ATLANTIC RBCA (Risk-Based Corrective Action)
Version 2.0

For Petroleum Impacted Sites in Atlantic Canada

User Guidance

Guidance for Soil Vapour and Indoor Air Monitoring Assessments

July 2006

ERRATA
(JULY 2012)

In January 2008, the Canadian Council of Ministers of the Environment (CCME) completed a review of the Canada Wide Standards for Petroleum Hydrocarbons for soil. Where each of the Atlantic Environment Ministers has signed the CCME Harmonization Agreements respecting environmental standards, they are each bound to ensure an equivalent level of environmental protection with CCME standards. As a result, Atlantic PIRI conducted a review of the 2007 CWS-PHC documents and recommended several changes to Atlantic RBCA Version 2. Several default modeling parameters were revised to harmonize with CWS.

The *Guidance for Soil Vapour and Indoor Air Monitoring Assessment,* dated July, 2006 was completed using the Atlantic RBCA Version 2.0 defaults and was originally published as an appendix (Appendix 9) of the *User Guidance*, Version 2.0. Therefore, there are some required updates, based on the changes incorporated into Atlantic RBCA Version 3.2. These changes are summarized in these errata. The *Guidance for Soil Vapour and Indoor Air Monitoring Assessment* (2006) is now considered a stand-alone document.

1. **Page 12/13, Pathway Operability Tables, Table 1 and Table 2 are to be removed and Appendix A to be removed. However, Atlantic PIRI still recommends that at source to building separation distances greater than 30 m, the indoor air pathway can be considered inoperable. For distances less than 30 m, assessment of the indoor pathway is required.**

   Justification
   Atlantic PIRI are in the process of researching other models for calculating operability distances. Revised tables may be produced in the future subject to the findings.

2. **Page 48, Table 7: Soil Gas to Indoor Air Dilution Factors (DFs) to be adjusted as follows:**

Table 7 Soil Gas to Indoor Dilution Factors (DFs)

Distance (m)	Residential		Commercial	
	Coarse	Fine	Coarse	Fine
1	2,500	31,000	6,300	64,000
2	4,000	33,000	8,500	65,000
3	5,500	34,000	10,000	67,000
5	8,500	36,000	15,000	71,000
10	15,000	42,000	26,000	80,000
20	30,000	54,000	48,000	98,000
30	45,000	66,000	70,000	110,000

Mandatory Criteria:

1. Concrete floor present in building.
2. Building volume equal to or greater than default volume. If building volume is less than the default volume, the DF must be adjusted down to account for smaller volume.
3. Mobile free product is not present in the subsurface within 30 m of the building.
4. Groundwater table >1 m below the building foundation.
5. Site conditions conform to the Atlantic RBCA Tier I default site conditions.

Justification
Several changes were made to the Atlantic RBCA default values and re-calculation of dilution factors was required including the following: total porosity, volumetric water content and volumetric air content for coarse and fine grained soils; vapour permeability for coarse grained soil; air exchange rate for commercial buildings; and the mixing zone for residential buildings. Refer to the Atlantic RBCA Version 3.2 User Guidance for further details on the changes.

3. **Page 51, Replace the following text: "The measured or predicted concentration is considered acceptable if:**

Indoor air concentration (mg/m^3) ≤ RfCi (mg/m^3)

Revised text to read: "The concentration is considered acceptable if:

Measured Indoor air concentration (mg/m^3) ≤ RfCi (mg/m^3)
Predicted indoor air concentration (mg/m^3) ≤ Target HQ x RfCi (mg/m^3)

Where Target HQ is 0.5 for TEX and 1.0 for TPH."

Justification
This change was made to harmonize with CCME 2004 and Health Canada 2010 *Guidance for Soil Vapour Intrusion Assessment at Contaminated Sites*.

4. **Page 51, Table 8: RfC_i for Toluene changed from 0.4 mg/m^3 to 3.8 mg/m^3.**

Justification
This change was made to harmonize with CCME 2004 and Health Canada 2009.

5. **Page 52, Section 6.5.3.1. Remove the following text: "The calculation of the $SSTL_{TPH}$ must include toluene as the Aromatic >C7-C8 fraction and ethylbenzene and xylenes in the Aromatic >C8-C10 fraction. Consequently, the measured or predicted concentration of TPH in indoor air must also include toluene as Aromatic >C7-C8 fraction and ethylbenzene and xylenes in the Aromatic >C8-C10 fraction to ensure an appropriate comparison."** Addition of toluene, ethylbenzene and xylenes to the appropriate fraction s is not required. Both the SSTL and measured or predicted concentrations will be modified TPH.

Justification
Due to the long history of managing toluene, ethylbenzene and xylenes as target compounds, CCME has excluded these compounds from total petroleum hydrocarbons. Atlantic PIRI has also made the decision to exclude these compounds to harmonize with CCME.

Further details on the parameters that have changed in Atlantic RBCA Version 3.2, are provided in the *Atlantic RBCA (Risk-Based Corrective Action) Version 3.2 User Guidance,* July 2012.

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Please refer to the Atlantic RBCA website www.atlanticrbca.com for the most current version of this and other supporting documents.

Acknowledgements

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ATLANTIC PIRI TASK GROUP COORDINATOR

David A. Rae, Jacques Whitford Limited

MEMBERS OF THE SOIL VAPOUR AND INDOOR AIR MONITORING TASK GROUP

Geoff Dickinson, TerrAtlantic
Thelma Green, Research and Productivity Council
Ian Hers, Golder Associates
Warren Kindzierski, University of Alberta
Scott MacKnight, OCL Services
Todd McAlary, GeoSyntec Consultants, Inc.
Peter Miasek, Imperial Oil
Tania Noble Sharpe, Jacques Whitford Limited

Preface

This document was developed by the Atlantic Partners in RBCA (Risk Based Corrective Action) Implementation (PIRI) Committee based upon the principle of protection of human health. It is intended to assist those involved with contaminated site management in understanding technical options and requirements, and their responsibilities from site characterization to site closure, specifically in the assessment of the subsurface vapours to indoor air exposure pathway.

This document is intended to guide the user by providing background discussion, technical options, recommended approaches and mandatory elements for assessing the subsurface vapours to indoor air exposure pathway. Specifically, guidance is presented on: understanding the processes that control subsurface vapour transport and intrusion into buildings; completing adequate site characterizations and developing appropriate conceptual site models; developing sampling strategies and determining which methods for sample collection and analysis should be employed; interpreting the results within the Atlantic RBCA framework; and applying the results within Provincial contaminated site management processes to obtain site closure.

Technical approaches and recommendations presented herein are based on review of current literature, including recent publications by the American Petroleum Institute (API, 2005) and Golder Associates (Golder, 2004), combined with the experience and professional judgement of the authors. Information presented is intended to provide a broad understanding and range of options for the Site Professional and is not intended to be universally applicable to all sites or situations. It is the responsibility of the Site Professional to apply their own professional judgement to site-specific circumstances and ensure appropriate and technically justifiable methods are being employed.

The focus of this guidance is the protection of chronic human health risks due to long term exposure. It does not address immediate safety issues (e.g., explosive conditions) and assumes that these situations have been identified and mitigative measures have been implemented.

Every attempt has been made to ensure that this document reflects current knowledge and recommended practice for assessing the subsurface vapours to indoor air exposure pathway. It is expected that this guidance will be updated as new research and information becomes available. Users should consult the Atlantic RBCA web site at www.atlanticrbca.com for the latest version of this document. Site Professionals should involve Provincial regulatory staff throughout the management process, particularly where there may be uncertainties related to Provincial policies.

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1.0 INTRODUCTION

1.1 Background

This document was prepared under the direction of the Atlantic Partners in RBCA Implementation (PIRI) Committee. RBCA stands for Risk Based Corrective Action, a process for managing impacted sites, originally defined in the ASTM Standard E1739-95 *Standard Guide for Risk Based Corrective Action Applied at Petroleum Release Sites*. Atlantic PIRI has sponsored development of a computer model (Atlantic RBCA Toolkit version 2.1) based on the ASTM standard with model inputs typical of Atlantic Canadian conditions. This model is accepted for use by the four Atlantic Provinces in the management of petroleum impacted sites within each of their individual contaminated site management processes. Atlantic PIRI also published a User Guidance document (Atlantic PIRI, 2003) that provides technical guidance on the use of the Atlantic RBCA model. These documents, along with Provincial management documents, are available on the Atlantic PIRI web site at www.atlanticrbca.com.

This document is an Appendix to the Atlantic RBCA v2.0 User Guidance and supplements the Atlantic RBCA toolkit and Provincial management processes by providing specific guidance on the assessment and quantification of the subsurface vapours to indoor air exposure pathway for petroleum hydrocarbons, through the measurement or prediction of soil vapour or indoor air concentrations. This option is available to Site Professionals and Responsible Parties as an alternative to Tier I/II assessment/remediation of potential indoor air impacts as a result of subsurface petroleum hydrocarbon impacts.

1.2 Purpose and Scope

The purpose of this document is to provide technical assistance to Responsible Parties and Site Professionals when assessing potential risks associated with subsurface vapour intrusion into occupied buildings, and guidance on developing appropriate remedial action plans, monitoring strategies, and obtaining site closure.

Indoor air sampling often presents practical difficulties. This document is therefore intended to guide Site Professionals and regulators by providing background discussion to the topic, a range of technical options, recommended approaches, and certain technically required minimum elements for assessing this exposure pathway. Collection and interpretation of soil vapour samples has historically been used for semi-quantitative purposes (e.g., presence or absence of vapours), but much more stringent protocols are required to provide data of sufficient quality for risk assessment, health protection, and

site closure. This guidance emphasizes and details a phased approach for evaluating petroleum hydrocarbon impacts to indoor air, beginning with an assessment of subsurface vapour concentrations.

The focus of this guidance, and of Atlantic RBCA in general, is the protection of human health due to long term exposure. The Site Professional is responsible for identifying potential acute risks due to vapour intrusion (e.g., wet basement in direct contact with contamination, explosive conditions, unacceptable odours) and developing, recommending and implementing mitigative measures in conjunction with the Responsible Party.

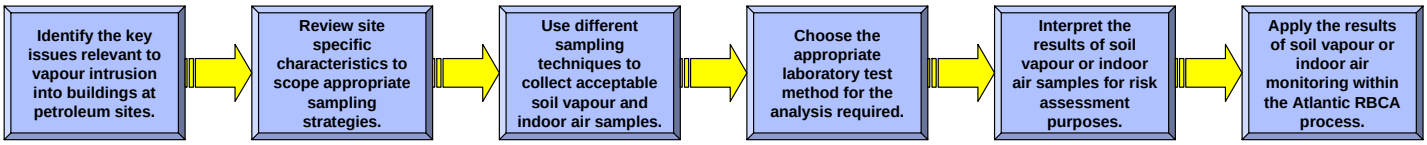
Atlantic RBCA was originally developed specifically for the management of petroleum hydrocarbon impacts and, at the time of writing this document, the Atlantic RBCA Toolkit is approved for use with petroleum hydrocarbons only. Therefore, the primary focus of this document is the assessment of petroleum hydrocarbon vapours. However, it is recognized that it may be possible to apply portions of this guidance, such as field methods and dilution factors, to non-petroleum vapours whose fate and transport properties are similar (e.g., chlorinated solvents). The Site Professional should consult with the Provincial regulator before applying this guidance to non-petroleum contaminants.

Every attempt has been made to ensure that this document reflects current knowledge and recommended practice for assessing the subsurface vapours to indoor air exposure pathway. It is expected that this guidance will be updated as new research and information becomes available. Users should consult the Atlantic RBCA web site at www.atlanticrbca.com for the latest version of this document.

1.3 How to Use this Guidance

This guidance document is primarily intended to be used by Site Professionals with detailed knowledge and experience in the management of petroleum impacted sites. The document provides information that they can use to develop and implement soil vapour and/or indoor air monitoring programs at petroleum impacted sites in Atlantic Canada.

It presents detailed guidance on how to:



The document provides straightforward instructions on each aspect of planning and implementing a soil vapour and/or indoor air monitoring program. Specific components of a monitoring program that are discussed include:

- **Section 2** reviews basic concepts in understanding the processes involved in soil vapour migration and vapour intrusion into buildings; the role of soil vapour and indoor air monitoring in the management of petroleum hydrocarbon impacted sites; and how to determine when this exposure pathway is operable.

- **Section 3** describes the factors to be considered in planning a soil vapour monitoring program; conceptual site models; sampling strategies; sampling design considerations; and field methods.

- **Section 4** discusses possible sampling techniques for sub-slab and indoor air sample collection; construction of sub-slab vapour probes; and suggested approaches to common issues with indoor air sampling.

- **Section 5** provides an overview of commonly employed laboratory test methods; sample submission requirements; and limits of detection.

- **Section 6** discusses the interpretation of results in the context of risk assessment and Atlantic RBCA; development of soil vapour to indoor air dilution factors; total petroleum hydrocarbons (TPH) fractionation results and development of TPH indoor air target concentrations; and exposure averaging of indoor air target concentrations.

- **Section 7** describes the role and application of soil vapour and/or indoor air monitoring within the Provincial contaminated site management processes; Remedial Action Plan (RAP) monitoring requirements; and Tier III site closure.

References are provided in **Section 8** and supporting information is included in appendices.

1.4 Further Reading

The primary intent of this document is to provide working guidance to Site Professionals when conducting subsurface vapour and/or indoor air assessments. It is not intended to be prescriptive, nor is it possible to provide discussion of all possible factors related to soil vapour and indoor air assessments within the scope of this document.

The guidance accommodates flexibility in approach, based on site-specific conditions, when supported by sound reasoning and professional judgement. It is expected that the Site Professional will conduct further reading of background materials to gain a more complete understanding of this technical practice area. To assist, a reference list is provided in Section 8. Key references that influenced the development of this guidance are listed below:

American Petroleum Institute (API), 2005.
Collecting and Interpreting Soil Gas Samples from the Vadose Zone: A Practical Strategy for Assessing the Subsurface Vapour-to-Indoor-Air Migration Pathway at Petroleum Hydrocarbon Sites. Publication No. 4741.

Electric Power Research Institute (EPRI), 2005.
Reference Handbook for Site-Specific Assessment of Subsurface Vapor Intrusion to Indoor Air. EPRI Report #1008492. March 2005.

Golder Associates, 2004.
Soil Vapour Intrusion Guidance for Health Canada Screening Level Risk Assessment (SLRA). Prepared for Health Canada. Final Draft, November, 2004.

Tillman, F. D. and J. W. Weaver. 2005.
Review of Recent Research on Vapour Intrusion. US EPA. Washington DC. EPA/600/R-05/106. September 2005.

United States Environmental Protection Agency (US EPA), 2002.
OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway From Groundwater and Soils (Subsurface Vapour Intrusion Guidance). http://www.epa.gov/epaoswer/hazwaste/ca/eis/vapor.htm

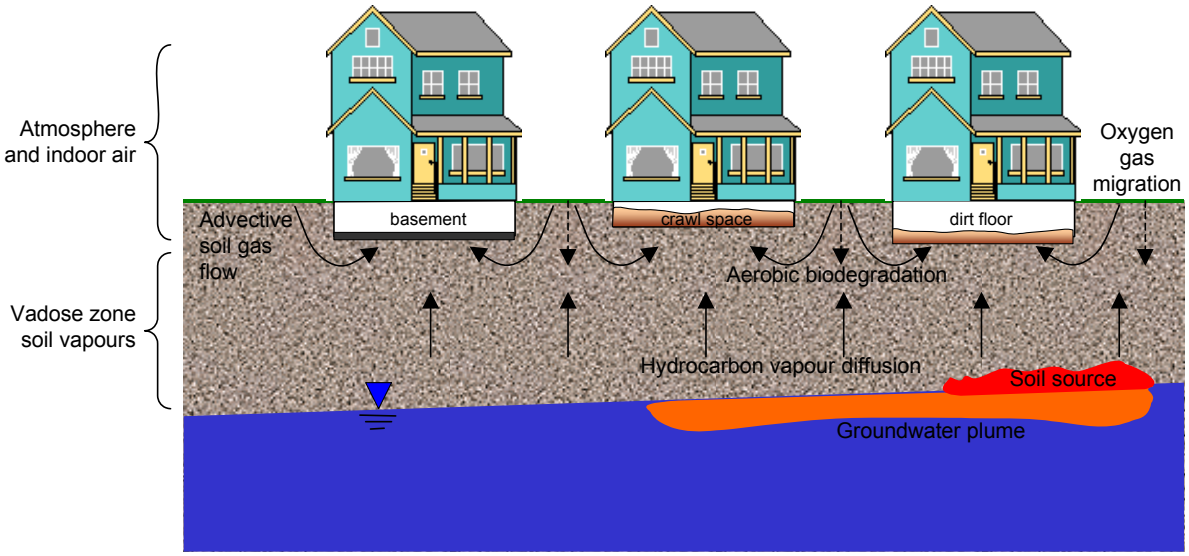
Weaver, J. W. and F. D. Tillman, 2005.
Uncertainty and the Johnson-Ettinger Model for Vapour Intrusion Calculations. US EPA. Washington DC. EPA/600/R-05/110. September 2005.

2.0 RATIONALE

2.1 Soil Vapour Transport at Petroleum Hydrocarbon Impacted Sites

To provide some background to users of this guidance, this section provides a brief overview of the general concepts and expectations for vapour transport at petroleum hydrocarbon impacted sites. For a more detailed discussion, the reader is referred to American Petroleum Institute (API) Publication 4741 – Collecting and Interpreting Soil Gas Samples from the Vadose Zone (API, 2005). Figure 1 illustrates generally accepted concepts for vapour migration and intrusion at petroleum impacted sites.

Figure 1 Typical Model of Soil Vapour Migration



Although Figure 1 illustrates various potential residential scenarios, the following discussion is broadly applicable to other settings (e.g., commercial) and building constructions. Current understanding of soil vapour transport indicates that vapour migration occurs primarily as the result of two processes:

- Diffusion - the movement of chemicals along a concentration gradient from an area of higher concentration to an area of lower concentration. Diffusive flux is proportional to the concentration gradient and effective diffusion coefficient, which is typically in the range of 0.001 – 0.01 cm^2/sec for vadose zone conditions.

- Advection - the movement of chemicals along a pressure gradient from an area of higher pressure to an area of lower pressure. Chemicals flow with the bulk motion of soil gas along pressure gradients that can be caused by factors such as soil-building pressure differentials.

