ATLANTIC RBCA (Risk-Based Corrective Action)

Version 3.0

For Impacted Sites in Atlantic Canada

Guidance for Vapour Intrusion Assessments (December 2016, updated April 2019)

Summary of Changes to Guidance for Vapour Intrusion Assessments (from December 2016 version to April 2019 version)

Location in document	Change made	Rationale
Title page	Date changed from "December 2016" to "December 2016 (revised April 2019)"	This was the approach used previously when updating User Guidance, Version 3 in January 2015 when drinking water guidelines changed
Section 2.2, page 4	"… as more data become~~s~~ available."	Typo in original version (data are plural)
Page 5, Page 11, Page 13	All references to (Atlantic PIRI, 2012) have been updated to (Atlantic PIRI, 2015)	Consistency with respect to how the User Guidance is referenced in the document.
Table 3, Page 7	Changed "Exceed Indoor Air PSSLs" to "Exceed Indoor Air PSSLs or PSSLs not applicable"	Added reminder to Site Professionals that if PSSLs are not applicable, they may not be used to screen out the VI pathway
Table 4, Page 8	"Samples should not be collected when soil surrounding the screen or implant is frozen, or within a day after a heavy rainfall event (defined here as more than 5~~10~~ mm)."	Reflects guidance from Exceed Indoor Air PSSLs or PSSLs not applicable CCME (2016) *Guidance Manual for Environmental Site Characterization In Support Of Environmental And Human Health Risk Assessment*, which defines significant rainfall event as 0.5 cm and recommends a minimum of 1 day wait after significant rainfall for coarse grained soil.
Section 3.1, Page 9	"The Site Professional may wish to consult ITRC (2014) ~~for their "Investigation Methods and Analysis Toolbox"~~ or CCME (2016) for their construction and sampling methods, or consult with the analytical laboratory for analytical methods."	CCME (2016) *Guidance Manual for Environmental Site Characterization In Support Of Environmental And Human Health Risk Assessment* (Volumes 1-4) reflects the most recent Canadian guidance on probe construction and sampling, and therefore reference added.
Section 3.1.2, Page 10	"An exception to this is soil vapour samples collected from an area of plume stability (e.g., at depth, within a source zone), and measured concentrations are at least an order of magnitude below concentrations of concern. ~~There is sufficient evidence to support that variations of orders of magnitude are not anticipated for stable source zones, and as such~~In these circumstances, one sampling event may be sufficient (~~Health Canada, 2008~~ CCME, 2016). The Site Professional is expected to provide justification for classifying the ~~source zone~~ sampling location as "stable" "	Updated to CCME (2016) and clarified meaning.

Summary of Changes to Guidance for Vapour Intrusion Assessments (from December 2016 version to April 2019 version)

Location in document	Change made	Rationale
Section 3.1.3, Page 10	"For indoor air ~~and sub-slab~~ samples, the sample duration is expected to reflect the exposure time of the building occupants (current or future). For residential buildings, exposure should be considered over a 24-hour period, while for commercial buildings, a sampling time of at least 8 hours is recommended."	From CCME (2016): "For subslab soil vapour probes, it may be desirable to collect a subslab vapour sample concurrently with an indoor air sample to enable comparison to indoor air data and to reduce short-term variability. However, given the overall variability in subslab measurements and processes for vapour intrusion, a shorter-duration subslab sample (e.g., 15 to 30 minutes) is considered acceptable and collection of concurrent subslab vapour and indoor air samples is not considered required practice."
Section 3.1.4, Page 11	Changed: "If leakage is greater than 10%, then either the probe or the sampling apparatus is leaking and corrective action must be taken." To "Leakage less than 2% is considered acceptable. At higher leakage rates, there is reason to suspect that either the probe or the sampling apparatus is leaking. Connections and the probe should be examined and potential sources of leaks addressed prior to repeating the leak test. If leakage remains above 2%, the suitability of the sample results and how the uncertainty associated with the results was incorporated into the assessment conclusions are to be documented in the report."	In 2016, CCME finalized their *Guidance Manual for Environmental Site Characterization In Support Of Environmental And Human Health Risk Assessment*. The final version of the document identified the threshold for acceptance as 2%.

