air concentrations due to vapor intrusion will vary over time and are likely to be (but not necessarily) higher during winter season.

6.3.5 Ambient air sampling

An outdoor ambient sample must be collected simultaneously with the indoor air samples to provide a baseline against which the indoor air sample concentrations can be compared. Outdoor ambient air samples should be collected from a representative location, preferably upwind and away from any wind obstructions such as trees or buildings.

6.3.6 Background air sampling

In some situations, it may be necessary to collect background indoor air samples. Such samples should be collected inside a non-impacted structure located away from the contaminant plume that is similar in construction to the structure where indoor air is being evaluated. OPS does not have an RBSL for indoor air. However, OPS does consider benzene concentrations that are greater than background levels to be an indicator of possible vapor intrusion.

6.3.7 Additional measurements

As stated in Section 4.6, radon and/or air pressure may be measured for comparison with sub-slab measurements to assist in the determination of the presence of vapor intrusion.

6.3.8 Sample shipment

Refer to Section 4.8 for information on shipping samples. Always follow laboratory instructions for shipping of sample canisters.

7.0 Laboratory Analysis

OPS requires that all soil vapor, sub-slab vapor, and indoor air samples be analyzed for BTEX. Several analytical methods are available to measure soil gas samples, all of which can give accurate results when followed with appropriate Quality Assurance and Quality Control (QA/QC) measures. Table 3 includes laboratory methods and associated collection methods for analysis of petroleum-based contaminants and other analytes in soil vapor and indoor air samples.

Table 3. Soil Vapor and Indoor Air Analytical Methods

Analytes	Method Reference	Description	Sample Container	Container Holding Time	Detection Limit
Soil Vapor Sample Analysis					
BTEX	8021B ^{1,2}	GC/PID analysis	G, MC, SC	30 days	10-100 µg/m ³
			T	48 hours	
			SY	Onsite analysis	
BTEX	8260B ^{1,2}	GC/MS analysis	G, MC, SC	30 days	50-200 µg/m ³
			T	48 hours	
			SY	Onsite analysis	
BTEX	TO-1	Tenax [®] adsorption, GC/FID, although sometimes equipped with GC/MS analysis	SC	30 days	1-3 µg/m ³
			T	48 hours	
BTEX	TO-3	Cryogenic pre-concentration, GC/FID analysis	SC	30 days	1-3 µg/m ³
			T	48 hours	
			T	48 hours	
Sub-slab Vapor and Indoor Air Sample Analysis					
BTEX	TO-15 ¹	GC/MS analysis	SC	30 days	1-3 µg/m ³
BTEX	TO-14A	GC/FID/ECD or GC/MS analysis	SC	30 days	1-3 µg/m ³
BTEX	TO-15 SIM	GC/MS (SIM mode) analysis (5 to 10 compound subset of TO-15)	SC	30 days	0.1-0.5 µg/m ³
BTEX	TO-17	Air pump drawing air through adsorbent tube, thermal desorption & GC/MS with FID analysis	AT	30 days	1-3 µg/m ³

1 - OPS preferred method

2 - Must be calibrated with a vapor standard

T = Tedlar Bag SC = Summa canister G = glass bulb SY = Syringe

MC = stainless steel vial (400 ml mini-can) AT = Multi-bed adsorbent tube

Note: Detection limits listed in Table 3 are realistic or practical detection limits, which are dependent upon sample volume.

There are several websites that provide a wide range of unit conversions. Listed below are useful conversions for commonly reported laboratory units to the OPS-required unit of µg/m³ for soil vapor and indoor air analytical results.

Parts per billion by volume (ppbv) x 3.25 = µg/m³ (for benzene only)

Parts per million by volume (ppmv) x 3,250 = µg/m³ (for benzene only)

Micrograms per liter (µg/L) x 1,000 = µg/m³

Milligrams per liter (mg/L) x 1,000,000 = µg/m³

Milligrams per cubic meter (mg/m³) x 1,000 = µg/m³

For any compound, the conversion of ppbv to $\mu\text{g}/\text{m}^3$ is obtained by use of the Ideal Gas Law as follows:

$$C(\text{ppbv}) \frac{MW_v P_v}{1000RT} = C \left(\frac{\mu\text{g}}{\text{m}^3} \right)$$

Where: MW_v = molecular weight (g/mole)

P_v = vapor pressure (atm)

T = temperature ($^{\circ}\text{K}$)

R = the universal gas constant ($8.204\text{E-}05 \text{ atm m}^3/\text{K mole}$)

8.0 Data Validation

The following equations can be used to estimate the maximum benzene concentration expected in soil vapor ($C_{\text{max,vapor}}$) adjacent to dissolved contamination in groundwater or free-product (light non-aqueous phase liquid [LNAPL]). If benzene concentrations in soil vapor are significantly higher than the estimated maximum concentrations, the data should be further evaluated for potential errors or unknown source(s).