Close to source areas and throughout most of the vadose zone, diffusion is typically the dominant transport process. However, closer to buildings, advective flow may become significant depending on site-specific factors such as soil type, building construction, building mechanical systems (e.g., building under-pressurization caused by heating systems or appliance exhausts), wind-load on the side of the building, and barometric pressure changes, etc.

An understanding of transport processes and expected soil vapour profiles is necessary for the proper planning and execution of a soil vapour monitoring field assessment. Based on the above concepts, some general characteristics of soil vapour profiles can be expected at most sites:

- The highest concentrations of petroleum hydrocarbon constituents will be found near the source.

- Concentrations of hydrocarbon soil vapours will decrease both laterally and vertically (e.g., toward ground surface) away from the source. However, subsurface features such as soil layering (e.g., confining layers) and preferential pathways (e.g., gravel seams, utility conduits) may affect vapour distribution.

- The composition of hydrocarbon vapours near the source will reflect the composition of the soil or groundwater source and the physico-chemical properties of the individual constituents (e.g., Henry's Law constant).

Additionally, it is likely that anaerobic and/or aerobic biodegradation is a significant process at many petroleum hydrocarbon impacted sites, especially as the source – building separation distance increases. The vapour transport model incorporated into the Atlantic RBCA Toolkit assumes no biodegradation and quantitative elements of this guidance (e.g., pathway operability matrices, dilution factors) also assume no biodegradation is occurring. This results in an inherently protective approach to assessment of the subsurface vapours to indoor air pathway for petroleum hydrocarbons. Where biodegradation is considered to be important, the Site Professional has the option to collect site-specific data to assess the significance.

2.2 Role of Soil Vapour and Indoor Air Monitoring at Petroleum Hydrocarbon Impacted Sites

2.2.1 Atlantic RBCA Context and Rationale

Tier I Risk Based Screening Level (RBSL) Tables were developed in 2003 using the Atlantic RBCA Toolkit v2.1. The Tier I RBSLs were based on the lowest applicable Pathway Specific Screening Levels (PSSLs) presented in Table 8 in the Atlantic RBCA User Guidance, version 2.0, October 2003. Five potential exposure pathways were modelled to derive the PSSLs:

- Indoor Air;
- Outdoor Air;
- Soil Ingestion;
- Soil Leaching; and
- Groundwater Ingestion.

A review of the PSSLs highlights the importance of the Indoor Air pathway to the management of petroleum impacted sites in Atlantic Canada. The Tier I RBSLs for benzene, toluene, ethylbenzene, xylenes (BTEX) and modified total petroleum hydrocarbons (Modified TPH) for all non-potable sites (except two fine-grained scenarios) are based on the subsurface vapours to indoor air exposure pathway. For sites characterized by potable water and coarse-grained soils, the Tier I RBSLs for Modified TPH in soil are also based on the subsurface vapours to indoor air pathway. As such, the indoor air pathway is a significant driver for remediation and therefore an accurate assessment of this exposure pathway is critical to the safe management of petroleum hydrocarbon impacted sites.

PSSLs and RBSLs were calculated using the Atlantic RBCA Toolkit, version 2.1, with an assumed set of site conditions, representative of the Atlantic Canadian experience. Default assumptions about site conditions used to generate the Tier I RBSLs were deliberately conservative, to ensure safe management of sites. Users of the PSSLs and RBSLs must decide whether their site conforms to the default assumptions. Where these assumptions do not apply, for example in the case of a basement with an earth floor, it may not be possible to apply the Tier I RBSLs or PSSLs at the site. In addition, the vapour transport model (Johnson & Ettinger, 1991) in the Toolkit provides an inherently conservative evaluation of hydrocarbon vapour migration and infiltration. For these reasons, situations arise where an alternative approach is preferred or required.

Collection and interpretation of empirical site data may be one means of replacing reliance on model calculations. For instance, this approach is often used in assessing the stability and natural attenuation of groundwater plumes. Direct measurement and monitoring of soil vapours and/or indoor air concentrations is analogous to this and is an acceptable means of empirically assessing the potential risks posed by the subsurface vapours to indoor air pathway on a site-specific basis.

2.2.2 General Approach to Monitoring Programs

One of the biggest challenges in assessing subsurface vapour intrusion to indoor air is the presence of detectable vapours in indoor air from consumer products, building materials, and even outdoor air. In some cases, background concentrations can exceed risk-based indoor air quality targets, and comprise some of the same chemicals that are present in the subsurface. Therefore, conclusions drawn from direct indoor air quality monitoring in the absence of other lines of evidence may result in a false positive determination (i.e., the conclusion that subsurface vapour intrusion is a problem, when in fact it is not). Generally, it is preferable to conduct a phased investigation, beginning with an assessment of subsurface vapour concentrations near the known or suspected source of vapours. It may be possible to demonstrate that subsurface concentrations attenuate below concentrations of potential concern at some distance from an occupied structure, in which case indoor air monitoring is not necessary for the assessment of this pathway.

The recommended approach to soil vapour and indoor air monitoring at petroleum hydrocarbon impacted sites is illustrated on Figures 2 and 3. As indicated, the preferred approach is initially to assess subsurface vapour concentrations near the soil or groundwater source (Figure 2). Only in situations where source vapours indicate a potential concern would sub-slab or indoor air monitoring be conducted (Figure 3).

2.3 When is the Indoor Air Pathway Operable?

As indicated in Figure 2, a critical step in the process after completion of any required emergency actions and site characterization is to determine whether the subsurface vapours to indoor air pathway is operable at the site. It is generally accepted that vapours generated “near” to occupied buildings have the potential to be transported into the building. However, there has been discussion on the extent of lateral separation between the vapour source and building foundation and if there is a distance beyond which the subsurface vapours to indoor air pathway would no longer be operable.

Figure 2 Soil Vapour Sampling Approach

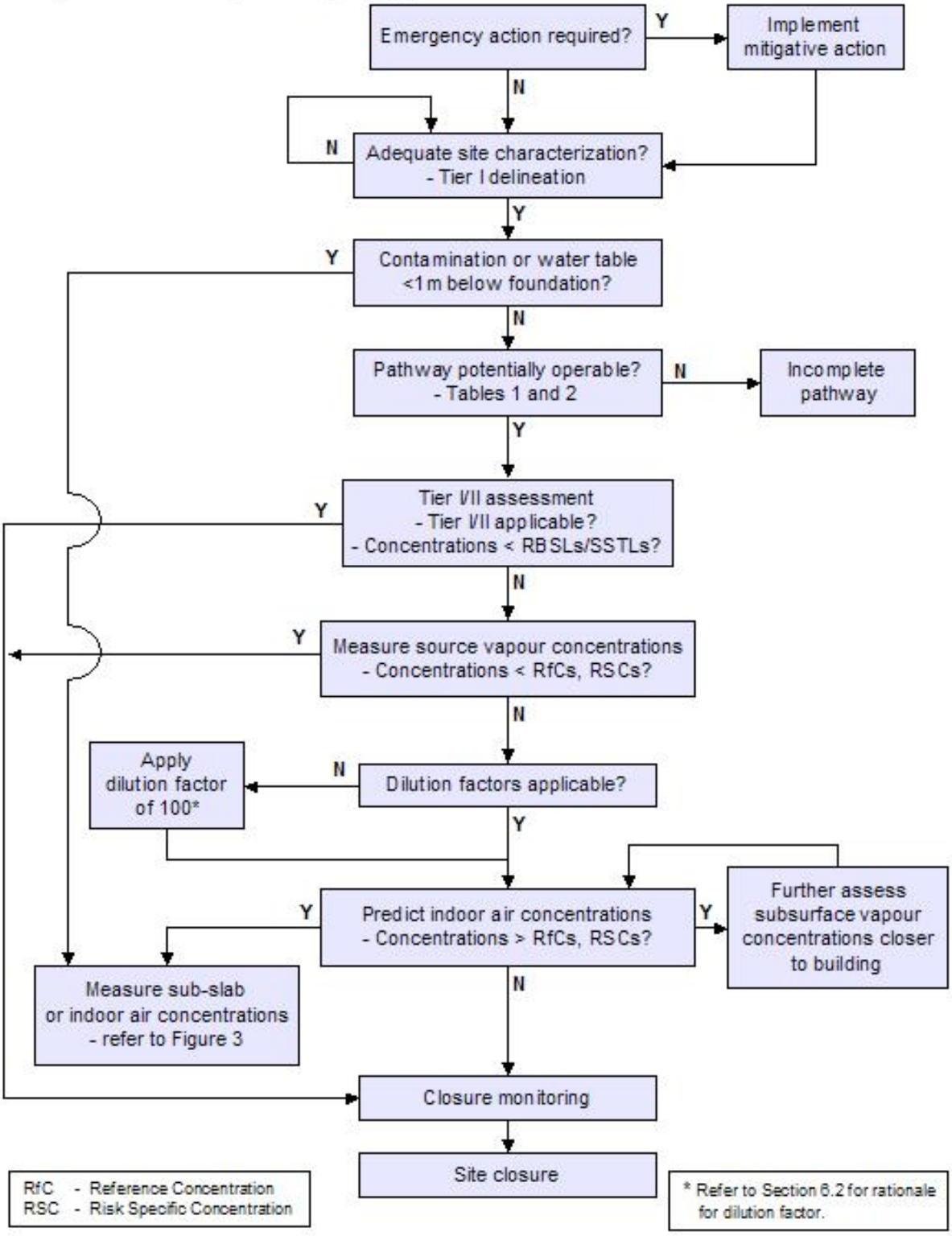
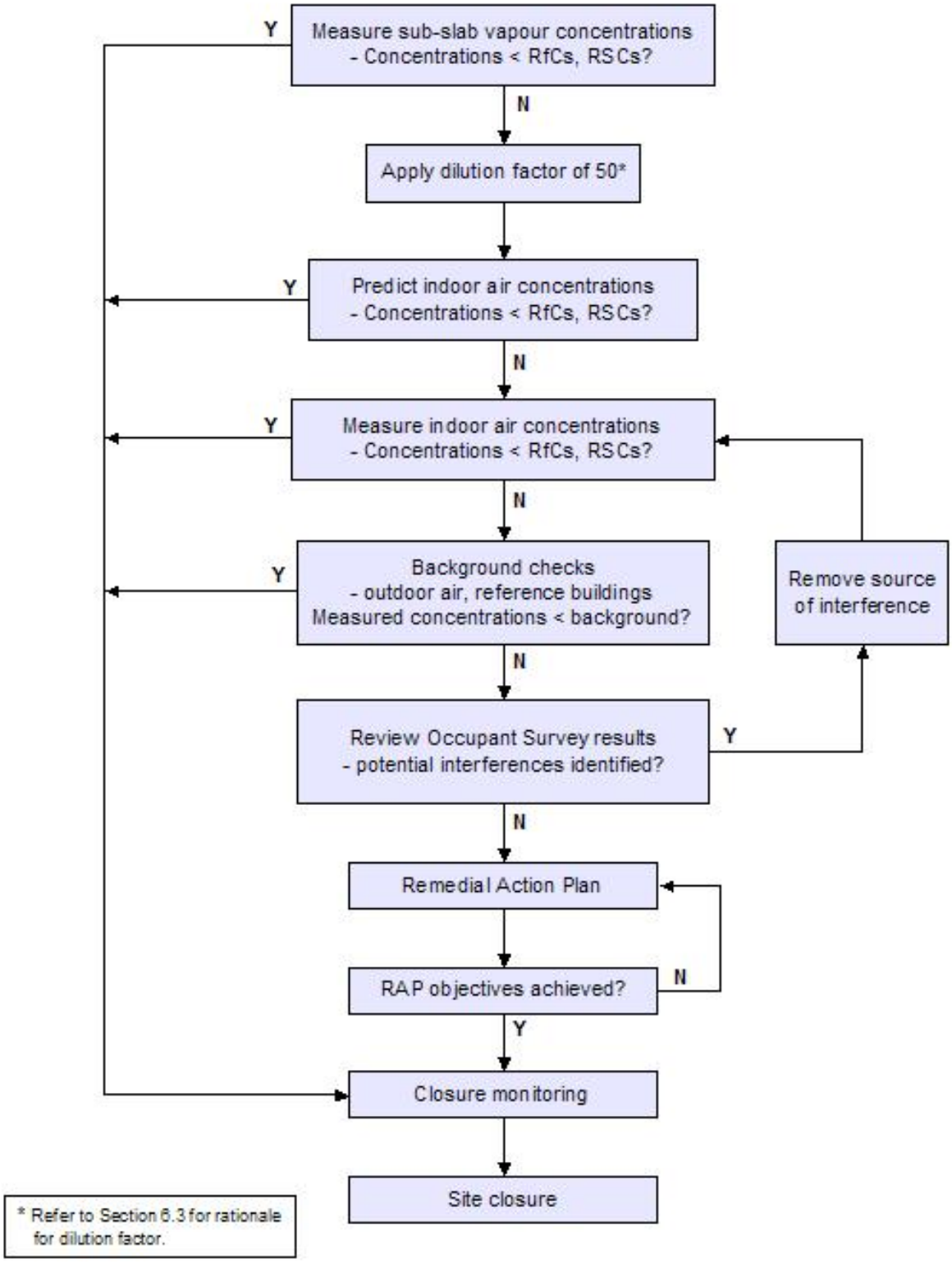


Figure 3 Sub-Slab and Indoor Air Sampling Approach



The United States Environmental Protection Agency (US EPA) recommended that an inhabited building be considered "near" if it is located within approximately 100 feet (30 m) laterally or vertically of the source (US EPA, 2002). This distance was a professional judgement based on qualitative consideration of a number of factors that would influence vapour migration, including chemical mobility and persistence, source geometry, subsurface materials, and building characteristics. This distance was supported by data from residential properties in Colorado where no significant indoor air concentrations were found in residences greater than one house lot from the edge of a groundwater plume. The US EPA cautioned that this distance may not be appropriate for all sites (e.g., sites with natural or man-made preferential pathways) and that it would be reviewed as additional empirical data are compiled.

Golder (2004) and API (2005) adopted the same lateral and vertical distance criterion of 30 m based on professional judgement but noted certain site conditions that may preclude the use of this criterion, as follows:

- Preferential pathways (e.g., fractured bedrock, utility conduits, layered soils [e.g., coarse gravel seams]);
- Landfill gas, migrating under pressure;
- Surface features that would block the flow of oxygen or prevent dissipation of vapours (e.g., impermeable cover); and/or
- Expanding source zone.

More recently, Abreu and Johnson (2005) conducted three-dimensional numerical modelling to assess the effect of vapour source to building separation and building construction on soil vapour intrusion. The authors demonstrated increases in vapour attenuation of two to five orders of magnitude over a lateral separation distance of 25 m. Modelling assumptions employed included:

- no biodegradation;
- relatively high volatility and low soil sorption potential;
- soil vapour permeability of 10^{-7} cm^2;
- source vapour concentration of 200 mg/L;
- 30 m x 30 m source zone; and
- typical residential construction.

These assumptions would likely result in the underestimation of vapour attenuation at petroleum hydrocarbon sites where aerobic biodegradation would be expected. Abreu and Johnson (2006) demonstrated increases in vapour attenuation of several orders of

magnitude due to biodegradation over distances up to 8 m, though biodegradation effects were minimal at short distances. The authors concluded that the establishment of regulatory criteria for vapour source to building distances beyond which the pathway is *a priori* not of concern would be dependent on the depth to the vapour source, the vapour source strength, and the chemical-specific reference concentration (RfC).

Based on a review of the available literature, Atlantic PIRI recommend that at source to building separation distances greater than 30 m, the indoor air pathway can be considered inoperable. For distances less than 30 m, Tables 1 and 2 present matrices, for different separation distances and analyte concentrations that can be used to identify when the indoor air pathway is considered operable, based on the results of Abreu and Johnson (2005). The matrices are applicable to soil and groundwater and incorporate source concentration, depth to source, and separation distance. Derivation of these tables is presented in Appendix A. Mandatory criteria for the application of these distances are listed below the tables. Factors such as the presence of preferential pathways preclude the use of these tables and require an assessment of the indoor pathway up to a source to building separation distance of 30 m and potentially beyond, based on professional judgement (e.g., the possibility of significant transport via utility conduits entering the building).

Table 1 Pathway Operability – Soil Source

Soil Source Concentration (ppm)		**Separation Distance – horizontal or vertical (m) (source edge to building)**							
Benzene	**TPH_{TOTAL}**[1]	0	5	10	15	20	25	30	35
≤0.16	≤39								
>0.16 – 1	>39 – 100								
>1 – 10	>100 – 1,000								
>10 – 100	>1,000 – 10,000								
>100 – 1,000	>10,000 – 100,000								
>1,000	>100,000								

Notes:

1. Total TPH including toluene, ethyl benzene, and xylenes

Indicates pathway is not operable.

If any of the following features are present, Table 1 cannot be applied and the subsurface vapours to indoor air pathway must be assessed up to a separation distance of 30 m:

- Preferential pathways (e.g., utility conduits, coarse gravel seams);
- Landfill gas, migrating under pressure;
- Surface features that would block the flow of oxygen or prevent dissipation of vapours (e.g., impermeable cover);
- Mobile phase-separated petroleum hydrocarbons (free product);
- Expanding source zone; and
- Site conditions that do not conform to the default site conditions used to calculate the Tier I RBSLs.

Table 2 Pathway Operability – Groundwater Source

Groundwater Source Concentration (ppm)		Separation Distance – horizontal or vertical (m) (source edge to building)							
Benzene	**TPH_{TOTAL} [1]**	0	5	10	15	20	25	30	35
≤1	≤12								
>1 – 10	>12 – 100								
>10 – 100	>100 – 1,000								
>100 – 1,000	>1,000 – 10,000								
>1,000	>10,000 – 100,000								
N/A	>100,000								

Notes:

1. Total TPH including toluene, ethyl benzene, and xylenes

Indicates pathway is not operable.

If any of the following features are present, Table 2 cannot be applied and the subsurface vapours to indoor air pathway must be assessed up to a separation distance of 30 m:

- Preferential pathways (e.g., utility conduits, coarse gravel seams);
- Landfill gas, migrating under pressure;
- Surface features that would block the flow of oxygen or prevent dissipation of vapours (e.g., impermeable cover);
- Mobile phase-separated petroleum hydrocarbons (free product);
- Expanding source zone; and
- Site conditions that do not conform to the default site conditions used to calculate the Tier I RBSLs.