Summary of Changes to Guidance for Vapour Intrusion Assessments (from December 2016 version to April 2019 version)

Location in document	Change made	Rationale
Section 3.2, Page 11	Changed "The toxicological information for PHCs and transport equations are summarized in Appendix D." To "The equations and values used to derive the VISLs are provided in Appendix C."	Change made to reflect updates to appendices.
References, Page 16	Removed "Health Canada. 2008. Guidance Manual for Environmental Site Characterization in Support of Human Health Risk Assessment. Volume 1 Technical Guidance, Contaminated Sites Division. July 2008." And replaced with: "CCME. 2016. Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment. Volumes 1 to 4. Contaminated Sites Division."	The CCME (2016) Guidance Manual supersedes the Health Canada (2008) guidance manual.
Appendix B, Table B1, page 1	VISLs for Soil Vapour (>1 m from foundation) updated for all petroleum hydrocarbons	For Agricultural/Residential, updated values have been corrected for an error found in the original calculation and incorporate a biodegradation factor (BAF) of 10, consistent with CCME (2014) guidance. For Commercial/Industrial, updated values incorporate a biodegradation factor (BAF) of 10, consistent with CCME (2014) guidance. We also updated several sub-slab residential VISLs, and the sub-slab and soil vapour commercial toluene VISLs to correct a rounding error in the original spreadsheet, and are shown in track changes. Revised values are slightly higher than previously reported. There have been no other changes to the indoor air or sub-slab VISLs.

Summary of Changes to Guidance for Vapour Intrusion Assessments (from December 2016 version to April 2019 version)

Location in document	Change made	Rationale
Appendix C and Appendix D	Previously, Appendix C was "Sample Calculation – Index of Additive Cancer Risk" and Appendix D was "Transport Equations and Toxicological Values for PHCs". Reversed order of Appendices.	The first reference to the toxicological information (page 11) is provided before the first reference to the sample calculation (page 12).
Appendix C – Equations used for the derivation of health-based VISLs	Substantially overhauled the appendix to: • Include full equations (not just the transport equations) • Updated the toxicity data for mTPH fractions (typographical error in original appendix) • Provided tables for summarizing chemical properties (obtained from Atlantic RBCA Toolkit), building and soil characteristics (obtained from Table 8 of User Guidance document), and exposure assumptions (obtained from Table 7 of User Guidance document)	By including equations in the form of VISL = … it will make it easier to follow the calculations for each type of VISL. Also uses similar nomenclature as CCME guidance documents to further simply understanding. By providing the additional data, the VISL document now contains all the information necessary to reproduce each of the VISLs provided in Table B.1. Updated the name of the Appendix to better reflect the revised contents
Appendix C, Page 3	Added the following text: "These same default attenuation factors may also be used for soil vapour samples (i.e., samples collected > 1 m from a building foundation) if site conditions do not meet generic criteria (e.g., presence of a dirt floor, the building is taller than 4 floors, residence does not have two floors, there are preferential pathways present). In other words, sub-slab VISLs may be applied to soil vapour probe sample results on sites where the default conditions do not apply."	The previous "Appendix 9" soil vapour guidance provided a default attenuation factor that could be applied to soil vapour results when building did not meet default requirements for applying J&E model. The wording matches guidance from CCME (2014). The key difference: where previously Atlantic PIRI accepted a default attenuation factor of 0.01 (dilution factor, DF = 100) for all buildings, the revised CCME (2014) guidance suggests that the default attenuation factor for a residential property should now be 0.03 (DF=33). This wording and intent should be confirmed by Atlantic PIRI.
Appendix D – Sample Calculations	Additions to the appendix to include calculation of residential soil vapour VISL for toluene.	Provided additional sample calculation to clearly demonstrate that the revised VISLs are correctly calculated and increase confidence of Site Professionals relying on the document.

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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

Atlantic PIRI would like to thank Stantec Consulting Limited for developing this guidance document. We would also like to thank our corresponding members for their comments, as well all the other stakeholders who provided input and comments as part of the public review process.

GLOSSARY OF TERMS

BTEX	Benzene, toluene, ethylbenzene, and xylenes
CCME	Canadian Council of Ministers of the Environment
CSM	Conceptual Site Model
ESA	Environmental Site Assessment
IAR	Index of Additive Risk
ITRC	The Interstate Technology & Regulatory Council
m bgs	Metres below ground surface
mTPH	Modified Total Petroleum Hydrocarbons
PHCs	Petroleum hydrocarbons
PIRI	Partnership in RBCA Implementation
POE	Point of Exposure
PSSL	Pathway-Specific Screening Level
QA/QC	Quality Assurance/Quality Control
RBCA	Risk-Based Corrective Action
RBSL	Risk-Based Screening Level
TPH	Total Petroleum Hydrocarbons
US EPA	United States Environmental Protection Agency
VI	Vapour Intrusion
VISL	Vapour Intrusion Screening Level

PREFACE

This Atlantic RBCA (Risk Based Corrective Action) document is founded on the principle of protection of human health. It is intended to assist those involved with contaminated site management in their assessment of the subsurface vapours to indoor air exposure pathway, also known as the vapour intrusion pathway.