Expected maximum benzene in soil vapor ($C_{\text{max,vapor}}$) adjacent to **contaminated groundwater**:

$$C_{\text{max vapor}} \left(\frac{\mu\text{g}}{\text{m}^3} \right) = H * C_{\text{max GW}} \left(\frac{\mu\text{g}}{\text{L}} \right) \left(\frac{\text{L}}{10^3 \text{ ml}} \right) \left(\frac{\text{ml}}{\text{cm}^3} \right) \left(\frac{10^6 \text{ cm}^3}{\text{m}^3} \right)$$

Where: H = Henry's Constant for benzene = 0.23 (dimensionless)

$C_{\text{max,GW}}$ = maximum benzene concentration in groundwater

For example, a concentration of 100 $\mu\text{g}/\text{L}$ benzene in groundwater could yield a benzene soil vapor concentration of:

$$C_{\text{max vapor}} \left(\frac{\mu\text{g}}{\text{m}^3} \right) = 0.23 * 100 \left(\frac{\mu\text{g}}{\text{L}} \right) * 10^3 = 23,000 \mu\text{g}/\text{m}^3$$

Expected maximum benzene in soil vapor ($C_{\text{max,vapor}}$) adjacent to **LNAPL**:

$$C_{\text{max vapor}} \left(\frac{\mu\text{g}}{\text{m}^3} \right) = NMF_{\text{benzene}} * \left(\frac{P_v(\text{atm}) * MW_{\text{benzene}} \left(\frac{\text{g}}{\text{mole}} \right) * 10^6 \left(\frac{\mu\text{g}}{\text{g}} \right)}{R \left(\frac{\text{atm} \cdot \text{m}^3}{\text{mole} \cdot ^{\circ}\text{K}} \right) T(^{\circ}\text{K})} \right) = 6.9\text{E} + 06$$

Where: P_v = vapor pressure of benzene = 0.1 atm

MW_{benzene} = molecular weight of benzene = 78.1 g/mole

R = universal gas constant = $8.204\text{E-}05 \text{ atm m}^3/\text{K mole}$

T = Standard temperature = 298 $^{\circ}\text{K}$

NMF_{benzene} = estimated mole fraction of benzene in LNAPL = 0.02 (dimensionless)

$$NMF_{benzene} = \frac{(MF_{benzene} * MW_{benzene})}{MW_{LNAPL}}$$

Where:

$MF_{benzene}$ = mass fraction of benzene in LNAPL = 0.025 g/g

$MW_{benzene}$ = molecular weight of benzene = 78.1 g/mole

MW_{LNAPL} = molecular weight of LNAPL (all components) = 103 moles

9.0 Mitigation Measures

Remediation of petroleum hydrocarbon contamination sources in soil and groundwater is the most effective way to mitigate soil vapor intrusion into indoor air. If source remediation (i.e. soil excavation, soil vapor extraction, etc.) does not immediately mitigate the vapor intrusion problem, additional mitigation methodologies must be implemented. As in the case of petroleum hydrocarbon source remediation systems, it is also necessary in vapor mitigation systems to include intrinsically safe equipment when potentially explosive situations are present. An example of this situation is when LNAPL is very close to the building and vapor concentrations exceed 10% of the Lower Explosive Limit (LEL).

Below are selected references associated with indoor air mitigation. Since most vapor intrusion mitigation design has been based on radon control systems, many of the references below pertain to the control of radon.

9.1 Existing buildings

Passive or active venting systems, and sub-slab depressurization and pressurization systems.

References:

Massachusetts DEP. 1995. *Guidelines for the Design, Installation, and Operation of Sub-slab Depressurization Systems.*

New Jersey Dept of Environmental Protection. 2005. *Vapor Intrusion Guidance.*

www.state.nj.us/dep/srp/guidance/vaporintrusion/vig.htm

USEPA. 1991. *Sub-slab Depressurization Handbook for Low-permeability Fill Material* (for home radon reduction). EPA /625/6-91/029.

USEPA. 1993. *Radon Reduction Techniques for Existing Detached Houses, technical guidance for active soil depressurization systems.* EPA 625/R-93/011.

USEPA. Revised April 1994. *Radon Mitigation Standards.* EPA 402-R-93-078.

Accessible at <http://www.epa.gov/iaq/radon/pubs/index.html>

USEPA. Revised February 2003. *A Consumer's Guide to Radon Reduction.* EPA 402-K-03-002. Accessible at <http://www.epa.gov/iaq/radon/pubs/index.html>

9.2 Future buildings

Passive and active venting systems using gas barrier/membrane technology.

References:

ASTM. 1992. *Radon Control Options for the Design and Construction of New Low-Rise Residential Buildings.* ASTM Standard Guide, E14655-92.

USEPA. March 1994. *Model Standards and Techniques for Control of Radon in New Residential Buildings.* EPA 402-R-94-009. Air and Radiation (6604-J). Accessible at <http://www.epa.gov/iaq/radon/pubs/newconst.html>