For the purposes of this guidance and the application of Tables 1 or 2, it is necessary to define the term “source”. The source is defined as the area of soil or groundwater impacts that exceed the applicable Tier II PSSLs for the indoor air pathway. If all soil and groundwater concentrations are less than the indoor air Tier II PSSLs, the indoor air pathway is not operable. It should be noted that by this definition soil and groundwater source areas may not be coincident and groundwater source areas may extend beyond the soil source area as a groundwater plume expands.

Application of Tables 1 and 2 to third-party properties requires the knowledge and informed consent of the third party property owner. Precluding factors listed in the table footnotes may not be fully characterized on the third-party property and/or may be changed by the owner in the future (e.g., locations of utility conduits). Exclusion of the indoor air pathway for a third-party, based on Table 1 or 2, may be considered a Conditional Closure and should be discussed with the Provincial Regulator.

3.0 SOIL VAPOUR MONITORING

3.1 Rationale for Phased Approach

Indoor air quality may be affected by the presence of chemicals that are unrelated to the subsurface contaminant source (e.g., consumer products, building materials, occupants' activities). Therefore, it is preferable to design the scope and methods to provide other lines of evidence and not rely on indoor air monitoring exclusively. In some cases, data from other lines of evidence may be sufficient to demonstrate that no significant subsurface vapour intrusion is occurring even without collecting any indoor air quality data. In such cases, the interpretive challenges associated with background sources or household interferences can be avoided.

Generally, it is preferable to conduct a phased investigation, beginning with an assessment of subsurface vapour concentrations near the known or suspected source of vapours. The source may be a primary source (e.g., release of petroleum hydrocarbons to the unsaturated zone near or below an occupied structure, with direct migration of vapours through unsaturated soil toward the building), or a secondary source (e.g. volatile chemicals dissolved in groundwater migrating away from a primary source, with subsequent off-gassing from the water table beneath an occupied structure at some locations downgradient from the source). It may be possible to demonstrate that subsurface concentrations attenuate below concentrations of potential concern at some distance from an occupied structure or to identify a limited area for indoor air quality investigations using soil vapour monitoring.

3.2 Conceptual Site Model

Prior to conducting soil vapour field investigations, an initial conceptual site model (CSM) is required. The CSM is a framework for interpreting the processes affecting the fate and transport of chemicals, and is required to categorize information in terms of the source, pathway and receptor. The CSM can be used as a guide to establish a scope for an initial phase of investigation and a logical plan for future directions, considering a range of possible outcomes. A CSM should be developed as early as possible in the process. Particular attention should be paid to conditions that might either prevent or exacerbate vapour intrusion, which will vary from site-to-site.

3.2.1 Minimum Requirements of a Conceptual Site Model

The development of a CSM can vary greatly in complexity, however, a fundamental understanding is required of certain site features. The CSM should clearly describe

important features of the source area, site geology and hydrogeology, building characteristics, and preferential pathways. To develop the CSM, it is necessary to review all available site information pertinent to an evaluation of the vapours to indoor air pathway, including at a minimum:

- Phase II and III environmental site assessment (ESA) reports; and
- Building design, including construction features and mechanical systems.

ESAs should conform to the *Minimum Requirements and Reference Guidelines for Environmental Assessments of Petroleum Impacted Sites in Atlantic Canada* provided in Appendix 2 of the Atlantic RBCA User Guidance, version 2.0 (2003). Table 3 highlights the minimum requirements of a CSM for the subsurface vapours to indoor air pathway.

Table 3 Minimum Requirements of a Conceptual Site Model

Source Area Characteristics
• A description of the types of petroleum products previously or currently handled or stored on the site. For sites where the scope of work is limited to a specifically identified release (e.g., fuel oil spill) follow applicable Provincial management process requirements. • A description of the petroleum hydrocarbon constituents present in soil and groundwater, including their concentrations and physico-chemical properties (e.g., Henry's Law constant). • An evaluation and reporting on the presence/absence of phase-separated liquid hydrocarbons (free product). • A discussion of the lateral and vertical dimensions and the extent of contamination delineated at the site. • A discussion of the predicted source stability (e.g., presence of free product may result in an expanding source; groundwater plumes may be characterized as expanding, stable, or shrinking based on time-series data).
Subsurface Characteristics
• Vadose zone soil stratigraphy, including layering. • Hydrogeological information including depth to the water table, anticipated or measured seasonal fluctuations, and flow direction. • A discussion of the presence of perched water tables or low permeability layers that may impact vapour migration. • The distance from source to nearest building. • The identification and evaluation of natural or man-made preferential pathways that may impact vapour migration.

Table 3 Minimum Requirements of a Conceptual Site Model

Building Characteristics
• Size, location, and type.
• A description of construction features including age, basement or slab on grade, foundation cracks, sumps.
• A description of heating systems (e.g., forced air furnaces, baseboard heaters).
• A description of mechanical systems (e.g., HVAC) and appliances.

Appendix B provides a summary checklist of required information for development of a CSM for the vapours to indoor air pathway.

3.2.2 Soil Vapour Sampling Depth

As indicated in Figure 2, subsurface vapour sources less than 1 m below the building foundation (greater than 1 m below grade for buildings with a basement) should be assessed by sub-slab and/or indoor air monitoring rather than by soil vapour monitoring. At depths < 1 m, there is the possibility of having contamination in direct contact with the basement (e.g., sumps, capillary rise) and at very shallow depths the Johnson & Ettinger model has been shown to become less reliable. For these reasons, soil vapour to indoor air dilution factors are not provided for soil vapour sources present at depths of less than 1 m. It may be desirable to conduct indoor air monitoring concurrently with sub-slab monitoring in these situations.

Recent research (Abreu, 2006) indicates that deeper soil gas samples are less likely to result in a false negative screening (failing to identify unacceptable risk) than shallow samples. Deeper soil gas samples collected close to the water table yield more reliable predictions. However, it is not possible to prescribe one required sampling depth or stipulate a minimum depth, as site assessments must take into account site-specific conditions. For instance, although recent research indicates reliable results from vapour probes installed 3 m below the bottom of a building foundation, any approach must account for shallower water tables or bedrock surfaces. Recommended approaches for determining appropriate soil vapour sampling depths based on varying source depths are outlined in Table 4. Emphasis is placed on having a complete CSM for the site. Site Professionals must complete an adequate ESA to characterize factors such as water table depth and expected seasonal fluctuations, and building construction, prior to initiating a soil vapour sampling program.

Table 4 Recommended Soil Vapour Sampling Depths (m)

Depth to Top of Source (m)[1]	Recommended Approach
<1	Soil vapour sampling not recommended. Site Professional should proceed directly to sub-slab and/or indoor air monitoring.
>1 – 5	Screened interval of vapour probe must be located greater than halfway from the bottom of the building foundation to the top of the vapour source or the water table. For instance, at a source depth of 3 m below the building foundation, the vapour probe must be installed greater than 1.5 m below the bottom of the building foundation. Vapour probes should be installed as close above the top of the capillary zone as is practicable, though care should be exercised not to place the probe through the capillary transition zone.
>5	Screened interval of vapour probe must be located greater than halfway from the bottom of the building foundation to the top of the vapour source or the water table, up to a maximum depth of 5 m. For instance, at a source depth of 7 m below the building foundation, the vapour probe must be installed greater than 3.5 m below the bottom of the building foundation.

Notes:

1. Depth from bottom of building foundation to top of contamination source or water table.

3.2.3 Other Considerations

In addition to the mandatory requirements listed above, there are many other aspects of vapour migration and intrusion that may be useful to evaluate depending on site-specific circumstances. Site Professional judgement is required to determine the importance of each factor at a specific site. For example:

- If the compounds of concern are aerobically degradable, focus may be given to characterizing the distribution of oxygen and carbon dioxide in the subsurface together with the hydrocarbon vapours of concern. Areas of oxygen depletion may have less bio-attenuation and therefore could be selected as areas to focus on for data collection to assess worst-case conditions.

- If the building has rooftop heating, ventilating and air conditioning (HVAC) units, it may be beneficial to assess the pressure differential between indoor air and sub-slab soil gas using digital micromanometers with data loggers. The ASTM Standard for radon mitigation systems specifies a pressure differential of 6 to 9 pascals as sufficient to curtail subsurface vapour intrusion, and HVAC units may produce this level of positive pressure within the building, which would block the pathway.

- If recharge via infiltration is high and groundwater is the suspected source of vapours, a fresh-water lens (shallow groundwater with no petroleum hydrocarbons) may develop with increasing distance from the source, and act as a barrier to off-gassing from the water table to soil gas. If so, field work may focus on vertical profiling of deep soil gas and shallow groundwater concentrations.

- If occupants report noticeable petroleum odours, the situation should be treated as a priority. Mitigative actions may include proactive indoor air quality monitoring, interim ventilation or filtration, or proactive sub-slab venting system installation and monitoring.

- If further assessment indicates a potential acute health risk, Site Professionals must advise the temporary relocation of the occupants and notify the Responsible Party and regulatory authorities immediately.

The diversity of these factors for consideration is such that each phase of investigation could produce results that necessitate a change in the strategy or sequencing of events. Therefore, it is important to take the time to consider possible outcomes in advance and be prepared to respond appropriately. Each data collection activity could result in an interpretation that supports or refutes vapour intrusion, or a result that is not certain either way. The decision framework should consider each possibility and plan an appropriate response in advance.

3.3 Work Plan Preparation

The strategy for a site-specific assessment should consider a series of factors and should be carefully planned in advance. For example, a soil vapour monitoring program may have to consider the following:

- Quality Assurance/Quality Control (QA/QC) samples;
- Analyte lists;
- Detection limits;
- Sampling and analytical methods;
- Sample locations, durations, and frequency;
- Security; and
- Other issues that most environmental scientists will be aware of from site-assessments of soil and groundwater quality.

It is usually advisable to develop a Work Plan to ensure that all these issues are addressed. Included in the Work Plan should be some consideration as to how the data will be interpreted. For example:

- How much data is enough to assess spatial and temporal variability?
- What is the target concentration for each of the known or suspected compounds of potential concern?
- Will there be a threshold above which an interim action will be required?
- What if only one of many samples exceeds the target concentration?
- If concentrations are all below target levels (Reference Concentrations or Risk Specific Concentrations), will further confirmation be required?

The Work Plan should be shared with other stakeholders, which may include regulatory agencies, public interest groups, building occupants and owners, for their review and approval in advance.

3.4 Sampling Strategy

Subsurface vapour sampling and analysis should generally be performed before any indoor air sampling and analysis when assessing the potential for subsurface vapour intrusion. Programs can be designed to provide some or all of the following information, as required:

- Soil vapour concentrations, which can be multiplied by measured, modeled, or generic dilution factors (DFs) to provide an estimation of indoor air concentrations needed to assess potential human health risk;

- A list of chemicals of potential concern, based on comparison between measured soil vapour concentrations and risk-based target concentrations;

- Evidence of hydrocarbon vapour biodegradation through analysis of transects or vertical profiles of hydrocarbon, O_2 and CO_2 concentrations;

- Assessment of the partitioning of chemicals between groundwater and soil vapour through comparison of concentrations in shallow groundwater and co-located deep soil vapour samples, and;

- Physical data regarding soil texture, moisture content, soil gas permeability, pressure gradients, or other factors that can be used to improve understanding of the

mechanisms controlling soil vapour migration and to provide input to mathematical model calculations.

3.5 Sampling Design Considerations

Most often, the early phase(s) of a site-specific assessment should focus on characterizing soil gas concentrations in proximity to the known or suspected sources of vapours. Source area investigations should generally be designed to provide basic information regarding the compounds present, their relative concentrations, possible presence (and distribution, if possible) of free product, and temporal variability through periodic monitoring in select locations. If such a survey identifies concentrations of potential concern, additional phases may be required to delineate the extent of vapours at concentrations of potential concern.

If source area concentrations are too low to pose a potential concern for indoor air quality, the scope of any further phases or confirmatory monitoring can be curtailed. In accordance with the process highlighted in Figure 2, soil vapour concentrations of concern are defined as concentrations exceeding their Reference Concentrations (RfCs) (non-carcinogens) or Risk Specific Concentrations (RSCs) (carcinogens).

3.5.1 Spatial and Temporal Variations

Soil vapour concentrations vary spatially and temporally, which will need to be considered in the selection of the number, locations, and frequency of soil gas sampling surveys. In particular, there can be significant attenuation of vapour concentrations over short distances as a result of aerobic biodegradation of hydrocarbon vapours or variation in soil moisture content. Soil vapour concentrations may vary by a factor of 10 to 100 between probes situated on either side of relatively small buildings (i.e., houses) (e.g., Sanders and Hers, 2006; DiGiulio, 2003). For large groundwater plumes, a soil gas probe spacing of several tens of meters may be adequate. For smaller plumes and areas where there is a rapid decline in concentrations, more closely spaced probes are warranted (e.g., 15 m to 20 m, or the spacing of a residential lot).

There can be temporal variations in soil vapour concentrations as a result of seasonal precipitation and barometric pressure fluctuations, and variations in temperature. Soil gas sampling should be avoided during and after heavy rain. The time for moisture to drain from soil pores will depend on the soil type. Coarse-grained soil (sand or gravel) will drain to field capacity within a few hours while fine-grained soil will take longer to drain. Field capacity is the soil water content after water drainage by the force of gravity is mostly complete.

Barometric pressure changes could have a significant influence on shallow soil vapour concentrations when there are thick coarse-grained unsaturated zones. A conservative approach would be to sample probes when the barometric pressure is decreasing. However, it is generally not practical to schedule soil gas programs to target the desired barometric pressure. Barometric pressure data for several days before and after sampling should be obtained from the nearest weather station, or recorded with a barometer with data-logging capabilities and included with the soil vapour monitoring results.

Frost cover can reduce soil gas flux through ground surface and could affect subsurface soil vapour concentrations. Consideration should be given to repeat sampling when frost cover is not present.

Based on an evaluation of the above variability, multiple samples from different locations on a site may need to be tested. Depending on the site conditions and initial results, repeat testing over different time periods (i.e., seasonal) may also be warranted, in which case, it is usually best to avoid using temporary probes. In addition, a phased sampling program may be needed to meet the site characterization objectives. For example, soil gas characterization will typically start with testing of soil gas samples collected in close proximity to the contamination source. If source vapour concentrations are above levels of potential concern, next steps could include collection of soil gas samples closer to the building (laterally and/or vertically) or collection of sub-slab soil gas samples.

3.5.2 Vertical and Lateral Variations

The soil gas sampling design may employ transects or vertical profiles to characterize spatial variation in concentrations. Transects are used when the contamination source is laterally removed from the building. Generally, a minimum of three samples should be used as part of a transect, consisting of soil gas samples from (i) the edge of the contamination source nearest to the building, (ii) mid-point between the source and building, and (iii) the edge of the building.

Vertical profiles are used when the contamination source is below the building or at a sufficient depth to warrant vertical profiles. Again, three or more samples should be obtained from (i) just above the contamination source, (ii) mid-point between upper and lower sampling point, and (iii) sampling point located near the foundation of the building. Since there is a tension-saturated zone above the water table (capillary fringe), it is not possible to obtain a vapour sample from within the tension-saturated zone. Based on theoretical considerations, and allowing for fluctuations in the water table, soil gas probes should generally be installed about 0.5 m to 1 m above the water table.

Vertical profiling of soil gas concentrations is often valuable to assess the linkages from deep soil gas to shallow soil gas to sub-slab soil gas, along with profiles of O_2, CO_2, moisture content, and texture or soil gas permeability, especially where there may be low permeability layers or active degradation in the vadose zone. These data are also valuable for refining the mathematical model, which should initially be conducted with conservative estimates of input parameters.

3.5.3 Biodegradation Assessment

In cases where the Site Professional considers that the default dilution factors are overly conservative and that biodegradation is likely a significant site-specific process, he/she has the option to conduct a site-specific biodegradation assessment. In these cases, more detailed monitoring of soil gas may be warranted to evaluate the biodegradation of petroleum hydrocarbon vapours and whether the subsurface vapours to indoor air pathway is complete (i.e., are hydrocarbon vapours biodegraded to negligible concentrations before reaching the building).

The recommended first-phase biodegradation assessment consists of sampling of vertical profiles beneath or adjacent to the buildings of potential concern. The building floor may inhibit oxygen transport to the subsurface; therefore, the probes should be situated below a surface cover of similar permeability and size to that of the building (concrete or asphalt of reasonable quality). The shallowest probe should coincide with the base of the building foundation or, for slab-on-grade buildings be at least 1 m below ground surface and located beside the building. The deepest probe should be close to the contamination source. One or more intermediate probes are advisable, depending on the distance between the source and the building.

Soil gas samples should be tested for the hydrocarbon vapours of potential concern, and as a minimum, for oxygen, carbon dioxide and methane. Landfill gas meters can provide all three measurements. These gases provide an indication of microbial activity occurring through aerobic or anaerobic processes. It should be noted that the results may show considerable variability from site to site (Roggemans et. al., 2001). Certain hydrocarbon compounds (e.g., cyclohexane and 2,2,4-trimethylpentane) are more volatile than the BTEX compounds, and potentially less biodegradable, so these compounds may serve as useful tracers for hydrocarbon vapour transport (Sanders and Hers, 2004).

3.5.4 Future Conditions

If the objective of the assessment is to predict exposure under future conditions, the soil gas sampling design should consider how land use changes will affect soil gas

measurements and data interpretation. Changes to surface conditions (i.e. construction of buildings) would tend to have the greatest potential effect on shallow vapour concentrations and the least effect on vapour concentrations near the contamination source. Therefore, it is recommended that soil gas characterization programs for the future use scenario focus on sampling of deep soil vapour.

3.6 Field Methods

This section describes the key considerations for site-specific sampling and analysis to evaluate subsurface vapour intrusion to indoor air. Site-specific conditions may vary, so the field methods may not be identical at all sites. This section provides some theory to assist the Site Professional in making appropriate site-specific modifications to their field program. Recommended approaches are also described, which are likely to be appropriate in most cases.

3.6.1 Minimum Requirements of a Field Program

Despite the variation in possible approaches to soil vapour field programs (e.g., soil gas probes can be constructed from a variety of materials and installed by a variety of techniques), there are certain minimum requirements for the collection of representative soil gas samples.