This document is intended to guide how the results of soil vapour and indoor air sampling programs are interpreted and applied within the Atlantic RBCA framework, and within Provincial contaminated site management processes, to obtain site closure. While it provides an overview of some best practices for completing vapour intrusion assessments in Atlantic Canada, Site Professionals are responsible for confirming that the testing methods and techniques they use are consistent with current day industry standards.

This guidance may be updated as new research and information becomes available. Users should consult the Atlantic RBCA web site at http://www.atlanticrbca.com/ for the latest version of this document.

Site Professionals are reminded to involve Provincial regulatory staff throughout the contaminated sites management process, particularly where there may be uncertainties related to Provincial policies or regulations.

TABLE OF CONTENTS

LIST OF FIGURES, TABLES, AND APPENDICES

FIGURES

TABLES

APPENDICES

1.0 INTRODUCTION

This document was prepared under the direction of Atlantic Partners in RBCA (Risk-Based Corrective Action) Implementation (PIRI). Atlantic PIRI also published a *User Guidance* document (Atlantic PIRI, 2015) that provides technical guidance on the use of the Atlantic RBCA tiered approach and the Atlantic RBCA toolkit. The *User Guidance* (Atlantic PIRI, 2015) provides Tier I Risk Based Screening Levels (RBSLs) for soil and groundwater that are considered protective of human health through multiple exposure pathways, and Tier II Pathway Specific Screening Levels (PSSLs), developed for individual exposure pathways. The *User Guidance*, along with provincial contaminated site management documents, may be updated from time to time. For the latest versions, users should consult the Atlantic RBCA web site at http://www.atlanticrbca.com/

This document provides specific guidance on the assessment of the migration of vapours from a subsurface contaminant source through unsaturated soil and into buildings, where vapours then mix with the indoor air. This is referred to as vapour intrusion (VI).

1.1 Background

In 2006, Atlantic PIRI published the *Guidance for Soil Vapour and Indoor Air Monitoring Assessment* as an appendix (Appendix 9) to the Atlantic RBCA v2.0 *User Guidance* to provide technical assistance to Responsible Parties and Site Professionals when assessing vapour intrusion and the indoor air pathway. It included vapour intrusion theory, sampling methods, and interpretation of monitoring results. In 2012, the *Guidance for Soil Vapour and Indoor Air Monitoring Assessment* was re-released as a stand-alone document that included errata to address changes associated with Atlantic RBCA Version 3.2, but it was not updated to reflect new information and research that had been published since 2006.

The *Guidance for Vapour Intrusion Assessments* (this document) supersedes the *User Guidance for Soil Vapour and Indoor Air Monitoring Assessments* (Atlantic PIRI, 2006).

1.2 Purpose

The purpose of this document is to produce simplified guidance for Site Professionals and property owners that outlines the Atlantic RBCA approach to assessing the potential for vapour intrusion, and provide Site Professionals with appropriate Vapour Intrusion Screening Levels (VISLs) that can be used to screen soil vapour, sub-slab, and indoor air monitoring results for potentially unacceptable risk.

1.3 Scope

This guidance document is primarily intended to be used by Site Professionals with detailed knowledge and experience in the management of contaminated sites in conjunction with the *User Guidance* (Atlantic PIRI, 2015).

The focus of this guidance is the protection of human health due to long term or chronic exposure. This document does not address potential short-term or acute health and safety risks from vapour intrusion. The Site Professional is responsible for identifying potential short term or acute health and safety risks due to vapour intrusion (*e.g.*, wet basement in direct contact with contamination, explosive conditions, strong odours) and for developing, recommending, and implementing mitigative measures for acute risks in conjunction with their client.

This guidance provides an overview of best practices for completing vapour intrusion assessments in Atlantic Canada. Site Professionals are responsible for confirming that the testing methods and techniques they use are consistent with current industry standards. Guidance documents from other jurisdictions and findings from the scientific literature current at the time of writing are cited throughout, and are considered additional resources for Site Professionals.

1.4 General Approach

The general vapour intrusion assessment approach recommended by Atlantic PIRI is illustrated in Figure 1 (adapted from ITRC, 2014). Each step of this approach is described in greater detail in Sections 2 to 5.

While the approach provided herein is applicable to volatile contaminants in general, Tier II Vapour Intrusion Screening Levels (VISLs) are limited to select petroleum hydrocarbons (PHCs). Specifically, these select PHCs include benzene, toluene, ethyl benzene, xylenes (collectively referred to as BTEX), and modified total petroleum hydrocarbons (mTPH).

Consistent with the Tiered approach described in the *User Guidance* (Atlantic PIRI, 2015), the assessment of those volatile contaminants for which there are no VISLs is considered a Tier III assessment.