Table 5 Minimum Requirements of a Soil Vapour Field Program

Probe Construction

• Probes must be constructed of inert materials (non-sorptive and non-reactive).
  ➢ Stainless steel, PVC, nylon, and HDPE are approved materials for probe construction and sampling train equipment.
  ➢ Tygon, neoprene, rubber, latex, or other soft tubing is not to be used.
  ➢ Adhesives must not be used on any fittings. Teflon tape is recommended on threaded joints to prevent air leakage.
• There must be a reliable seal to prevent leakage of atmospheric air or soil gas along the annulus between the probe and the geologic or building materials.
  ➢ Use of granular bentonite, hydrated during installation is preferred.
• A sand pack must be installed around the screened interval, similar to a groundwater monitoring well.
  ➢ Installation methods should ensure that there is no bridging of the sand pack.
  ➢ Bentonite seals should be placed directly above each sand pack.
• The probe must remain sealed between monitoring events.

Table 5 Minimum Requirements of a Soil Vapour Field Program

Sampling Techniques

• Equilibration of soil gas must be permitted after probe installation and prior to sampling.
  ➢ Atmospheric air entrained during installation should be purged as soon as practical after installation.
• Probes must be purged of standing air prior to sampling.
  ➢ A minimum of 3 volumes (probe plus sample train tubing) should be purged.
  ➢ Typically, no more than 5 volumes are required to achieve consistent results.
  ➢ Purge rate should be constrained to maintain a vacuum less than approximately 10" of water column. The rate will vary depending on the permeability of the soil.
  ➢ Purge rates should be in the same range as the subsequent sampling rate.
• Sampling rates will most likely be in the range of 1L/hour – 1L/min and may require sampling periods up to 8 hours (e.g., commercial) or possibly up to 24 hours (e.g., residential), depending on the sampling device.
• Sample collection devices (e.g., Summa™) and analytical methods must be capable of achieving the required detection limits.

3.6.2 Soil Gas Probe Design and Installation

Several options are described below to provide the Site Professional with alternatives to accommodate site-specific conditions and constraints.

3.6.2.1 Permanent Probes Installed in Boreholes

Permanent probes are installed in a similar fashion to monitoring wells; however, there are important differences in design. Generally short screens (0.15 to 0.3 m length) should be used for probes since typically the objective is to characterize local soil gas concentrations. It may also be appropriate to select a screened interval as a proportion of the thickness of the unsaturated zone (i.e. 0.3 m screen for a 3 m thick unsaturated zone is comparable to 1 m long screens in a 10 m thick unsaturated zone, both providing resolution of 10% of the unsaturated zone thickness). The screened portion of the probe can consist of slotted PVC pipe, steel-mesh screen, or holes drilled through inert tubing. The diameter of the probe should be relatively small (e.g. nominal 1-inch to ¼ inch) to minimize the volume of air needed to purge the probe and to minimize the surface area for adsorption of VOCs on probe surfaces. Smaller diameters may be appropriate where very discrete vertical profiling is required; however, smaller diameters also impose line-losses and reduce the utility of the probes for pneumatic testing, which may require flow rates greater than those typically used for purging and sampling. Probes may be constructed of pipe or tubing (appropriate materials for probe construction are described in Section 3.6.2.5, below). Where pipe is used, the joints should be threaded, and the threads wrapped with Teflon tape to prevent leaks.

Coarse sand or fine gravel should be placed surrounding the screened portion of the probe, and a bentonite seal should be constructed above the screened portion of the probe. The Site Professional should employ an appropriate method for installing a bentonite seal that will not leak. One effective method for making a seal is to pour dry "granular bentonite" down the annulus between the probe and the drill stem or rods to rest on top of the sand filter pack in a lift of a few centimeters thickness, followed by a few hundred millilitres of water. Bentonite chips or pellets will not hydrate before the water drains away, while powdered bentonite may bridge in the annulus between the probe and the casing, augers, or soil. "Granular bentonite" has a texture much like the sand used for a filter-pack, so it will settle effectively within the borehole, and will hydrate instantaneously. Two or three lifts of granular bentonite and water is usually sufficient to form a competent seal. The remainder of the borehole annulus can be filled with a slurry of powdered bentonite and water, pre-mixed above ground to a thick consistency, and poured into the borehole annulus. It is generally advisable to finish the installation with a secure or locking cover to prevent damage or tampering.

If multiple probes are installed in a single borehole, the borehole above and below each probe should be sealed with granular bentonite and water. If the sealed interval is a meter or less, several lifts of granular bentonite and water may be sufficient to seal the interval between multi-level probes. If longer seals are required, it may be better to mix a slurry of powdered bentonite and water, with bentonite chips added for structural support, so that the overlying granular bentonite and water bridge and the filter pack does not cave into the slurry below.

After allowing seals to set overnight, the competence of multi-level seals should be confirmed by drawing a vacuum on each probe in succession and monitoring the vacuum in the overlying and underlying probes. A leaky seal will be indicated by an instantaneous transmission of vacuum from one probe to the next. If the seal is competent, vacuum may still develop in the monitored probe, but it will develop slowly, and will not approach the same magnitude as the vacuum exerted on the pumped probe.

The top of the soil gas probe must be finished with an air-tight valve, and should be completed with a locking protective casing for security and weatherproofing. If multi-level probes are used, each probe should be tagged with a permanent label, using no glues, or markers.

Potential advantages of permanent probes installed in boreholes are that deep probes can be installed in various geologic layers. In addition, the filter pack that surrounds the screen provides for more open area for drawing a soil gas sample than a driven probe. A potential disadvantage of probes installed in boreholes may be drill-rig access restrictions.

Soil samples should be collected during drilling of boreholes for soil gas probes. While soil sampling protocols go beyond the scope of this section, the soil lithology should be visually logged, with selected samples collected for laboratory testing of relevant soil properties, including at a minimum moisture content and grain size distribution for each representative soil horizon.

3.6.2.2 Permanent Probes Installed Using Direct Push Technology

Direct-push techniques can be used to install a single soil gas implant at a single location. Vertical profile data can be collected by installing multiple probes to various depths in locations immediately adjacent to one another. Direct push rods are pushed to the desired depth, and implants are installed after the desired depth is reached by lowering the implant down the hollow rods and attaching it to a detachable anchor drive point. A sand pack and seal should always be installed through the push rods as they are removed and the position of the filter pack and seal should be confirmed using a tamping rod. Natural collapse of the formation around the probes should never be relied on to create a competent seal.

The presence of gravel or cobbles may hinder or preclude the use of direct-push technology. Direct-push technology should not be used in low-permeability soils, because the risk of annular leakage of atmospheric air is significantly greater than in high-permeability materials where the geologic media impose little resistance to soil gas flow. Where geologic conditions are not known in advance the probes should be designed to include annular seals, as described above.

There is also direct push equipment that enables collection of multiple depth samples during a single push where soil gas samples are collected through a screen located within a retractable protective sleeve. This method is not recommended, because if a zone of high concentrations, or NAPL is encountered, deeper samples will likely be positively biased, and the magnitude of the bias will be unpredictable.

3.6.2.3 Driven Probes

Driven probes in their simplest form are hollow steel rods or pipes with an internal diameter typically ranging between 12.5 and 25 mm (sometimes referred to as ground probes). The probes can be driven by hand, or with the aid of direct-push equipped vehicles. The rods typically include a loosely fitting conical tip that dislodges after the probe is driven slightly beyond the desired depth and withdrawn slightly. Several holes may also be drilled near the tip of the probe to increase the open area through which soil gas is drawn into the probe. Driven probes are often temporary installations in that the probe is removed after the soil gas sample is obtained.

Driven probes may be advantageous in terms of flexibility of installation and cost; however, they can be difficult to install in over-consolidated or coarse-grained soils, especially at greater depths. Driven probes should only be used where there is advance knowledge that the permeability of the subsurface material is high enough to allow a soil gas sample to be collected easily (i.e. flow rates > 100 mL/min) with minimal vacuum (<0.1-inch of water column), because it is difficult to ensure the absence of annular leakage, which is more likely to become a path of least resistance in low permeability soils.

3.6.2.4 Use of Water Table Monitoring Wells as Soil Gas Probes

Shallow groundwater monitoring wells with screened intervals that extend both above and below the water table can be used for soil gas sampling by drawing a modest vacuum on the well. However, there are potential sources of error with this approach and it is recommended primarily as a screening method. For instance, studies have shown vapour concentrations in well headspace were elevated compared to soil vapour concentrations collected from above the capillary zone in adjacent soil vapour probes. Attenuation across the capillary transition zone is best measured in dedicated soil gas probes. Other factors that require careful sampling design and approach are described below.

Care is needed to ensure that the vacuum does not cause up-coning of the water level within the well to a height above the top of the well screen, which will depend on the permeability of the geologic materials and the length of the well screen above the water table. The contribution of vapours from the standing water column within the lower part of the well screen will be minimal, providing several casing volumes (volume of air within the well casing above the water table) of soil gas are purged prior to sample collection, and the purging and sampling procedure is done expeditiously (i.e. over a period of less than an hour). Groundwater monitoring wells typically have larger diameter than soil gas probes, so the casing volume is generally larger; therefore, purge rates of several litres per minute may be required, and an appropriate sized sampling pump is needed for this approach. Groundwater monitoring wells typically have vented caps, so a retrofit will be required to cap the well with an air-tight cap and valve. In some case, the length of the well screen above the water table may be too long to provide the appropriate level of vertical discretization, so this method is not always applicable.

Soil gas data collected by this method are ideal for assessing whether a fresh-water lens is present, because the method provides soil gas samples from the deep portion of the vadose zone. The measured soil gas concentrations can then be compared to the soil gas concentrations that would be calculated by multiplying the groundwater concentrations by the Henry's Law Constant. If the measured concentrations are

substantially lower than the calculated values, this indicates that there is some resistance to off-gassing from groundwater, which may be a significant attenuation mechanism.

3.6.2.5 Probe Materials

Relatively inert and non-porous materials are preferred for soil gas sampling. While probes constructed of stainless steel are desirable, based on practical considerations, polyvinyl chloride (PVC) probes are often installed. There is little quantitative information on the best type of sample tubing to use. Teflon is sometimes cited as the plastic of choice, but others indicate that Teflon is porous and is a poor choice of tubing material for vapour sampling (Kreamer, 2001). Some practitioners indicate that nylon and high-density polyethylene (HDPE) have reasonable sorption characteristics compared to other types of plastic. Glue, tape or other materials that could emit volatiles should not be used as part of probe construction. Tygon, neoprene, rubber, latex, or other soft tubing materials should never be used because they will allow sorption and desorption to affect sample integrity. The most inert plastics are very rigid, therefore compression fittings generally provide the best seals at points of connection. Barbed fittings are difficult to handle with rigid tubing, but generally provide good seals when the tubing extends over at least 2 barbs and vacuum levels are low (<10" H_2O).

3.6.2.6 Short-Circuiting Considerations

Short-circuiting of atmospheric air to the probe can result between the probe and soil, and leakage of soil gas and/or atmospheric air can occur at probe joints. Prevention of short-circuiting and leaks is particularly important for low permeability soil deposits. Leak testing is generally good practice, and should be performed at least once to test the seals preventing short-circuiting of atmospheric air into soil gas probes, and at least once on the apparatus used for collecting a sample. Shut-in tests and tracers are appropriate methods, described in Section 3.6.3.4, below.

3.6.3 Soil Gas Sampling Procedures

The steps in soil gas sampling procedures are described in detail below. Procedures address soil gas equilibration; sampling containers; decontamination; methods to detect leaks and short-circuiting; and purging and sampling. The methods used should be documented throughout the sampling process, particularly any modifications to accommodate site-specific conditions. Additional information regarding sampling procedures is provided by API, 2005. The ASTM guide for soil gas sampling (ASTM, 1992) is valuable for mapping areas of high concentration, but was not designed for the

low-level concentrations that must be characterized for assessing subsurface vapour intrusion.

3.6.3.1 Soil Gas Equilibration

Soil gas should be allowed to equilibrate after probes are installed prior to sampling. The time required for equilibration will depend on the disturbance caused during installation and the extent of purging after installation. The least disturbance is caused by driven probes, or probes installed using direct-push technology. Moderate disturbance is caused by auger drilling while the greatest disturbance is caused by air rotary drilling, since air is introduced into the formation during drilling. For driven probes or probes installed in auger boreholes, purging after installation will usually be sufficient to remove air entrained during installation.

Mud rotary and water rotary methods cannot be used for soil vapour probes because the water pressure causes a thin slurry to flow out into the formation, partially sealing fractures and pores. Air rotary drilling is only recommended where geologic materials cannot be penetrated using augers and where known or suspected free product is absent. For probes installed using air rotary drilling, several weeks are recommended for equilibration of soil vapour concentrations prior to initial sampling. Repeat monitoring should be conducted several weeks after the first sampling to evaluate whether soil vapour concentrations surrounding the probe have recovered. Otherwise (or additionally), a tracer (e.g. He) may be added to the drill air and monitored during probe development and purging until it is removed.

3.6.3.2 Sampling Container or Device

The selection of a collection device is influenced by analytical requirements. For example, samples for laboratory analysis should generally be obtained using Summa™ canisters or sorbent tubes. Glass cylinders or Tedlar™ bags may be appropriate for light gas analysis (oxygen, carbon dioxide, methane), especially when a field instrument is used for analysis and the sampling holding time is therefore very short. Summa™ canisters or sorbent tubes are preferred for laboratory analysis. Gas-tight syringes are often used for on-site analysis using mobile laboratories. Procedures and issues associated with different sampling containers are described below:

Stainless Steel or Glass-lined Canisters, including Summa™ Canisters

Summa™ canisters are readily available in volumes ranging from 400 ml to 6 litres. Summa™ canisters are cleaned and evacuated in the laboratory before shipping. Prior to sample collection, the secure cap is removed and a vacuum gauge attached to

confirm that the vacuum has not dissipated, which would indicate leakage during shipment. The vacuum gauge is then removed and a flow controller is attached, calibrated for a flow-rate inversely proportional to the intended sample duration in order for the canister to fill gradually over the duration of the sampling period. At the end of the sampling event, the valve is closed, the flow controller removed and the vacuum upon completion is also recorded. There should be a small, but measurable residual vacuum; otherwise, the sample would not represent the entire planned sampling interval. The laboratory confirms the residual vacuum prior to analysis to confirm the absence of leakage during return shipping. For a grab sample of soil gas, it may not be necessary to use a flow controller or retain a residual vacuum, however, there is a risk of drawing pore water into the canister if there is no flow controller.

Sorbent Tubes

There are a wide range of sorbent media available, which must be carefully selected in consultation with the analytical chemist based on the types and concentrations of volatile chemicals expected in soil gas and desired detection limits. Sorbent tube samples are collected by connecting the tube to a sampling pump and drawing a steady flow of air through the tube for a specified period. A second tube is often placed in series to assess whether there is any breakthrough past the first tube.

For sorbent tubes, it is recommended that samples be collected in duplicate for two reasons: the analysis is destructive and any re-analysis that may be required can only be done if a second tube is available; and in some cases the pumps used to draw air through the tubes may fail, so a second sample is a good fail-safe. Duplicate samples may be collected using two pumps, each fitted with sorbent tubes, or using one pump connected to a splitter, although the latter requires either an assumption that both sets of sorbent tubes impose essentially identical resistance to flow or confirmatory flow measurements on both tubes. Subsequent chemical analysis measures the mass of chemical trapped on the tube. The air concentration is calculated by dividing the mass by the total volume of air drawn through the tube. The sampling flow rate and duration will depend on a number of factors including the expected soil vapour concentrations, chemical type, sorbent type, and desired detection limit.

For instance, the Risk Specific Concentration of benzene at a 1 in 100,000 risk level is 3µg/m^3 and a typical benzene detection limit on a charcoal tube is 0.4 µg. In order to achieve a detection limit < 3 µg/m^3, approximately 140 L of air would have to be drawn through the tube ((0.4 µg / 140 L) x 1,000 L/m^3) = 2.9 µg/m^3. At a flow rate of 200mL/min, the required sampling period would be approximately twelve hours, so this method may not be practical for low-permeability materials or low concentration soil gases.

Sampling pumps for this method are designed to provide steady flow rates, and often have built-in rotameter-style flow meters. In some cases, the flow rate may not remain constant (due to plugging of the tube with air-borne particulates, battery failure on the pump, etc.). Therefore, it is critical to record the flow rate at the beginning and end of the sampling event, and where the two are not the same, it may not be possible to accurately quantify concentrations.

Glass Cylinders

Glass cylinders are available in a range of volumes; typically a 0.5 to 1 litre cylinder is used for soil gas sampling. The glass cylinder has two stop-cocks and is placed in-line between the probe and pump during purging. Glass cylinders are typically supplied by the analytical laboratory filled with high-purity nitrogen at atmospheric pressure. Once purging of the probe is complete, the sample is captured by simultaneously closing both stopcocks. Glass cylinders should be analyzed within 24 and 48 hours.

Tedlar™ Bags

Tedlar™ bags are available in volumes ranging from 10 ml to 10 litre; typically a 0.5 to 3 litre bag is used for soil gas sampling. The Tedlar™ bag may be filled from the effluent of a pump when collecting samples for O_2, CO_2 and N_2, or for coarse screening of total VOCs in areas of relatively high concentrations (>100 ppmv). When assessing lower level concentrations, the Tedlar™ bag should be filled using a lung box or vacuum chamber. A new and dedicated section of inert tubing is used to connect the Tedlar™ bag to the valve at the top of the soil gas probe through the wall of the lung box. The box is then sealed and a pump is used to evacuate the space inside the box and outside the Tedlar™ bag. This creates suction on the bag, which draws soil gas out of the probe and into the bag without risk of cross-contamination that may occur via sorption/desoprtion within a pump. Once the bag fills, the valve at the head of the soil gas probe is closed, the vacuum in the box is relieved, and the box is opened to remove the filled bag.

Tedlar™ bag samples should be analyzed as quickly as possible, typically within 24 to 48 hours (using appropriate air-tight fittings). Tedlar™ bags are ideal for field screening with portable instruments during purging, regardless of whether another container may ultimately be used for collecting a sample for laboratory analysis. A filled Tedlar™ bag can also be connected to a Summa™ canister to allow transfer of the sample to a container that allows a longer holding time (up to two weeks), in which case the bag contents can also be screened with field instruments to provide both field and lab data on exactly the same sample of gas.

Gas-Tight Syringes

Gas-tight syringes are typically used for on-site analysis only when there is a portable analytical laboratory on site. Typically, samples are analyzed within a short time (i.e., 30 minutes) of sample collection.

3.6.3.3 Decontamination of Sampling Equipment

Clean equipment and sample containers should be used for soil gas sampling. This can be implemented through decontamination of equipment or through the use of new, unused equipment. Care should also be taken when handling, since sampling equipment could be contaminated through dirty containers, hands, vehicle exhaust, etc. The level of decontamination may depend on the objectives of the soil gas survey and detection limits for analytical testing. For field screening, simple flushing may be sufficient; however for laboratory analysis, the use of new materials is generally recommended, or equipment blank samples should be added to the analysis.

If the soil gas survey methods involve re-use of soil gas probes, tubing and/or sampling containers (e.g., Tedlar™ bags); prior to each use, a field blank sample comprised of ambient air should be collected through the entire sampling train and tested using the field PID or FID. If concentrations in the field blank are higher than direct readings of ambient air, the equipment should be cleaned or new equipment should be used.

3.6.3.4 Testing of Equipment for Leaks and Short Circuiting

The annular seal between a probe and the surrounding material can be tested by constructing a shroud around the ground surface at the top of the probe and filling it with a tracer gas (e.g. He). A tube is connected through the shroud to the top of the soil gas probe and a pump. The pump is used to draw soil gas into a Tedlar™ bag, which is then screened for the concentration of He. Portable helium meters are capable of reading from 100% to 0.01% He, so they provide ample resolution of any leak of atmospheric air that may be occurring. If the He contribution is very small (<1% of the shroud concentration), any leakage may be negligible, but if the He concentration is more than 10%, the probe should be replaced. In between, the He data can be used to make a correction using mass balance principals.

Leaks in the sampling train fittings can be tested in two practical ways. In the first method, the pump used to draw a vacuum would simply be reversed to create positive pressure, and a soapy water solution poured on connections where a leak might occur. Soap bubbles will form if air is leaking. In the second method (API, 2005), a Tedlar™ bag is filled with a known concentration of a gas (e.g. use the span-gas for the PID or

FID being used for monitoring the progress of purging), and a valve is connected to its opening. The valve is closed until the vacuum in the sampling train roughly matches the vacuum encountered when drawing soil gas from a probe (simulating resistance to flow imposed by soil gas permeability), at which time a sample is collected. If the sample collected from this apparatus has the same concentration as the source gas, this would indicate the absence of leaks. Otherwise the fittings should be tested individually using pressure and soapy water until the leak is located and corrected.

Potential short-circuiting of atmospheric air during sampling can also be indirectly evaluated through careful examination of oxygen and carbon dioxide data. For example, if oxygen concentrations at a probe installed within a petroleum hydrocarbon source zone are at atmospheric levels, further investigation should be conducted to determine if the soil gas sample was representative. If O_2 concentrations are initially low, but increase during purging, this may also indicate a leak.

3.6.3.5 Soil Gas Probe Purging and Sampling

The purpose of purging is to remove stagnant air from the probe and filter pack to ensure that the subsequent sample is representative of soil vapours in the geologic material surrounding the sampling interval. The number of recommended purge volumes in the literature varies between 1 and 5 dead volumes (Hartman 2002; Cody, 2003, CSDDEH 2002). Cody (2003) evaluated purge volumes on the basis of a differential equation for the sequential and complete mixing of VOCs over each time step within the entire volume under consideration (probe and tubing). On the basis of this equation, the estimated concentration within the probe volume reaches 90 percent of the input concentration after purging about three volumes. For narrow diameter tubing, fewer purge volumes are likely needed to obtain a representative sample due to reduced mixing resulting from a “plug flow” phenomenon.

Larger purging volumes draw soil gas from greater distances from the screen of the soil gas probe. This may be undesirable, because it may upset the local conditions temporarily. It may also be desirable, because it provides an indication of conditions beyond the immediate proximity of the soil gas probe and therefore yields an integrated average sample of a larger volume of the subsurface. If volatile organic compound (VOC) concentrations (indicated by FID or PID readings) increase as soil gas purging proceeds, this would indicate the presence of higher concentrations at some distance from the soil gas probe. If VOC concentrations remain consistent, this would indicate that spatial variability is minimal. If VOC concentrations decrease, with no corresponding change in O_2 or CO_2 readings, this would indicate the probe location provides a conservative estimate of soil gas quality. If O_2 and CO_2 readings change toward atmospheric levels, this would indicate that the volume of soil gas purged was

sufficient to draw in atmospheric air. In this case, the test should be terminated and any interpretation should be limited to the earlier time data.

In general, small sample volumes provide better resolution, but more spatial variability; larger sample volumes provide more integrated average concentrations, as long as the volume purged is not large enough to draw atmospheric air into the sample and cause dilution. Site-specific conditions may favour small volume samples or larger volume samples, and the Site Professional should consider the site characteristics and study objectives before selecting the sample volume.

Regardless of whether the volume purged prior to sampling is a minimal 3 to 5 casing volumes, or something more, field screening should be performed using an FID or PID to assess consistency of soil vapour concentrations prior to sampling. For sites with vapours that are aerobically degradable, field screening should also be performed for O_2 and CO_2 using a landfill gas meter.

The sampling flow rate should generally be between about 1 L/hour and 1 L/minute (API, 2005). Alternatively, the vacuum generated during sampling can be limited to <10 inches of water (Lahvis, 2002) which would allow higher flow rates for more permeable soils. The use of higher vacuums increases the potential for leakage of air into the soil gas probes and tubing and/or for enhanced volatilization of the more volatile compounds in a chemical mixture (API, 2005). If a flow rate of 1L/hour cannot be sustained with a vacuum less than 10 inches of water, the soil gas permeability is too low to enable a representative soil gas sample by advective sampling methods. Alternative methods should be considered, such as headspace analysis of soil samples. Conversely, if the soil permeability is high enough to allow flow rates of several litres per minute with a vacuum of <10 inches H_2O, the flow rate may be increased if needed to purge 3 to 5 casing volumes in a practical time period.

The following purging procedure is recommended:

- Calculate the dead volume based on the inner volume of the probe and sample tubing.

- Purge the probe using a flow rate to maintain the vacuum less than 10" H_2O. The rate and vacuum should be monitored and recorded. Use gas-tight fittings. Monitor and record the vacuum during purging using a vacuum gauge or manometer attached to a "T"-fitting at the soil gas probe head and the flow rate using a rotameter or flow controller. Reduce the flow rate if the vacuum exceeds 10 inches water.

- Purge between 3 to 5 casing plus sample tubing volumes.

The purge volume and purge rate should be recorded and could be used to assess the soil gas permeability using the method of Johnson et al, (1990). Optionally, it is possible to monitor stability of field gas readings as a measure of purging, analogous to recording of chemical parameters (e.g., conductivity, pH) during purging of a groundwater monitoring well. Purge three to five dead volumes into a dedicated Tedlar™ bag using a lung box. Screen each Tedlar™ bag with a field-calibrated FID or PID at a minimum, with a landfill gas meter for O_2, CO_2 and methane for hydrocarbon sites. After purging and field screening demonstrates steady readings, close the sampling valve and allow the vacuum generated to dissipate before collecting a sample.

Once purging is complete, soil gas samples can be collected either by filling one more Tedlar™ bag, connecting it to a Summa™ canister of smaller volume using a short length of new HDPE tubing and compression fittings and slowly opening the valve on the Summa™ canister. Otherwise, the Summa™ canister can be connected directly to the soil gas probe, as long as a flow controller is also installed to prevent excessive vacuum and possible entrainment of soil moisture. For sub-slab soil gas probes, it is acceptable to collect a sub-slab gas sample concurrently with an indoor air sample. Indoor air samples are typically obtained over an 8-hour to 24-hour period. The soil gas sampling rate for a 6-litre Summa™ sample collected over 24 hours is about 6 mL/min.

Soil gas samples should not be placed in a chilled cooler for transport since volatiles may condense out the vapour phase at lower temperature (Hartman, 2002). Samples should also not be subject to excessive heat. Tedlar™ bags and glass cylinders should be placed inside a container immediately after collection to avoid possible photo-oxidation reactions.

Sampling of probes at a site should be completed over a relatively short time period to provide an internally consistent data set (Lahvis, 2002).

3.6.3.6 Weather Conditions

As part of the soil gas sampling program, the following should be noted:

- Weather conditions during sampling (e.g., temperature, wind speed, barometric pressure, humidity, sunny/cloudy), and;

- Date of the last precipitation event and the approximate precipitation amount.

4.0 SUB-SLAB AND INDOOR AIR MONITORING

If the initial phases of characterization of the source and distribution of subsurface vapours indicate potentially unacceptable vapour intrusion, further characterization will usually require entry into one or more buildings to conduct sub-slab and/or indoor air monitoring.

4.1 Public Communication

In most cases, this raises the level of concern and awareness of the occupants sufficiently to justify consideration of a Community Relations Plan. Before conducting intrusive investigations, it is also highly recommended to prepare a survey questionnaire for the sampling team to fill out with the building occupants, particularly regarding building design and ventilation and an inventory of consumer products within the building and any attached garage that may contain VOCs. The questionnaire should include occupant activities that might affect indoor air quality (e.g., smoking, scented candles, hobbies, etc.).

The scope of the intrusive investigations should be carefully considered in terms of how many buildings would be included. From a community relations perspective, it is very important to consider the emotional response of those individuals at the perimeter of the study area, who may justifiably ask why they are not included, when their neighbours are. If the distribution of subsurface vapours has been adequately mapped, there may be sufficient information to justify a “primary” investigative zone (most likely to have vapour intrusion at unacceptable levels), a “secondary” zone (unlikely to have unacceptable vapour intrusion, but included in the monitoring program as a precaution to account for spatial variability and subsurface heterogeneity), and a “tertiary” zone which would not be monitored unless nearby properties in the secondary zone are found to have unacceptable vapour intrusion. It may also be advisable to collect a comprehensive set of data (indoor air samples, sub-slab samples, barometric pressure variations, indoor-to-subslab pressure differential) in a single visit to a particular building, rather than over multiple visits, in order to minimize disruption to the occupant’s activities.

4.2 Sub-Slab Vapour Monitoring

4.2.1 Sampling Design Considerations

Sub-slab soil gas is the gas that exists immediately beneath the floor of the occupied structure, regardless of whether the structure is a slab-on-grade or basement design.

Sub-slab soil gas data may not be relevant for buildings with suspended floors and crawlspaces.

Concrete floor slabs are usually placed on a layer of compacted granular fill for structural support, and the gas permeability of the fill material is usually relatively high. Sub-slab soil gas sampling is relatively simple and can be accomplished typically with an electric hammer-drill, avoiding the need for a more-costly drilling rig. Sub-slab soil gas concentrations will typically be higher than indoor air concentrations by a factor of 100 to 10,000 where soil vapour intrusion is occurring, so it may be easier to quantify potential vapour intrusion risks against analytical reporting limits from sub-slab samples, relative to indoor air quality data. Furthermore, the relative proportion of vapours from indoor (background) sources should be much lower in sub-slab samples than indoor air samples, although with barometric pressure fluctuations, it is possible for indoor air sources to cause vapours to move from the building into the sub-slab soil gas.

In practice, laboratory analytical detection limits in the range of a few micrograms per cubic meter (or less) are sensitive enough to detect VOCs in both outdoor air and in indoor air where the VOCs may originate from various consumer products and building materials. As a result, it is not uncommon to find a dozen or more detectable VOCs in indoor, outdoor, and sub-slab samples, even where there is no subsurface contamination. If concentrations of VOCs in all three media (sub-slab, indoor air and outdoor air) are similar, this would indicate that subsurface vapour intrusion is not the responsible mechanism.

Sub-slab sampling has certain drawbacks. It requires an access agreement from the building owner, and is intrusive to the extent that equipment must be brought into the building, dust is generated and floor-coverings may be damaged, all of which is often disruptive or unpleasant for property owners. Relatively little information is available to demonstrate how sub-slab soil gas concentrations vary over time, or in response to barometric pressure changes. The US EPA preliminary guidance for sub-slab sampling (US EPA, 2004) recommends three samples for a building the size of a typical domestic residence (although this may be more than needed), so sub-slab sampling costs are not insignificant, especially if the vapour intrusion assessment includes a neighbourhood of residences and temporal monitoring is required. In many cases, the locations of sub-slab utilities (sewer, water, gas, electrical, etc.) are not marked and may not be provided on private property by third party utility clearance agencies, so there is a risk of causing property damage when drilling through the floor slab.

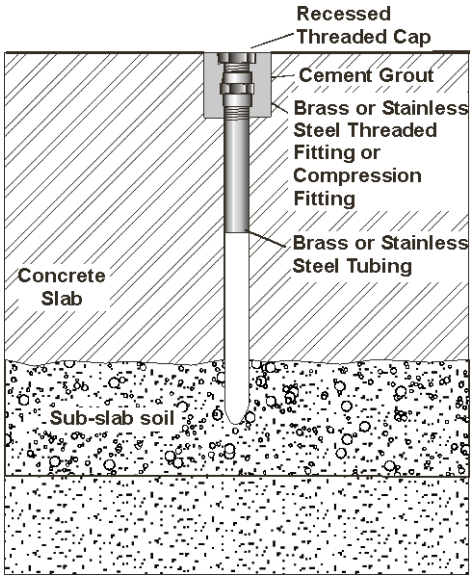
4.2.2 Probe Design

Prior to drilling or coring through concrete slabs, relevant structural and utility information should be reviewed to evaluate whether drilling or coring could adversely affect the integrity of the building envelope, foundation slab or subsurface utilities, and whether there are any potential health and safety issues with drilling or coring.

The US EPA has a recommended protocol for sub-slab soil gas probe installation and sampling that recommends drilling a pilot hole through the slab similar in diameter to the insert, which consists of a brass or stainless steel tube with a threaded cap (US EPA, 2004). The upper part of the hole is reamed to a larger diameter to allow an annulus for a seal. The insert is extended into the pilot hole, but not past the bottom of the slab. This allows for collection of gas from any gap that may form below the slab in response to settlement or heave. The annulus between the upper reamed hole and the insert is sealed with hydrating (swelling) cement grout. The grout should not contain any additives that could contain volatile organic chemicals.

The seal between the sub-slab probe and the concrete floor is a common source of leakage. 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 the metal probe, so it is not unusual for the probe to spin while fittings are being attached. Attaching all fittings before the probe is installed may minimize stresses on the seal. A tracer may be useful to confirm the absence of unacceptable leaks as described by EPRI (2005).

Figure 4 Suggested Design for Sub-Slab Soil Gas Probes (after EPA, 2004)



If the building is pressurized at the time of sub-slab probe installation, indoor air can flow into the sub-slab region between drilling and sealing. To minimize this possibility, the hole may be corked using plastic wrap, or a latex or nitrile glove, crumpled and wedged into the hole. If the probe is being sampled soon after installation, purging of a few litres of soil gas prior to sample collection will minimize the effect of any such disturbance.

4.3 Indoor Air Monitoring

Indoor air quality monitoring is a relatively mature scientific discipline, and should be conducted by a specialist with experience in this area. Valuable information is provided by the Massachusetts Department of Environmental Protection (MADEP, 2002).

4.3.1 Building Inspection and Occupant Survey

A sample Building Inspection and Occupant Survey Form is provided in Appendix C, based on a similar form presented in US EPA, 2004. Building design and other factors potentially influencing ventilation should be documented, including whether there is a basement, crawlspace, slab-on-grade, or suspended floor; sumps, floor cracks, or floor drains; thermal windows; any noticeable drafts around windows and doors; exhaust fans (kitchen, bathrooms, central vacuum, clothes dryer), window-mounted air conditioners, attic vents or fans, fire-places, or wood-burning stoves. The building heating, ventilating and air-conditioning (HVAC) system affects pressure gradients, mixing and dilution, all of which affect subsurface vapour intrusion. Where buildings are heated, convection cells develop with hot air rising and leaking to some extent through roofs and upper-floor windows. The escaping air will be replaced to some degree by soil gas entry below the neutral pressure plane (i.e. lower levels/basements). This phenomenon is referred to as the “stack effect”. Even where buildings are not purposefully heated, solar radiation on rooftops can heat air in the attic significantly and cause the same effect. Bathroom exhaust fans, central vacuum cleaners, and kitchen exhaust fans all remove air from a building. Elevator shafts can also cause localized pressure gradients. Window-mounted air conditioners blow air into a building so they should not be operated during sampling. Each of these features should be noted on the building survey form.

In commercial/industrial buildings, HVAC units are usually mounted on the roof, and blow air into the building, heating or cooling it as appropriate for the season or climate. There are often also exhaust fans that extract air out of restrooms, or rooms with heat sources or chemical vapours, which may operate continuously or intermittently. HVAC units are usually designed to recirculate a portion of the indoor air and to provide a certain amount of outdoor air into the building as fresh air or “makeup air”. Often the ventilation requirements of commercial or industrial buildings are dictated by local building codes. Operation of HVAC units can generate sufficient pressure or vacuum to

significantly influence vapour intrusion. Verification of these pressure gradients typically requires a digital micro-manometer, which are in common use in the HVAC industry. Alternatively, there are smoke-sticks that produce smoke without heat, and the smoke stick can be held near suspected areas of air leakage to assess whether there is any visible flow into or out of the building. In many cases, valuable information can be obtained from the HVAC maintenance engineer.

In the immediate proximity of the building envelope, the subsurface vapours to indoor air pathway includes foundation cracks, utility penetrations, differential settlement, sumps, cellars, and owner/occupier modifications. Floor drains, for example, are designed to allow water to drain away, but are not designed to eliminate soil gas entry. Floor drains usually are constructed with sewer gas traps but these are not always effective in preventing soil gas entry because the sewer pipe is seldom sealed to the floor with an air-tight seal and vapours can migrate through the granular fill surrounding the sewer pipe. Foundation walls are typically constructed first, then floor slabs are poured, typically leaving a space between the floor slab and walls (i.e., perimeter crack) for expansion and contraction. This perimeter crack is often obscured by wall-coverings, and may not be accessible for inspection or direct testing.

Consumer products stored, used and/or handled within a building and materials used in the construction and furnishing of the building are the most common source of chemical vapours in indoor air, and can be responsible for dozens of compounds at concentrations above detection limits, and in some cases, above concentrations that might pose a long-term health risk. A survey should be conducted and documented prior to any indoor air sampling and analysis. Any containers with the potential to emit VOC vapours should be temporarily removed from the building as well as from attached garages or sheds and stored in a separate space (bins outside, for example) for several days prior to indoor air sampling. Furthermore, housecleaning activities should be curtailed, along with use of deodorizers, aerosols, paints, glues, smoking, or any other activity likely to influence indoor air quality or cause odours. The occupants should be interviewed at the end of each indoor air sampling event to document any inadvertent use of any such consumer products.