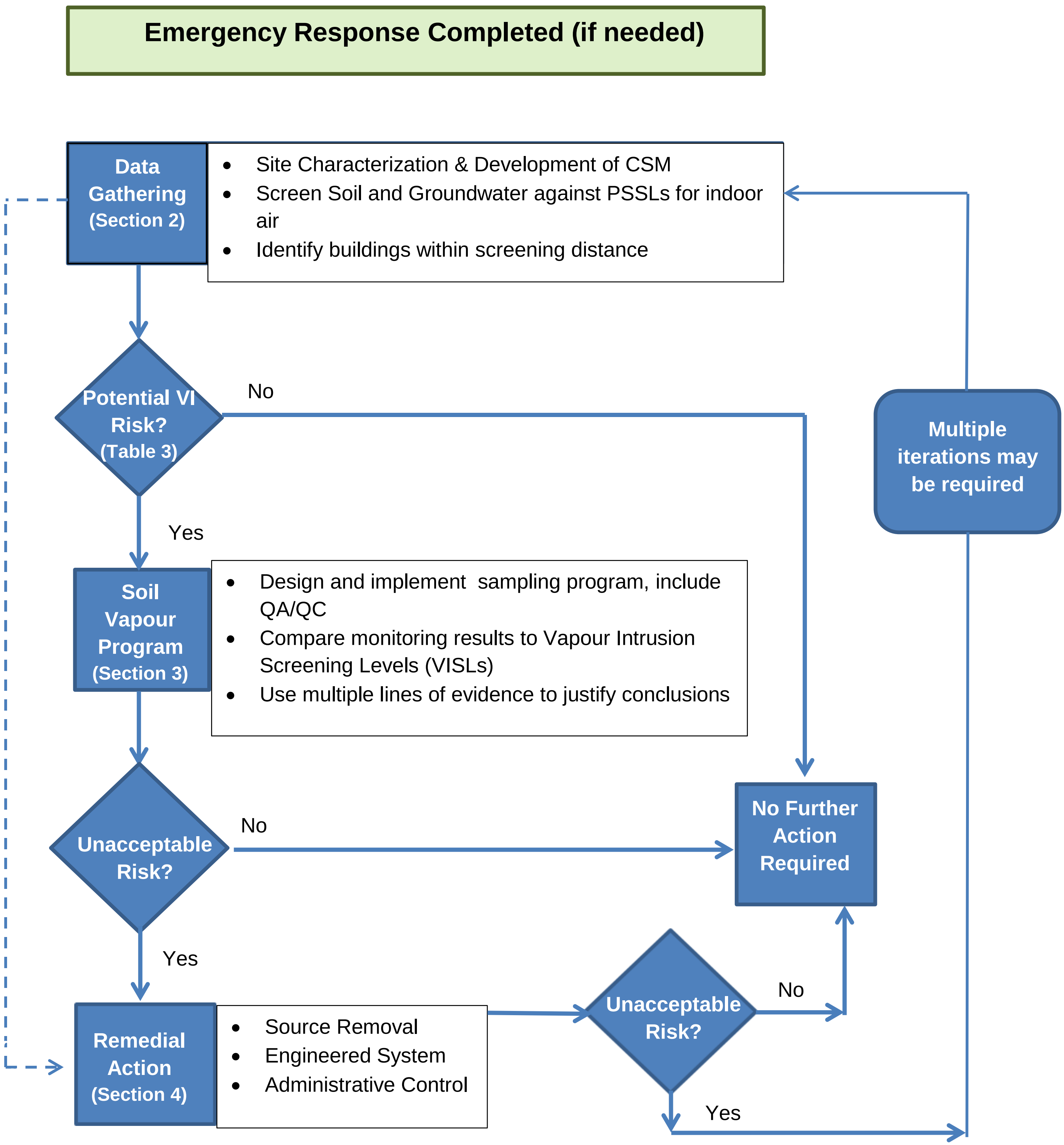

Figure 1 **Generalized Vapour Intrusion Assessment Approach (details provided in subsequent sections of document)**

2.0 DATA GATHERING

For there to be a vapour intrusion risk, there must be a source of volatile-producing contaminants in soil or groundwater, and a building must be present (or could be constructed) near that source. The purpose of the data gathering step is to collect sufficient information to confirm if these conditions are met.

2.1 Site Characterization

Vapour intrusion investigations are conducted as part of a phased environmental site assessment, typically when contaminant concentrations in soil or groundwater exceed generic Tier II PSSLs for indoor air, or when generic PSSLs for indoor air are not applicable (*e.g.*, dirt floor basement). Environmental site assessments should be conducted according to industry best practices, consistent with the *User Guidance* (Atlantic PIRI, 2015) and any applicable provincial guidance documents. The environmental site assessment(s) should provide sufficient site characterization data for the Site Professional to develop a conceptual site model (CSM).