4.3.2 Survey Design

Indoor air quality surveys require careful consideration during design to ensure that the data collected are useful for risk assessment purposes. The target analyte list should be given very careful consideration. It may be appropriate to analyze for all VOCs, recognizing that some VOCs that are not present in the subsurface will probably be detected, and may be at levels that pose a potential health risk. Alternatively, it may be preferable to establish a target analyte list of only those compounds known or suspected

to be present in the subsurface at concentrations higher than the target indoor concentrations. In some cases, it may be appropriate to identify a single compound as the dominant potential risk driver, and analyze indoor air for that compound alone. It may also be worth considering indoor air monitoring for Radon, if it is naturally occurring in the subsurface, since Radon can be used as a tracer to demonstrate the fraction of subsurface gas present in indoor air.

Health-based target indoor air concentrations should be established. In some cases, background air quality may have concentrations of some compounds higher than risk-based target concentrations; therefore it may be impractical to discern subsurface vapour intrusion at levels below background. Provincial policy requirements for such a condition should be determined prior to sampling and communicated to occupants.
Quality assurance and quality control will typically require additional samples, data validation, and in some cases additional measures. Data quality objectives should be established in advance. Detection limits should be sufficiently lower (preferably an order of magnitude) than target indoor air concentrations to provide resolution to account for natural variability, although this might not be possible for some compounds. Duplicate samples should have concentrations with relative percent differences less than about 30%. Inter-lab comparisons may be appropriate in some instances.

Survey design should specify the number of samples, their locations (typically in the breathing zone of the most frequently occupied room(s)), for example, the living room, and possibly bedrooms. The duration over which a sample is collected is often 8 hours for workplace settings and 24 hours for residential settings. Longer durations may be appropriate to integrate over short-term weather conditions that might affect indoor air quality, especially when the goal is to be protective of long-term exposure risks. It may be sufficient to collect samples on a single occasion (e.g., if all results of analyses are dramatically lower than target concentrations), or it may be appropriate to perform more than one sampling event (summer and winter conditions for example).

Outdoor air samples should be collected as controls when indoor air samples are collected, especially where there are nearby industrial emissions, roadways with automotive exhausts, gasoline service stations, or other potential sources of outdoor air VOCs. Wind speed and direction should be recorded with each outdoor air sample. Special security may be required for weather-proofing and prevention of tampering/vandalism/theft of outdoor probe installations.

Laboratory methods of analysis should be discussed with the analytical laboratory once the target analyte list and target detection limits have been established. In most cases, indoor air samples for VOC analysis are either collected using Summa™ canisters or sorbent tubes. For some target analytes, either method can be used. Draeger tubes,

Gastechtors, explosimeters, charcoal badges, handheld photoionization detectors (PIDs) or flame ionization detectors (FIDs) can be used for screening to assess acute risks, explosion hazards, or possibly preferential pathways of vapour entry, but target indoor air concentrations are typically lower than their limits of detection by a large enough margin that these instruments cannot be relied on for assessment of long-term exposure risks.

Considering the potential scope of an indoor air quality survey, and the potential site-specific conditions that may require customization of the scope of work, it is generally recommended to prepare a Work Plan detailing the scope and methods in advance, and to have the Work Plan reviewed and approved by interested parties prior to implementation.

5.0 ANALYTICAL METHODS

5.1 Field-Based Techniques

5.1.1 Explosive Meters

Gases are detected by combustion of the gas across a heated filament in the meter. The detection limits are in percent for methane and other explosive mixtures. The instruments are easy to use, give an instant reading, are compact and battery operated. Generally the detection limit is in the % range and is only useful for field screening of acute concerns (e.g., explosive conditions) that would require emergency actions. The instrument should be calibrated prior to each use.

5.1.2 Photoionization and Flame Ionization Detectors

Gases are ionized by a UV lamp and then detected as a voltage. The detection limits are about 1 ppm, although there is an instrument that is capable of 10 ppb. The instruments are very easy to use, provide instant readings, and are compact and battery operated. The instrument has a different response factor for each VOC and is non-specific to individual chemicals, which makes it difficult to calibrate when you are working with a mixture of VOCs. Results are semi-quantitative and cannot be used for comparison to health-based target concentrations. However, when combined with data-logging capabilities, these instruments, can provide useful information on short-term temporal variation in concentrations (e.g., peak daily concentrations). They are also useful for field screening during soil gas probe purging, and potentially identifying consumer products that may be acting as background sources of VOCs.

Flame ionization detectors are generally better suited to monitoring hydrocarbon vapor concentrations, and can provide lower detection limits than PIDs; however, they require transportation of H_2 cylinders, which can be hazardous and the flame can extinguish if soil gas samples have low oxygen levels, which is common near hydrocarbon sources.

5.1.3 Tedlar™ Bags

Tedlar™ bags are inert to a wide range of chemicals and available in sizes from 0.5L to 100L. The gas in the bag can be analysed directly or the air can be concentrated on a tube (see below) or a cryogenic concentrator. The detection limit is poor when the sample is directly injected into an instrument. Samples should be analysed within 48 hours and are therefore preferred for on-site analysis or screening. Compounds such as

naphthalene and semi-volatile organic compounds may absorb to the inner surface, causing a negative bias.

5.2 Laboratory-Based Techniques

5.2.1 Collection on Sorptive Media Tubes

There are many different types of sorptive media tubes available. The most common for VOCs are charcoal tubes, automatic thermal desorption (ATD) tubes, and volatile organic sampling train (VOST) tubes. Air or soil gas is passed through the tube and the VOCs are adsorbed onto the tube. They are then removed by solvent in the case of the charcoal tube, or by heat and a gas stream in the case of the ATD tubes. The tubes are either analyzed by gas chromatograph with flame ionization detector (GC-FID) or gas chromatograph with mass spectrometer (GC-MS).

The detection limit is inversely proportional to the volume of air collected. Tubes are inexpensive and the thermal desorption tubes can be re-used. The samples are very stable on the tubes and can be analysed up to 4 weeks after collection without loss of sample. In the case of the charcoal tubes, the desorbing solvent used is carbon disulfide which contains a small amount of benzene as an impurity which makes detection of benzene more difficult.

5.2.2 Summa™ Canisters

Summa™ canisters can be purchased in sizes from 400 ml to 6 L. They need to be evacuated prior to sampling and then they are simply opened on site to introduce the sample. A flow restrictor can be used if there is a requirement to collect the sample over a time period. Summa™ canisters are analysed using a cryogenic concentrator and injection into a GC-MS. The canisters are relatively expensive and they must be specially cleaned after each use. Refer to Section 3.6.3.2 for a more detailed description of Summa™ canister use.

5.3 Laboratory Analytical Methods

Analytical methods must be appropriate for analyzing soil vapour samples and will depend on the sampling method selected and the desired data quality objectives.

5.3.1 Analytical Method Selection

There are a range of potential analytical methods that could be employed depending on the site-specific objectives. Consultation with the analytical laboratory prior to the field

program is recommended to reach agreement upon sampling techniques and laboratory methods. To assist in this consultation, the following questions, taken from API, 2005, are suggested:

- *What sample collection methods will be used?*
  The sample collection method and the analytical method often define each other as well as the sample preparation that is required (e.g., Summa™ versus ATD tubes).

- *What are the specific chemicals of concern for the analysis?*
  Specific analytes will often be a mix of VOCs (e.g., benzene) and SVOCs (e.g., TPH) and the chosen analytical method(s) must be able to detect and quantify a range of chemicals. For petroleum hydrocarbon sites in Atlantic Canada, soil vapour and indoor air monitoring programs must include, at a minimum, BTEX and TPH fractionation. Other possible chemicals of concern (e.g., naphthalene) should be assessed on a site-specific basis, as required.

- *What are practical quantitation limits (PQLs) required to adequately assess the chemicals of concern?*
  It is essential that laboratory PQLs are less than the target indoor air concentrations (Reference Concentrations [RfCs] or Risk Specific Concentrations [RSCs]). RfCs and RSCs for each chemical of concern should be identified in advance and used to identify the necessary detection limits.

5.3.2 Common Analytical Methods

Table 6 lists common laboratory analytical methods for petroleum hydrocarbons.

Table 6 Common Analytical Methods

Analyte	Collection Device	Methodology	Detection Limit
Benzene	Thermal desorption tube	GC/FID or MS	0.4 μg
BTEX	Charcoal tube	GC/FID	0.4 μg
	Summa™ canister	GC/MS	1 ppb
TPH Fractionation	Charcoal tube	GC/FID	BTEX 0.4 μg each $C_6 – C_{10}$ 2 μg $C_{10} – C_{21}$ 10 μg
	Summa™ canister	GC/MS	1 ppb
Naphthalene	Charcoal tube	GC/FID	10 μg
	Summa™ canister	GC/MS	1 ppb

5.3.3 Data Quality

Quality assurance/quality control (QA/QC) measures should be planned in advance and may include field blanks, duplicates, laboratory replicates, and method blanks. QA/QC measures should be designed to permit an assessment of the accuracy and precision of the data. Analytical laboratories have internal QA/QC controls and should be accredited for the test method by the Standards Council of Canada (SCC) to Canadian Association of Environmental Analytical Laboratories (CAEAL) standards, where possible.

6.0 INTERPRETATION OF RESULTS

The purpose of this section is to provide guidance as to how to interpret the laboratory results in the context of the Atlantic RBCA process. Laboratory reports for vapour sampling using sorbent tubes are typically provided as a mass (in mg or µg). These masses should then be converted into an air sample concentration (in mg/m^3 or $\mu g/m^3$) by the Site Professional. If the sample was collected within the building, it is considered an indoor air sample. Alternatively, if the sample was collected from a soil probe, a dilution factor will need to be applied in order to predict the indoor air concentration. The measured or predicted indoor air concentration is compared to a Reference Concentration (RfC) (e.g., toluene, ethylbenzene, xylenes [TEX]), a Risk Specific Concentration (RSC) (e.g., benzene) or to a calculated indoor air site-specific target level (SSTL) (e.g., total petroleum hydrocarbons [TPH]) to determine what remedial or site management actions are required.

6.1 Converting Laboratory Results

6.1.1 Converting Results from Mass to Concentration

Laboratory results for samples collected using sorbent tubes will typically be expressed as a mass (i.e., the mass of the chemical detected in the sample media). This mass is converted into an air concentration by dividing the mass by the total volume of air pumped through the sample media (i.e., the flow rate x the time of sampling). This is expressed as:

$$\text{Conc. in air [µg/L]} = \text{Mass [µg]} / (\text{Flow rate [L/min]} \times \text{Sample Time [min]})$$

Units of µg/L, calculated above, are equivalent to units of mg/m^3 that are used to express RfCs and RSCs. If a parameter was not detected, one half of the detection limit should be used as the mass for use in subsequent calculations.

6.1.2 Converting Concentration Units

Summa™ canister analysis provides concentrations directly in units of parts per billion by volume (ppbv). These units must be converted to match the units for the RfCs and RSCs (mg/m^3), as follows:

$$\text{Conc. in air [mg/m}^3\text{]} = (\text{Conc. in air [ppbv]} \times MW / RT) \times 0.001 \text{ [mg/µg]}$$

where:

MW = Molecular weight (g/mol)
R = Gas constant (0.0821 L-atm/mol-K)
T = Absolute temperature (^{o}K)

6.2 Soil Vapour Sampling Results

6.2.1 Default Site Conditions

Where soil vapour concentrations have been measured, the corresponding indoor air concentrations must be calculated. Table 7 provides default dilution factors (DFs) calculated by the authors. These default DFs were calculated from soil vapour at the measurement location to indoor air using the Johnson and Ettinger (1991) model, which is consistent with the Atlantic RBCA Tool Kit, version 2.1. DFs were calculated for a range of source to building separation distances up to 30 m (laterally or vertically) and default site conditions identical to those used in the calculation of the Tier I RBSL Look Up Tables. DFs are provided for coarse- and fine-grained soil at residential and commercial sites.

Table 7 Soil Gas to Indoor Air Dilution Factors (DFs)

Distance (m)	Residential		Commercial	
	Coarse	Fine	Coarse	Fine
1	8,580	71,600	24,900	141,000
2	10,100	82,100	26,700	154,000
3	11,600	92,500	28,600	167,000
5	14,600	113,000	32,200	193,000
10	22,100	166,000	41,400	257,000
20	37,000	270,000	59,900	385,000
30	52,000	374,000	78,300	513,000

Mandatory Criteria:
1. Concrete floor present in building.
2. Building volume equal to or greater than default volume. If building volume is less than the default volume, the DF must be adjusted down to account for the smaller volume.
3. Mobile free product not present in the subsurface within 30 m of the building.
4. Groundwater table > 1 m below the building foundation.
5. Site conditions conform to Atlantic RBCA Tier I default site conditions.

Indoor air concentrations are calculated from the soil vapour sample result as follows:

$$\text{Conc. in indoor air } [mg/m^3] = \text{Conc. in soil vapour sample } [mg/m^3] / DF$$

These DFs are only applicable at sites that conform to the default site conditions assumed in the Atlantic RBCA Toolkit, v2.1, for the development of the soil and groundwater Tier I RBSL Look Up Tables. Mandatory criteria for the application of the DFs are listed below Table 7.

6.2.2 Non-Default Site Conditions

For sites that do not conform to the default site conditions assumed for Tier I RBSLs, where soil vapour monitoring has been conducted, an alternative DF is required to calculate indoor air concentrations. Review of literature (US EPA, 2002; API, 2005) and empirical data (as cited in Golder, 2004), indicates that dilution factors for soil vapours to indoor air would be in the range of 100 to 10,000 (Johnson, 2002). Model runs conducted using the Atlantic RBCA Toolkit, with a variety of non-default site conditions (e.g., dirt floors) supports this general range of values. Therefore, a generic DF of 100 is recommended as a conservative end member for soil vapours (collected from >1m below building foundations) to indoor air at sites that do not meet the mandatory criteria listed in Table 7.

6.3 Sub-Slab Vapour Sampling Results

For sites where sub-slab vapour monitoring has been completed, the general approach to predicting indoor air results will be the same as for soil vapour samples collected from >1m below building foundations. However, the DFs presented in Section 6.2 do not apply. US EPA (2002) recommended a dilution factor of 10 for shallow soil gas (≤ 1.5 m below the building foundation) based on limited data available at that time. Using more recent data, US EPA calculated a minimum dilution factor of 50 (http://iavi.rti.org/WorkshopsAndConferences.cfm?PageID=documentDetails&AttachID=170). Empirical data have demonstrated that sub-slab soil gas concentrations will typically be higher than indoor air concentrations by a factor of 100 to 10,000 where soil vapour intrusion is occurring (Johnson, 2002). Golder (2004) state that sub-slab to indoor air dilution factors less than approximately 50 likely indicate a possible background effect that has lowered the apparent dilution factor.

Based on the above, a generic DF of 50 is recommended for sub-slab vapours (<1m below building foundations) to indoor air. This value is considered applicable to all sites, regardless of whether the site conforms to Tier I default site conditions, and is likely to provide a protective evaluation of the sub-slab vapours to indoor air pathway.

6.4 Indoor Air Sampling Results

Directly measured indoor air results do not require application of dilution factors. However, there are several issues that should be carefully evaluated when interpreting indoor air results, including but not limited to:

- *Sources of Interference*
  Buildings should be inspected and occupant surveys completed prior to any indoor air quality testing. There are a variety of possible sources of interference with indoor air results (see Section 4.3 above).

- *Ambient Background Levels*
  Ambient background concentrations of some chemicals (e.g., benzene) may exceed health-based target concentrations. Comparison of results to published data can provide useful comparison.

Consideration should be given to collection of background samples at outdoor locations or in similar buildings not subject to subsurface contamination. Relative proportions of compounds in sub-slab samples should be compared to those for indoor air samples. Increased concentrations of specific compounds in indoor air samples, relative to other compounds, indicate a background contribution.

6.5 Interpretation of Measured or Predicted Indoor Air Concentrations

6.5.1 Carcinogens

For carcinogenic parameters, the measured or predicted concentrations in indoor air are evaluated by comparing the indoor air concentration to the RSC for a target risk of 1 in 100,000 (10^{-5}). The measured or predicted concentration is considered acceptable if:

$$\text{Indoor air concentration } (\mu g/m^3) \leq \text{RSC } (\mu g/m^3)$$

RSCs are not directly provided in the Atlantic RBCA Toolkit, which employs Unit Risk Factors (URFs) for evaluation of carcinogens by the inhalation pathway. An RSC for a target risk of 1 in 100,000 (10^{-5}) can be calculated from the URF as follows:

$$\text{RSC } (\mu g/m^3) = 10^{-5} / \text{URF } (\mu g/m^3)^{-1}$$

URFs can be obtained from the chemical database in the Atlantic RBCA Toolkit, version 2.1.

It is important to note that the Atlantic PIRI Committee has pre-approved the Atlantic RBCA model for only one carcinogen – benzene. The inhalation unit risk factor for benzene as provided in the Atlantic RBCA Toolkit, v2.1, is 3.3 x 10^{-6} $(\mu g/m^3)^{-1}$. Other carcinogenic chemicals present in the Atlantic RBCA Toolkit have not been reviewed for applicability of physico-chemical and toxicological properties. Consequently, URFs listed for other carcinogens may not be consistent with either Provincial or Health Canada guidance. A qualified professional should complete the selection of toxicological data for all other carcinogenic chemicals.

6.5.2 Non-Carcinogens

For non-carcinogenic parameters that are not part of a mixture, the measured or predicted concentration in indoor air is evaluated by comparing the concentration in indoor air to the inhalation reference concentration (RfC_i). The measured or predicted concentration is considered acceptable if:

$$\text{Indoor air concentration } (mg/m^3) \leq RfC_i \ (mg/m^3)$$

RfCs can be obtained from the chemical database in the Atlantic RBCA Toolkit, v2.1.

It is important to note that the Atlantic PIRI Committee has pre-approved the Atlantic RBCA model for only three non-carcinogens – toluene, ethyl benzene, and xylenes. The inhalation RfCs for toluene, ethyl benzene, and xylenes are provided in Table 8. Other non-carcinogenic chemicals present in the Atlantic RBCA Toolkit have not been reviewed for applicability of physico-chemical and toxicological properties. Consequently, RfCs listed for other non-carcinogens may not be consistent with either Provincial or Health Canada guidance. A qualified professional should complete the selection of toxicological data for all other non-carcinogenic chemicals.

Table 8 Reference Concentrations – Non-Carcinogens

Parameter	Inhalation Reference Concentration, RfC_I (mg/m^3)
Toluene	0.40
Ethyl benzene	1.00
Xylenes	0.18

6.5.3 Total Petroleum Hydrocarbons

It is recommended that all soil vapour and indoor air samples collected from petroleum hydrocarbon impacted sites be analyzed for TPH Fractionation in order to obtain results

that can be compared to fraction-specific RfCs. However, it is recognized that in some instances there will be insufficient TPH in the sample for fractionation testing to be completed by the laboratory. In these cases, a method of interpreting Alberta MUST (Management of Underground Storage Tanks) TPH results is required. The following sections outline recommended approaches for the interpretation of TPH results in either scenario.

6.5.3.1 Interpretation of TPH Fractionation Results

The lowest RfC for any of the individual TPH fractions is 0.2 mg/m^3. Therefore, if the total concentration of TPH in indoor air is less than 0.2 mg/m^3, the measured or predicted concentration is considered acceptable. If the concentration is greater than 0.2 mg/m^3, and TPH fractionation results are available, the fraction concentrations may be evaluated by developing a site specific target level (SSTL) for TPH in indoor air.

The SSTL for TPH in indoor air may be calculated as:

$$SSTL_{TPH} = [\Sigma\ MF_{fraction\ i} / RfC_{i\ fraction\ i}]^{-1}$$

Where:
- $SSTL_{TPH}$ = site-specific target level of TPH in indoor air
- $MF_{fraction\ i}$ = mass fraction of TPH sub-fraction *i* in air
- $RfC_{i\ fraction\ i}$ = inhalation reference concentration for TPH sub-fraction *i*

If the measured or predicted concentration of TPH in indoor air is less than the $SSTL_{TPH}$, the indoor air concentrations are considered acceptable. The calculation of the $SSTL_{TPH}$ must include toluene as the Aromatic $>C_7$-C_8 fraction and ethyl benzene and xylenes in the Aromatic $>C_8$-C_{10} fraction. Consequently, the measured or predicted concentration of TPH in indoor air must also include toluene as the Aromatic $>C_7$-C_8 fraction and ethyl benzene and xylenes in the Aromatic $>C_8$-C_{10} fraction to ensure an appropriate comparison.

It should be noted that a direct comparison of the concentrations of individual fractions to their respective inhalation reference concentration alone is not sufficient for the evaluation of TPH as it does not account for the cumulative effects of all the TPH fractions. An advantage of calculating the $SSTL_{TPH}$ is that, once a representative fractionation test result for one sample is obtained, additional air samples may be analyzed using only the Alberta MUST methodology and compared directly to the $SSTL_{TPH}$.

RfCs for the TPH fractions can be obtained from the chemical database in the Atlantic RBCA Toolkit, v2.1. The inhalation reference concentrations for the TPH fractions are provided in Table 9.

Table 9 Reference Concentrations – TPH Fractions

Parameter	Inhalation Reference Concentration, RfC_I (mg/m^3)
Aromatic >C_7-C_8	0.40
Aromatic >C_8-C_{10}	0.20
Aromatic >C_{10}-C_{12}	0.20
Aromatic >C_{12}-C_{16}	0.20
Aliphatic >C_6-C_8	18.4
Aliphatic >C_8-C_{10}	1.00
Aliphatic >C_{10}-C_{12}	1.00
Aliphatic >C_{12}-C_{16}	1.00

Notes:

1. Concentrations of toluene should be included in Aromatic >C_7-C_8; ethyl benzene and xylenes should be included in Aromatic >C_8-C_{10}
2. Inhalation toxicity data for the aromatic and aliphatic fractions between C_{16} and C_{35} are not available. The contribution of these fractions to the inhalation pathway is considered negligible and is not included in the Atlantic RBCA Toolkit and is not typically reported by the laboratory.

6.5.3.2 Interpretation of Alberta MUST TPH Results

In cases when TPH fractionation cannot be completed on soil vapour or indoor air samples, it is necessary to apportion the Alberta MUST result, reported in carbon ranges of C_6 – C_{10} and C_{11} – C_{21}, into fractions in order to evaluate the results against RfCs. A recommended approach is outlined below:

1. Based on the site characterization and CSM, determine whether the vapour source potentially impacting a building is a primary soil source zone or is a secondary groundwater plume.

2. Obtain representative soil and/or groundwater TPH fractionation results from the impacted site, as applicable based on the CSM.

3. Use the Atlantic RBCA Toolkit, v2.1, and the soil or groundwater fractionation result(s) to calculate indoor air Point of Exposure (POE) concentrations for each TPH fraction.

4. Use the relative proportions of the indoor air POE concentrations calculated above to apportion the measured soil vapour or indoor air Alberta MUST result into TPH fractions.

5. Interpret the calculated TPH fraction result as described in Section 6.5.3.1.

It is expected that all petroleum hydrocarbon impacted sites currently under assessment will have soil and/or groundwater fractionation data collected. For historic sites (i.e., assessed prior to the introduction of Atlantic RBCA in 1999), TPH fractionation data may not be available. In the absence of any site-specific TPH fractionation data, it is acceptable to enter one of the default fuel compositions provided in the Atlantic RBCA version 2.0 User Guidance (2003). The most conservative fuel type must be selected based on the known history of petroleum product handling and storage at the impacted site. Mass fractions provided by the User Guidance must be prorated to the highest site-specific soil or groundwater TPH result, as appropriate, prior to calculating POE concentrations in order to account for effects of soil saturation and groundwater solubility limits.

A worked example, employing the Atlantic RBCA version 2.0 User Guidance default fuel type for gasoline, is provided in Appendix D to illustrate the application of the above methodology.

6.5.4 Exposure Averaging of RfCs and RSCs

RfCs and RSCs are chemical concentrations in air to which the human population, including sensitive sub-groups, can have a lifetime of daily exposure without experiencing chronic health effects or without appreciable risk of deleterious effects. The assumption inherent in direct comparison of indoor air concentrations to the RfCs and RSCs is that the receptor is subject to continuous lifetime exposure.

Less-than-lifetime or less-than-continuous exposures can be accommodated with factors such as Exposure Time (ET), Exposure Frequency (EF), Exposure Duration (ED), and Averaging Time (AT) to reflect anticipated exposure. These factors are built into the Atlantic RBCA Toolkit v2.1 calculations but are omitted from this simple comparison of indoor air concentration to RfC or RSC.

The RfC or RSC can be modified prior to comparison with indoor air concentrations, as follows:

$$RfC_{exp.\ avgd.} = RfC \div \frac{ET\ [hours/day] \times EF\ [days/year] \times ED\ [years]}{24\ hours/day \times 365\ days/year \times AT\ [years]}$$

For instance, $RfC_{exp.\ avgd}$ for toluene (RfC = 0.4 mg/m^3) in a default commercial exposure scenario would be calculated as follows:

$$RfC_{exp.\ avgd.} = 0.4 \div \frac{10\ [hours/day] \times 240\ [days/year] \times 4.5\ [years]}{24\ hours/day \times 365\ days/year \times 4.5\ [years]}$$

$$= 0.4 \div 0.274$$

$$= 1.46\ mg/m^3$$

This adjustment reflects the fact that for shorter or less frequent exposures, higher air concentrations can be tolerated with the same level of risk protection. Default values for ET, EF, ED, and AT can be obtained from the Atlantic RBCA Toolkit, v2.1.

Use of exposure averaging factors other than those published in the Atlantic RBCA Toolkit may be proposed by the Site Professional on a case-by-case basis but must be supported by sound reasoning and may be considered to represent an institutional control on current and future land use.

7.0 PROVINCIAL CONTAMINATED SITE MANAGEMENT PROCESSES

Each Province maintains separate contaminated site management documents and the Site Professional should verify Provincial requirements in the jurisdiction in which he/she is operating. The most recent versions of these documents are available on the Atlantic RBCA web site (www.atlanticrbca.com).

Certain fundamental aspects of contaminated site management related to Atlantic RBCA implementation are common to all four Atlantic Provinces. Figure 5 illustrates an abbreviated flowchart of common steps to be followed in application of soil vapour and indoor air monitoring at petroleum impacted sites. Each step is described in the following sections.

7.1 Site Characterization

When addressing indoor air exposures, provincial regulators will require Site Professionals and responsible parties to conduct an appropriate environmental site assessment (ESA) that reflects the CSM developed for the site. ESAs should conform to the relevant requirements of the current version of the *Minimum Requirements and Reference Guidelines for Environmental Assessments of Petroleum Impacted Sites in Atlantic Canada* (www.atlanticrbca.com). Critical factors associated with an ESA include:

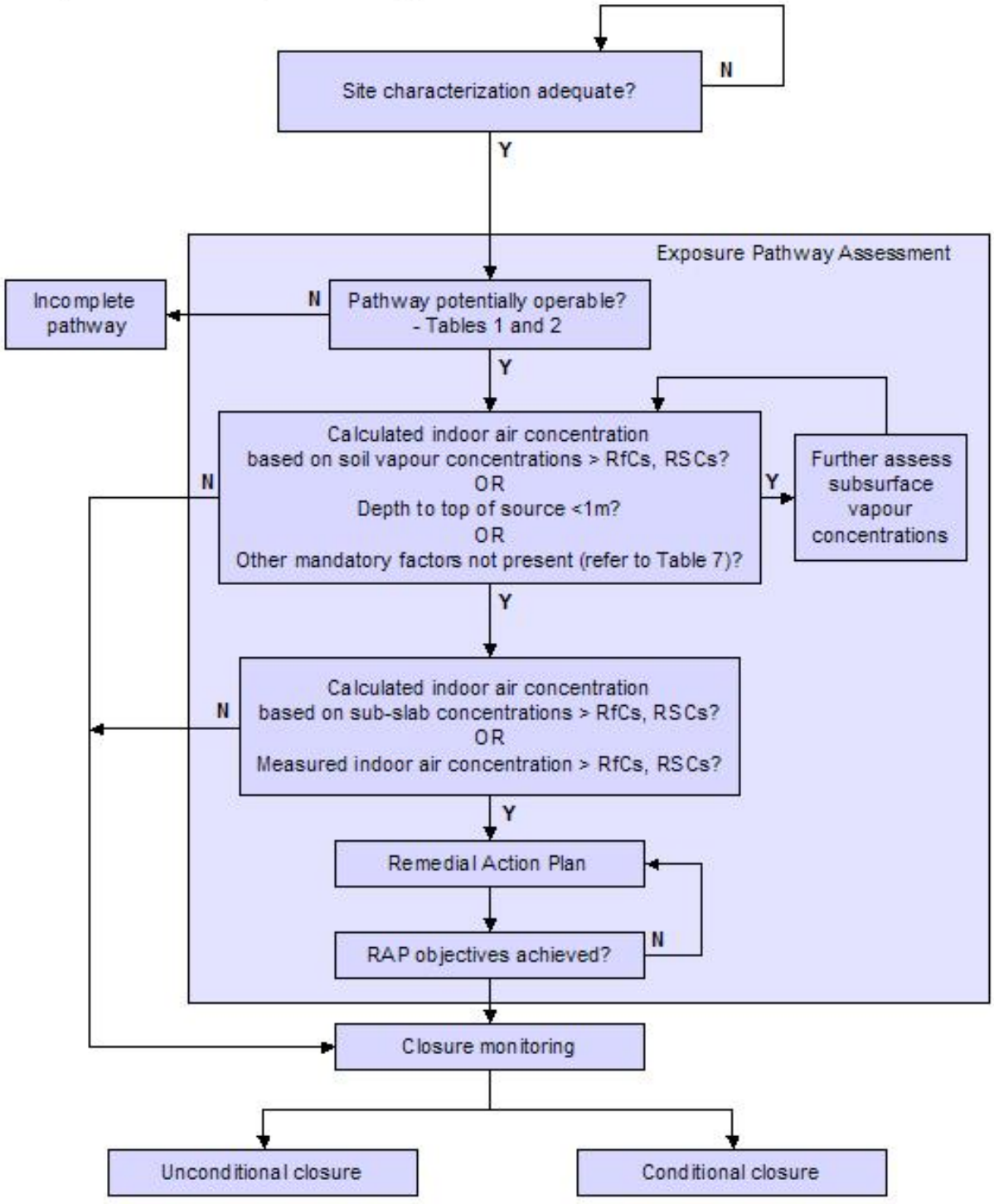
- An understanding and reporting of the types of petroleum products identified of concern at the site that may include products previously handled or stored on the site.

- The delineation of the extent of impacts in soil and groundwater to below the Tier I RBSLs, even if impacts have crossed the source property boundary.

- An evaluation and reporting of the presence of phase-separated liquid hydrocarbons (free product).

- A demonstrated understanding and reporting of subsurface characteristics that would influence soil vapour transport, including vadose zone soil stratigraphy, hydrogeological information including depth to the water table, anticipated or measured seasonal fluctuations, and flow direction, distance from source to nearest building, and presence of natural or man-made preferential pathways.

Figure 5 Summary of Site Management Process



A demonstrated understanding and reporting of building characteristics that would influence vapour intrusion, including size, location, and type, construction features such as foundation cracks and sumps, heating and mechanical systems (e.g., forced air furnaces, HVAC).

Once the ESA is complete, the Site Professional will compare results to applicable Tier I RBSLs or indoor air Tier II PSSLs. Should the screening criteria be exceeded, or deemed to be not applicable (e.g., dirt floor construction), the Site Professional and Responsible Party may choose to pursue soil vapour and/or indoor air monitoring to manage the site.

7.2 Indoor Air Exposure Pathway Assessment

Once the ESA has been completed and is considered adequate for the purposes of assessing the soil vapours to indoor air pathway, the completeness and significance of this pathway should be assessed, following the guidance and recommendations presented herein.

7.2.1 Exposure Pathway Completeness

Provincial regulators will require an evaluation and reporting of the completeness or operability of the soil vapours to indoor air pathway, to be based primarily on consideration of two main factors:

- Vapour source – building separation distance; and
- Source concentrations.

For vapour source to building separation distances greater than 30 m, the subsurface vapours to indoor air pathway is considered incomplete. For distances less than 30 m, the Site Professional must evaluate source distance and strength, as well as potential precluding factors (e.g., preferential pathways), to determine the completeness of this pathway (see discussion on this issue, Section 2.3 above).

In each case, site professionals will be required to provide detailed support and site analysis when determining the exposure pathway completeness during site assessment and/or RAP development.

7.2.2 Exposure Pathway Significance

To determine if a potentially operable soil vapours to indoor air pathway is likely to be significant, provincial regulators require that a phased sampling program be implemented by the Site Professional, based on sequential application of soil vapour, sub-slab, and indoor air monitoring. Decision points will be based on comparison of sample results to RfCs and RSCs, and may be as follows:

- If the calculated indoor air concentrations based on concentrations of petroleum hydrocarbon constituents in soil vapours near the source are less than the corresponding RfCs and/or RSCs, and all other mandatory factors are met, then the pathway is likely insignificant and site management can be moved to a closure monitoring stage.

- If the calculated indoor air concentrations based on concentrations of petroleum hydrocarbon constituents in soil vapours near the source are greater than the corresponding RfCs and/or RSCs, then further evaluation of the pathway is required.

As part of phased sampling, further evaluation may take the form of soil vapour monitoring between the source and the building to determine if the calculated indoor air concentrations based on soil vapour concentrations decline to less than the RfCs and/or RSCs prior to reaching the building. Alternatively, the Site Professional may choose to proceed directly with sub-slab or indoor air monitoring. If the calculated indoor air quality based on these concentrations is less than the corresponding RfCs and/or RSCs, then the pathway is likely insignificant and site management can be moved to a closure monitoring stage

7.3 Remedial Action Plan

If the calculated indoor air concentrations based on concentrations of petroleum hydrocarbon constituents in soil vapours exceed RfCs and/or RSCs and do not decline to less than these values prior to reaching the building, then a Remedial Action Plan (RAP) is required. A variety of actions can be proposed by the Site Professional for the RAP, including but not limited to:

- Implement engineered controls along the soil vapour transport pathway to reduce vapour intrusion. Examples of engineered controls include sub-slab vapour barriers, passive venting systems, and active air exchange systems.

- Implement remedial actions such as soil or groundwater removal to reduce source concentrations.

Technical aspects of the RAP will be developed by the Site Professional on a site-specific basis. However, there are certain mandatory requirements that must be present in all RAPs:

- A reporting schedule and anticipated timeline;
- A detailed workplan of proposed activities at the site(s);
- A copy of the completed building and occupant survey;
- A clear statement of the remedial criteria or objectives including any indoor air concentrations for analytes of concern;
- A completed and detailed CSM;
- The identification of the parameters to be monitored or measured;
- A description of the planned monitoring program (e.g., when, where, how and for how long); and
- A description of how achievement of RAP objectives will be confirmed and reported.

Provincial regulators will require the Responsible Party and site professional to submit the RAP prior to implementation for review and approval.

7.4 Closure Monitoring

For sites where the soil vapours to indoor air pathway has been assessed to be insignificant and sites where RAP objectives have been achieved, a period of closure monitoring is required to confirm these conclusions under different site conditions. For instance, a single monitoring event does not account for potential seasonal variations nor provide an assessment of vapour plume stability. This is analogous to monitoring of a groundwater plume in which verification of seasonal fluctuations and plume stability is an expected part of the closure documentation. For soil vapour plumes, there are two primary considerations:

- Time for the vapour plume to reach to steady state; and
- Potential for seasonal fluctuations.

API, 2005, provide discussion on estimating the time necessary to achieve near steady state conditions. Based on an equation presented by Johnson et al. (1999), the time to reach near steady state varies with the length of the vapour transport pathway. For vapour sources <1 m from the building, steady state conditions may be reached in a few hours to a few days; for vapour sources up to 3 m depth, in a few months to a few years; and for deeper vapour sources (> 10 m depth) as much as a year to decades. However, it should be noted that for distant sources (laterally or vertically), aerobic biodegradation

will likely significantly reduce the path length over which concentrations decrease, thereby reducing the time taken to reach near steady state conditions.

Seasonal effects are known to influence vapour intrusion into buildings (e.g., building under-pressurizations) and measurements taken in summer may be different than measurements taken in winter.