2.2 Development of a Conceptual Site Model

A CSM is a written or graphical representation of the site characterization data where contaminant sources, exposure and migration pathways, and receptors are identified. The CSM should be developed as early as possible in the environmental site assessment process, and continually refined as more data become available. Information gathered during the phased environmental site assessment forms the basis of the CSM which is required to design subsequent vapour intrusion sampling programs, if required. If sufficient site details are not available to complete the CSM, additional environmental site assessment may be warranted. The CSM should describe each of the elements provided in Table 1.

Table 1 Elements of a Conceptual Site Model

Source Area Characteristics
• Contaminants of concern, including physical/chemical properties (approved physical/chemical properties for PHCs are included in the Toolkit model). • Source area(s) • Extent of contaminant concentrations in soil and groundwater • Depth of contaminants and distance (lateral and vertical) to receptors (*i.e.*, current and/or future occupied buildings) • Presence/absence of free product, and if present, findings of assessment completed as per the *User Guidance* (Atlantic PIRI, 2015) (*e.g.*, expanding source zone)

Table 1 Elements of a Conceptual Site Model

Subsurface Characteristics
• Unsaturated zone stratigraphy, including layering • Depth to water table, groundwater flow direction and gradient, and seasonal fluctuation • Perched water tables or low permeability zones • Natural or man-made preferential pathways for vapour migration   ◦ Thickness of relatively clean soil between source and building foundation. For the purpose of vapour intrusion assessment of PHCs, relatively clean soil is defined by Tier II PSSLs for indoor air for residential land use (applies to both residential and commercial contaminated sites)
Building Characteristics
• Building use (residential, commercial, industrial) • Size and construction, including foundation type, depth, condition, and presence of dirt-bottom sumps • Location relative to contamination • Heating and mechanical systems, presence of elevators

2.3 Screening Soil and Groundwater Sampling Results

Concentrations of contaminants in soil and groundwater should be screened against the applicable Tier II PSSLs for indoor air provided in the *User Guidance* (Atlantic PIRI, 2015). If maximum concentrations of contaminants are higher than the Tier II PSSLs, there is a risk of vapours intruding into buildings within the vapour intrusion screening distance (see Section 2.4) at concentrations above human-health based guidelines and additional assessment or remediation will be required.

Users are reminded that certain mandatory criteria must be satisfied in order to apply the Tier II PSSLs for soil and groundwater, as listed in the *User Guidance* (Atlantic PIRI, 2015). Mandatory criteria that are specific to the indoor air pathway include:

- Non-aqueous phase liquids must not be present in soil or groundwater within the applicable vapour intrusion screening distance (see Section 2.4) or adjacent to existing or potential receptors; and
- The site characteristics and exposure scenarios must be compatible with the Atlantic RBCA default values.

If these mandatory criteria are not met, Site Professionals may proceed directly to soil vapour or indoor air testing (Section 3.0) or remedial action (Section 4.0) to address the vapour intrusion pathway.

For contaminants that do not have RBSLs or PSSLs, the *User Guidance* (Atlantic PIRI, 2015) provides instructions for alternative means of evaluation as part of a Tier III assessment. Users are cautioned that when using soil or groundwater indoor air specific screening levels from other jurisdictions, it is the responsibility of the Site Professional to be familiar with the limitations associated with those guidelines, and confirm that site conditions are compatible with the use of those guidelines. Consultation with Provincial regulatory staff to confirm acceptance is also recommended.

2.4 Vapour Intrusion Screening Distance

There is a limited distance over which vapours can migrate from a source zone, through relatively clean soil, before concentrations are attenuated to levels that would not generate a vapour intrusion concern.

Although buildings within 30 m laterally or vertically of subsurface vapour sources are generally considered sufficiently close to be at risk of vapour intrusion (CCME, 2016; US EPA, 2013b), aerobic biodegradation of petroleum hydrocarbon vapours substantially reduces the migration distance with a number of studies indicating that a vertical distance of 5 m is protective for petroleum sources, including those sites with LNAPL present (Davis, 2009; Lahvis et al., 2013; US EPA, 2015; ITRC, 2014). The vertical screening distances are generally expected to apply laterally in the absence of preferential pathways (ITRC, 2014). For most soils, sufficient moisture, nutrients, and oxygen are present such that microbial biodegradation of petroleum hydrocarbons is not inhibited (ITRC, 2014). As a result, Atlantic PIRI has adopted revised screening distances for identifying current or future occupied buildings at risk of vapour intrusion, as shown in Table 2.

Table 2 Screening Distance for Potential Vapour Intrusion

Contaminant Type	Vapour Intrusion Screening Distance (Lateral and Vertical)
PHCs (BTEX, mTPH) (all cases except as noted below)	5 m
PHCs (BTEX, mTPH) in highly organic soils	30 m
PHCs (BTEX, mTPH) from fuels that are greater than 10% ethanol	30 m
Other volatile compounds	30 m

To apply the screening distances, the following mandatory criteria must be satisfied:

a. Mobile non-aqueous phase liquids (mobile free product) must not be present in soil or groundwater (i.e., the lateral extent of any NAPL plume is not advancing)
b. Preferential pathways (including both constructed features such as utilities and natural features such as bedrock fractures) that intercept both the source zone and a building foundation must not be present
c. On-going releases are not occurring and the groundwater plume front is stable
d. Vapours are not migrating under pressure (such as landfill gas)
e. For PHCs, the screening distance does not include high organic content soils (such as wetlands or peat bog areas) that would result in anaerobic conditions.

For the special case of sites contaminated with fuels containing more than 10% ethanol, or with contamination in high organic soils (i.e., wetland or peat bog areas), the 5 m screening distance may not apply.

2.5 Assessment of Potential Vapour Intrusion

Based on the Data Gathering process outlined in Sections 2.1 to 2.4, potential vapour intrusion risks can be identified using Table 3.

Table 3 Identification of Potential Vapour Intrusion Based on Data Gathering

		Buildings Present or Reasonably Foreseen Within Vertical or Lateral Screening Distance?	
		No	**Yes**
Concentrations in Soil and Groundwater	**Meet Indoor Air PSSLs**	Vapour intrusion pathway screened out	Vapour intrusion pathway screened out
	Exceed Indoor Air PSSLs or PSSLs not applicable	Vapour intrusion pathway screened out	**Unacceptable vapour intrusion risk – further investigation, risk management or remediation required**

Where a potentially unacceptable vapour intrusion risk is identified, proceeding to a soil vapour investigation (Section 3.0) or remedial action (Section 4.0) is required to address the potential human health risks associated with this exposure pathway.

3.0 SOIL VAPOUR PROGRAM

3.1 Design of the Sampling Program

The sampling program is to be designed to collect sufficient information to make appropriate decisions. A sampling program should be designed to determine if soil or groundwater concentrations in a source area are resulting in a vapour source that may represent a vapour intrusion risk, or if vapours are present beneath an existing building at concentrations that could present a vapour intrusion risk, or where vapours are entering an existing building.

The vapour sampling program can include one or more of the following: soil vapour probe samples (from source zone or shallower), sub-slab vapour probe samples, and indoor or outdoor ambient air samples, as described in Table 4. Samples are typically collected on sorbent material or in canisters.

Additional guidance on sample density, sampling frequency, sampling duration, and quality assurance and quality control are provided in the following sub-sections.

Table 4 Overview of Vapour Sampling Options

Sample Media	Description in Context of this Guidance	Notes
Soil Vapour	Soil vapour that is outside the zone of influence of the building (greater than 1 m from foundation). Probe may be designed to collect a sample directly from the source zone or between source and receptor.	Samples collected from the source zone represent the highest vapour concentrations at the site; however, the results do not reflect losses during transport (such as biodegradation, which is an important transport mechanism for PHCs). Samples collected between the source and the receptor will reflect transport mechanisms, including biodegradation. The depth of soil vapour samples collected outside the building zone of influence should be no shallower than one half the distance between the source depth and the building foundation (*e.g.*, if the building foundation is at 2 m depth, and the source of vapours is at 4 m depth, soil vapour samples from outside the building footprint must be at least 3 m deep). Samples collected at shallow depths (< 1 m bgs) may be less stable and are at greater risk of leakage from surface (ITRC, 2007), although studies have shown that it is possible to collect samples from depths as shallow as 0.6 m (USEPA, 2010). The onus is on the Site Professional to confirm that samples from shallow depths are representative and meet the sampling program objectives. Samples should not be collected when soil surrounding the screen or implant is frozen, or within a day after a heavy rainfall event (defined here as more than 5 mm).
Sub-slab vapour	Soil vapour samples that are typically collected directly beneath a floor slab, but also includes those collected up to 1 m below floor slab, or up to 1 m laterally beyond building footprint.	Samples collected within 1 m of a building foundation are potentially under the influence of the heating/cooling/air exchange of the building. Vapour concentration in sub-slab samples may vary based on occupant activities, and seasonally based on influence from building (heating/cooling), but are not influenced by rainfall.