The Site Professional is responsible to develop a closure monitoring program appropriate for the site-specific circumstances. Based on the above, closure monitoring may include, at a minimum, measurement of soil vapours or indoor air concentrations over a one year period with sampling conducted in the winter heating season as well as the summer months.

7.5 Site Closure

When the Responsible Party and the Site Professional are satisfied that the objectives of the RAP and the closure monitoring have been achieved, a closure report can be prepared and submitted to the Provincial regulator. Two general types of closure mechanisms are acceptable, each described briefly below.

7.5.1 Unconditional Closure

Unconditional closure allows for unrestricted future use of the property, based on reasonably foreseeable changes in land use, or for unrestricted use within a particular land use designation (e.g., commercial). Unconditional closure can be achieved by demonstrating that the objectives of the RAP and the closure monitoring have been achieved without further requirement for active site management, remediation, institutional or engineered controls.

7.5.2 Conditional Closure

Conditional closure is a mechanism that identifies requirements for on-going site management to protect human health, after remedial actions and monitoring are complete. Typically, these can be either institutional or engineered controls. Institutional controls serve to limit the use made of a property, for instance by limitations on human occupancy. Engineered controls serve to interrupt the transport pathway between the source and the receptor while allowing both to remain on site. Engineered controls may be passive or active. Examples of passive controls include sub-slab ventilation and vapour barriers. Examples of active controls include air exchange units and vapour extraction systems.

Regardless of the specific nature of the control(s) (i.e., institutional or engineered, passive or active), when controls are placed on sites to minimize risk, the Provincial regulator and all affected stakeholders must be in agreement with the specific controls.

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Appendix A: Derivation of Pathway Operability Tables

Derivation of Subsurface Vapours to Indoor Air Pathway Operability

US EPA (2002) published a draft Subsurface Vapour Intrusion Guidance that proposed a source – building separation distance of 30 m at which point the subsurface vapours to indoor air exposure pathway was no longer a concern. This guidance was based on a review of limited empirical data, use of the Johnson and Ettinger model, and professional judgement. Recent research has further evaluated the effect of source – building separation on vapour intrusion. Abreu and Johnson (2005) used three dimensional numerical modelling as a tool to anticipate relationships between vapour dilution factors and the following variables:

- source - building lateral separation;
- vapour source depth; and
- building construction.

The research was based on a specific set of assumptions about site conditions, including:

- non-degrading chemicals;
- steady source concentrations;
- homogeneous soil properties;
- permeable soil (vapour permeability = 10^{-7} cm^2); and
- typical residential construction.

These assumptions are likely to underestimate vapour dilution for petroleum hydrocarbon sites where biodegradation will have increasing effect as source – building separation distance increases. The authors demonstrated increases in vapour dilution from two to five orders of magnitude over a lateral separation distance of 25 m, depending on the depth of the vapour source. In addition to the factors listed above, establishment of a source – building separation distance beyond which the pathway is not of concern must also incorporate the vapour source strength and target RfC or RSC.

To apply these findings within Atlantic RBCA, there are two main assumptions:

- The permissible chemical concentration in soil or groundwater at any source – building separation distance can be referenced from the permissible soil or groundwater concentration directly below the building. Atlantic PIRI published indoor air Pathway Specific Screening Levels (PSSLs) for a set of default site conditions. The PSSLs represent the permissible levels of BTEX and TPH in soil or groundwater directly underneath a building.

- At soil or groundwater concentrations less than saturation or solubility limits, the source vapour concentration is directly proportional to the source soil or groundwater concentration.

Based on these assumptions, an increase in the vapour dilution factor of one order of magnitude (e.g., due to increasing source – building separation) would permit a corresponding one order of magnitude increase in the source soil or groundwater concentration without causing an increase in the resulting indoor air concentration. For instance, if the benzene PSSL equals 1 ppm, then up to 10 ppm would provide the same level of risk protection with an increase in vapour dilution of one order of magnitude.

To ensure a simple and protective approach, the Tier II PSSL tables in the Atlantic RBCA User Guidance (2003) were reviewed to identify the most stringent benzene and TPH indoor air PSSLs for soil or groundwater, for any land use, soil type, or fuel type. These values are:

- Benzene - 0.16 ppm (soil PSSL for coarse grained soil, residential land use)
  1 ppm (groundwater PSSL for coarse grained soil, residential land use)
- TPH - 39 ppm (soil PSSL for gasoline fuel type, coarse grained soil, residential land use)
  12 ppm (groundwater PSSL for gasoline fuel type, coarse grained soil, residential land use)

These criteria were then adjusted to calculate permissible source soil or groundwater concentrations at increasing source – building separation distances. For instance, for a source depth of 3 m, there was a one order of magnitude increase in the dilution factor with a source – building separation of 10 m. On this basis, source soil or groundwater benzene concentrations could be up to 1.6 ppm and 10 ppm, respectively, without resulting in increased risk to indoor air.

Similar derivations were made over increasing source – building separation distances, to develop tables of permissible source soil and groundwater concentrations. Based on the assumptions made by Abreu and Johnson and assumptions made in defining default site conditions when calculating the Tier II PSSLs, there are certain site conditions that preclude the use of these criteria, as follows:

- Preferential pathways (e.g., fractured bedrock, utility conduits, layered soils [e.g., coarse gravel seams]);
- Landfill gas, migrating under pressure;
- Surface features that would block the flow of oxygen or prevent dissipation of vapours (e.g., impermeable cover); and
- Expanding source zone.

Pathway Operability – Soil Source

Soil Source Concentration (ppm)		**Separation Distance – horizontal or vertical (m) (source edge to building)**							
Benzene	**TPH_{TOTAL}**[1]	0	5	10	15	20	25	30	35
≤0.16	≤39								
>0.16 – 1	>39 – 100								
>1 – 10	>100 – 1,000								
>10 – 100	>1,000 – 10,000								
>100 – 1,000	>10,000 – 100,000								
>1,000	>100,000								

Notes:

2. Total TPH including toluene, ethyl benzene, and xylenes

Indicates pathway is not operable.

If any of the following features are present, Table 1 cannot be applied and the subsurface vapours to indoor air pathway must be assessed up to a separation distance of 30 m:

- Preferential pathways (e.g., utility conduits, coarse gravel seams);
- Landfill gas, migrating under pressure;
- Surface features that would block the flow of oxygen or prevent dissipation of vapours (e.g., impermeable cover);
- Mobile phase-separated petroleum hydrocarbons (free product);
- Expanding source zone; and
- Site conditions that do not conform to the default site conditions used to calculate the Tier I RBSLs.

Pathway Operability – Groundwater Source

Groundwater Source Concentration (ppm)		Separation Distance – horizontal or vertical (m) (source edge to building)							
Benzene	**TPH_{TOTAL}** [1]	0	5	10	15	20	25	30	35
≤1	≤12								
>1 – 10	>12 – 100								
>10 – 100	>100 – 1,000								
>100 – 1,000	>1,000 – 10,000								
>1,000	>10,000 – 100,000								
N/A	>100,000								

Notes:

2. Total TPH including toluene, ethyl benzene, and xylenes

Indicates pathway is not operable.

If any of the following features are present, Table 2 cannot be applied and the subsurface vapours to indoor air pathway must be assessed up to a separation distance of 30 m:

- Preferential pathways (e.g., utility conduits, coarse gravel seams);
- Landfill gas, migrating under pressure;
- Surface features that would block the flow of oxygen or prevent dissipation of vapours (e.g., impermeable cover);
- Mobile phase-separated petroleum hydrocarbons (free product);
- Expanding source zone; and
- Site conditions that do not conform to the default site conditions used to calculate the Tier I RBSLs.

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Appendix B: Conceptual Site Model Checklist (after API, 2005)

Conceptual Site Model Checklist

The information in this checklist is intended to assist the Site Professional in developing relevant and specific conceptual site models for assessment of the subsurface vapours to indoor air pathway. The checklist is broadly organized by source, pathway, and receptor.

Source

- Complete an adequate site characterization that delineates the lateral and vertical extent of soil and groundwater contamination > Tier I RBSLs. Define the source area for the subsurface vapours to indoor air pathway.

- Identify the presence of phase-separated petroleum hydrocarbons (free product) and determine distribution and composition.

- Identify the chemicals of potential concern for the subsurface vapours to indoor air pathway and document their concentrations, physico-chemical properties, and potential for biodegradation.

- Describe the environmental media (e.g., soil ,groundwater, or both) containing petroleum hydrocarbons.

- Estimate source – building separation distances, both laterally and vertically.

- Consider the stability of the source area (i.e., stable, shrinking, expanding) and the potential effect on pathway assessment.

Pathway

- Log soil vadose zone properties including soil type, grain size distribution, moisture content, and presence of distinct soil layers that may influence vapour migration.

- Document the depth to impacts from ground surface.

- Monitor and record relevant hydrogeological characteristics including depth to the water table, hydraulic gradient, and flow direction. Document or estimate the potential for seasonal fluctuations.

- Map all underground utility lines in the area of the soil or groundwater impacts. Pay particular attention to conduits that connect the source area to the building and assess the potential for preferential vapour migration.

- Describe the surface cover over the source area and between the source and the potentially impacted building. Make particular note of impermeable cover materials such as asphalt paving.

Receptor

- Map the location, size, and type of all potentially impacted buildings.

- Identify the current and reasonably foreseeable future use and occupancy of the buildings.

- Inspect the potentially impacted buildings to identify relevant construction details including materials (e.g., concrete block walls), openings (e.g., sumps, windows, doors), height (i.e., number of storeys), and presence of elevator shafts.

- Where possible, inspect the basement and document the type of foundation (e.g., stone, poured concrete), floor condition (e.g., dirt floor, deteriorated slab), and depth below grade.

- Record the presence of any building mechanical systems (e.g., HVAC, furnaces) and document their potential effect on building characteristics such as indoor/outdoor pressure differentials (e.g., air exhausts, stack effects, source of return air [e.g., inside, outside, combination]).

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Appendix C: Building Inspection and Occupant Survey Form (after US EPA, 2002)

Building Inspection and Occupant Survey Form

Occupant Information

Date: _____

Name: _____

Address: _____

_____

_____

Home Phone: _____ Work Phone: _____

❒ Owner
❒ Tenant
❒ Other Specify: _____

Number of permanent occupants in this residence? _____

Number of children? _____ Ages: _____

How long have you lived in this residence? _____

Home Description

Age of home: _____

Type of home?
❒ Single family
❒ Duplex
❒ Townhouse
❒ Apartment
❒ Other Specify _____

Home dimensions?
Length: _____
Width: _____
Height: _____
No. of storeys: _____

Home construction? ❒ Wood
❒ Brick
❒ Concrete
❒ Cement block
❒ Other Specify _____

Foundation? ❒ Basement ❒ Slab on grade ❒ Crawl space
❒ Poured concrete
❒ Cement block
❒ Stone
❒ Brick
❒ Other Specify: _____

Water supply? ❒ Municipal ❒ Private Well
Location: _____

Septage? ❒ Municipal sewer ❒ Private system
Septic bed location: _____
_____

Do you have standing water around your home?

❒ No ❒ Yes Describe: _____
_____

Basement Details (if there is no basement, proceed to next section)

Is the basement finished? ❒ Yes ❒ No
❒ Utility/furnace room
❒ Rec. room
❒ Bedrooms Number: _____
❒ Other Specify: _____

Basement occupancy? ❒ Frequent (> 2 hours/day)
❒ Occasional (1-2 hours/day)
❒ Rare (<1 hours/day)

Basement floor?
- ❒ Concrete
- ❒ Wood
- ❒ Tile/linoleum
- ❒ Carpet
- ❒ Dirt
- ❒ Other Specify: _____

Moisture problems?
- ❒ Yes ❒ No
- ❒ Frequent (>3 times/year)
- ❒ Occasional (1-2 times/year)
- ❒ Rare (<1 time/year)

Flooding?
- ❒ Yes ❒ No
- ❒ Frequent (>3 times/year)
- ❒ Occasional (1-2 times/year)
- ❒ Rare (<1 time/year)

Does the basement contain:
- ❒ Floor cracks Extent: _____
- ❒ Wall cracks Extent: _____
- ❒ Sumps Number: _____
  Construction: _____
- ❒ Floor drains Describe: _____
- ❒ Other openings Describe: _____

Mechanical/Heating Systems and Appliances

Home heating?
- ❒ Natural gas
- ❒ Fuel Oil
- ❒ Electric
- ❒ Wood
- ❒ Coal
- ❒ Other Specify: _____

Heat distribution?
- ❒ Forced hot air
- ❒ Forced hot water
- ❒ Baseboard
- ❒ Wood stove
- ❒ Fireplace
- ❒ Other Specify: _____

Air conditioning? ❒ Yes ❒ No
❒ Central
❒ Window mounted
❒ Other Specify: _____

Water heater? ❒ Natural gas
❒ Electric
❒ By furnace
❒ Other Specify: _____
Location: _____

Clothes dryer? ❒ Yes ❒ No
❒ Vented outdoors
Location: _____

Stove exhaust hood? ❒ Yes ❒ No
❒ Vented outdoors
Location: _____

Household Activities

		Type/Quantity
Basement storage items?	❒ Paint	_____
	❒ Paint stripper	_____
	❒ Paint thinner	_____
	❒ Solvents	_____
	❒ Gasoline	_____
	❒ Diesel fuels	_____
	❒ Glues	_____
	❒ Cleaners	_____
	❒ Other	_____

Recent re-modelling/painting (within last 6 months)?
❒ Yes ❒ No
Describe (what, where, when):
_____
_____
_____
_____

Recent carpeting (within last 6 months)?

❒ Yes ❒ No

Describe (where, when):

_____

_____

_____

Indoor home hobbies? ❒ Yes ❒ No

❒ Soldering
❒ Welding
❒ Model glues
❒ Painting
❒ Wood finishing
❒ Other Specify: _____

_____

Smoking in the home? ❒ Yes ❒ No

❒ Cigarettes
❒ Cigars
❒ Pipe
❒ Other Specify: _____

Use of consumer products:

Product	Frequency of Use				
	Never	Rare	Occasional	Regular	Frequent
Air fresheners	❒	❒	❒	❒	❒
Insecticides	❒	❒	❒	❒	❒
Disinfectants	❒	❒	❒	❒	❒
Window cleaners	❒	❒	❒	❒	❒
Oven cleaners	❒	❒	❒	❒	❒
Nail polish removers	❒	❒	❒	❒	❒
Hair sprays	❒	❒	❒	❒	❒
Aerosol deodorizers	❒	❒	❒	❒	❒
Other _____	❒	❒	❒	❒	❒

Rare: < once/month
Occasional: ~once/month
Regular: ~once/week
Frequent: > once/week

Household cleaning:

Activity	Frequency				
	Never	Rare	Occasional	Regular	Frequent
Dusting	❒	❒	❒	❒	❒
Dry sweeping	❒	❒	❒	❒	❒
Vacuuming	❒	❒	❒	❒	❒
Polishing (furniture, etc.)	❒	❒	❒	❒	❒
Washing/waxing floors	❒	❒	❒	❒	❒
Other _____	❒	❒	❒	❒	❒

Rare: < once/month
Occasional: ~once/month
Regular: ~once/week
Frequent: > once/week

Additional comments: _____

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Appendix D: Example Calculation of Application of Soil TPH Fractionation to Indoor Air Results

Example Calculation of Application of Soil TPH Fractionation to Indoor Air Results

In cases when TPH fractionation cannot be completed on soil vapour or indoor air samples, it is necessary to apportion the Alberta MUST soil vapour or indoor air sample result, reported in carbon ranges of $C_6 – C_{10}$ and $C_{11} – C_{21}$, into fractions in order to evaluate the results against RfCs and calculate a TPH SSTL for indoor air. The recommended approach is to use the Atlantic RBCA Toolkit to predict Point of Exposure (POE) indoor air mass fractions, based on site-specific soil or groundwater TPH fractionation, and apportion the soil vapour/indoor air Alberta MUST result according to the calculated POE TPH mass fractions.

It is expected that all petroleum hydrocarbon impacted sites currently under assessment will have soil and/or groundwater fractionation data collected. For historic sites (i.e., assessed prior to the introduction of Atlantic RBCA in 1999), TPH fractionation data may not be available. In the absence of any site-specific TPH fractionation data, it is acceptable to enter one of the default fuel compositions provided in the Atlantic RBCA User Guidance. An example calculation is provided in the table below to illustrate this methodology.

Example Calculation

TPH Fraction	Default PIRI TPH Mass Fractions (gasoline)	Pro-Rate PIRI MFs to Maximum Site Concentration (5,000 ppm)[1]	POE Indoor Air Concentration (mg/m^3)[2]	POE Indoor Air Mass Fractions[3]	Alberta MUST Soil Vapour/Indoor Air Result (mg/m^3)	Apportioned Soil Vapour/Indoor Air Result (mg/m^3)
Al $C_{>6} – C_8$	0.22	1,447	35.51	0.64	100	65.2
Ar $C_{>7} – C_8$	0.06	395	10.26	0.18		18.8
Al $C_{>8} – C_{10}$	0.13	855	4.55	0.08		8.4
Ar $C_{>8} – C_{10}$	0.15	987	4.13	0.07		7.6
Al $C_{>10} – C_{12}$	0.1	658	0.54	0.01	10	5.4
Ar $C_{>10} – C_{12}$	0.1	658	0.46	0.01		4.6
Al $C_{>12} – C_{16}$	0	0	0	0		0
Ar $C_{>12} – C_{16}$	0	0	0	0		0

Notes:

1. For the purposes of this calculation, TPH mass fractions must be pro-rated to the maximum site concentration to ensure that effects of saturation or solubility limits are incorporated. For instance, the value of C_{sat} for Al $C_{>10} – C_{12}$ for default coarse grained soil equals 43 mg/kg. Above this soil concentration, there is no further increase in equilibrium vapour concentrations. In the example above, the POE Indoor Air mass fraction for Al $C_{>10} – C_{12}$ would be different if the Atlantic RBCA Toolkit calculations were conducted with the soil TPH mass fractions directly.
2. Values provided in the Indoor Air Risk by Pathway worksheet in the Atlantic RBCA Toolkit.
3. Note that the relative mass fractions in air at the POE are noticeably different to the relative mass fractions in soil at the source. This difference reflects differences in physico-chemical properties of the fractions (e.g., Henry's Law constant, K_{oc}, C_{sat}).