Table 4 Overview of Vapour Sampling Options

Sample Media	Description in Context of this Guidance	Notes
Ambient indoor air	Air sample that is representative of occupant exposure, collected over a representative exposure period (*e.g.*, 24 hours for residential exposure) and from the breathing zone (approximately 1.0 to 1.5 m above the floor).	Indoor air quality varies based on occupant activities. Many household products and building materials emit volatile organic compounds. These background sources complicate the determination of whether vapour intrusion is occurring at the site and may result in considerable temporal and spatial variability. In these cases, paired ambient air and sub-slab samples may be required to distinguish background sources. A Building Inspection and Occupant Survey form is provided in Appendix A to aid the user in identifying common sources of volatile contaminants, and potential building influences on ambient conditions. Removal of identified volatile-containing products and abstinence from activities that release volatiles (*e.g.*, indoor grilling, using chemical air fresheners, smoking) at least 1 week in advance of sampling is recommended.
Ambient outdoor air	Air sample that is representative of outdoor air that is likely entering the building.	Outdoor air samples are typically collected at the same time as indoor air samples, over the same collection period. These outdoor air samples may be used to identify background sources outside the building such as vehicle emissions or other local sources of air pollution. Outdoor air samples may be collected from the breathing zone (approximately 1.0 to 1.5 m from ground surface) or near a known air intake for the building. Considerable temporal variability is possible.

There are a wide variety of sampling methods and analyses for soil vapour, sub-slab gas, and indoor air. It is not the mandate of this document to provide a prescriptive methodology. The Site Professional may wish to consult ITRC (2014) or CCME (2016) for their construction and sampling methods, or consult with the analytical laboratory for analytical methods.

3.1.1 Sample Density

The number of sample locations (sample density) required to meet the program objectives will vary from site to site. The following guidance is considered best practice:

- For the assessment of individual buildings, two or three soil vapour or sub-slab probes are recommended for a typical residential dwelling (US EPA, 2004).

- For source areas potentially affecting many buildings, it may not be necessary to have two or three soil vapour or sub-slab probes per building; however, there should be a minimum of one soil vapour (or sub-slab) sample for every existing or future building (ITRC, 2007).
- When the soil vapour program is limited to samples collected outside of buildings, there is a need to collect enough soil vapour samples to determine a representative soil vapour concentration given that soil vapour concentrations may vary by a factor of 10 to 100 between probes situated on either side of relatively small buildings such as houses (Sanders and Hers, 2006; DiGiulio, 2003).
- For small buildings (*i.e*., similar to Atlantic PIRI default residential building of 150 m^2), one indoor ambient sample per level may be sufficient, while larger buildings may require additional samples.

The Site Professional is responsible for designing the soil vapour assessment program and is expected to provide their rationale for the number of sample locations selected.

3.1.2 Sampling Frequency

As temporal variation is common for the same media, a minimum of two seasonal events (spring/summer and fall/winter) is recommended for decision making to confirm that the seasonal influences, including any heating and cooling systems, have been captured. An exception to this is soil vapour samples collected from an area of plume stability (*e.g*., at depth, within a source zone), and measured concentrations are at least an order of magnitude below concentrations of concern. In these circumstances, one sampling event may be sufficient (CCME, 2016). The Site Professional is expected to provide justification for classifying the sampling location as “stable”.

3.1.3 Sampling Duration

The duration of soil vapour sample collection (*i.e*., the time over which a sample is collected) may vary, but samples should be collected at flow rates between 10 and 200 mL/min.

For indoor air samples, the sample duration is expected to reflect the exposure time of the building occupants (current or future). For residential buildings, exposure should be considered over a 24-hour period, while for commercial buildings, a sampling time of at least 8 hours is recommended.

Site Professionals are reminded that for collection of samples on sorbent tubes, the sample duration must be sufficient to result in a detection limit concentration that is lower than the appropriate screening level.

3.1.4 Quality Assurance/Quality Control

Quality Assurance/Quality Control (QA/QC) should be part of any vapour intrusion assessment plan, and include:

- Leak testing: Soil vapour and sub-slab vapour probe integrity should be tested for leaks following installation once grout has hardened (if applicable), and before subsequent sampling events. A Helium shroud is commonly used to leak test the probe and the apparatus, while a shut-in test may be used to leak test the sampling apparatus. In the case of a large sampling program (*i.e.*, 10 or more probes), testing only a representative number of the probe locations may be acceptable. Leakage less than 2% is considered acceptable. At higher leakage rates, there is reason to suspect that either the probe or the sampling apparatus is leaking. Connections and the probe should be examined and potential sources of leaks addressed prior to repeating the leak test. If leakage remains above 2%, the suitability of the sample results and how the uncertainty associated with the results was incorporated into the assessment conclusions are to be documented in the report.
- Purging: the probe (and tubing volume) is to be purged 3-5 volumes prior to sampling.
- The vacuum on the sampling apparatus (for sorbent tube sample collection) is less than 10 inches of water.
- Vacuum on canisters: the vacuum on canisters is to be recorded at the end of the sampling period and is expected to be not less than 2 inches of mercury. If the canister pressure is less than 2 inches of mercury, or at atmospheric pressure when the final pressure check is performed, the sampling period may be suspect (ASTMD5466). In these circumstances, Site Professionals are expected to discuss how the lack of adequate vacuum may have affected their results.
- Field duplicates: a minimum of 1 field duplicate per sampling event is required, or 10% per media type per sampling event. If the relative percent difference between the duplicate and parent sample is greater than 50%, the Site Professional should provide an explanation of how this variability may affect the findings and conclusions of the assessment.
- Field blanks: field blanks may be useful to meet certain design objectives but are not mandatory.

3.2 Assessment of Monitoring Results

The Tier II VISL Table values (provided in Appendix B) are to be used to screen sites for vapour intrusion, including sites where NAPL is present. The VISLs were calculated for PHCs based on default values for building and soil characteristics from Tables 7 and 8 of the *User Guidance* (Atlantic PIRI, 2015), the physical, chemical, and toxicological information for PHCs from the Atlantic RBCA Toolkit and using the standard transport equations provided in CCME (2008, 2014). The equations and values used to derive the VISLs are provided in Appendix C.

The following sections describe how to use the VISLs, and discuss how a Site Professional may calculate Tier III SSTLs.

3.2.1 Tier II Vapour Intrusion Screening Levels

The Tier II VISLs for PHC sub-slab vapour and ambient air results are not dependent on building characteristics. However, Site Professionals must confirm that the building characteristics at the site conform with Atlantic RBCA defaults prior to applying the soil vapour VISLs. Factors that may preclude the use of soil vapour VISLs include:

- Residential single story house (*i.e.,* no basement)
- Floor slab thickness less than 11.25 cm (or no floor slab)
- Concrete floor with cracks exceeding the default crack fraction (which assumes no openings, such as sump pits or floor drains)
- Dirt floor or rock wall basements

For the assessment of petroleum hydrocarbons (mTPH), the Index of Additive Risk (IAR) must also be assessed to account for the cumulative effects of the mixture. Measured concentrations are considered acceptable if each subfraction is below its respective VISL and the calculated IAR is less than 1. A sample calculation of IAR is provided in Appendix D.

Although it is recommended that samples from petroleum contaminated sites be analyzed for TPH fractionation, it is recognized that in some instances, there will be insufficient TPH in the sample to provide meaningful TPH fractionation results. In these instances, the laboratory may provide a concentration for $>C_6-C_{10}$, and $>C_{10}-C_{16}$ and the Site Professional may conservatively compare the $>C_6-C_{10}$ and $>C_{10}-C_{16}$ concentrations to the lowest VISL of any individual PHC fraction in that group and conduct an IAR check.

3.2.2 Tier III Site-Specific Target Levels

Where the default characteristics used to develop the VISLs do not represent site conditions, or a VISL has not been developed for the contaminant of concern at the site, Tier III SSTLs can be calculated using the same equations that were used to develop the Tier II VISLs. Similar to the approach for Tier II VISLs for mTPH, measured concentrations are considered acceptable if each subfraction is below its respective Tier III SSTL and the calculated IAR is less than 1. These equations are provided in Appendix C. Limitations have been placed on some parameters to minimize inadvertent unreasonable input assumptions, which commonly lead to unreasonable outputs (Johnson, 2005). These limitations are indicated in Appendix C.

As noted in the *User Guidance* (Atlantic PIRI, 2015), provincial regulators may require a peer review of a Tier III approach.

3.3 Assessment of Vapour Intrusion Using Multiple Lines of Evidence

The goal of any vapour intrusion assessment is to accurately predict whether indoor air quality is being adversely affected by subsurface contaminants. However, several issues can introduce uncertainty in predicting indoor air concentrations related to vapour intrusion, including: spatial and temporal variations, biodegradation, preferential pathways, sampling and analytical methods, fate and transport modeling from subsurface into buildings (particularly for vacant properties), and background sources. It is the responsibility of the Site Professional to develop an accurate conceptual site model of potential vapour intrusion, starting with the data available from preliminary site investigations and collecting additional data as necessary to make an informed decision. The Site Professional is expected to critically review all the data collected in order to reach a conclusion on whether vapour intrusion is occurring (or in the case of vacant properties, will occur) and whether there are unacceptable health risks as a result. The use of the findings from several different data sets for making site decisions is termed the "multiple lines of evidence" approach (DOD, 2009).

The ITRC (2007) identified a number of possible lines of evidence that could be used to determine if the vapor intrusion pathway is complete. These include:

- Soil and groundwater concentration data (spatial distribution - lateral, vertical, and magnitude of concentrations)
- Building construction and current conditions
- Effects of soil stratigraphy
- Implications of groundwater table relative to observed soil impacts
- Soil vapour concentrations
- Sub-slab vapor concentrations
- Background concentrations (from indoor and outdoor sources)
- Site or building ownership and control

The Site Professional may not require all the typical lines of evidence to make a site management decision. It is possible that the findings of some lines of evidence may conflict with others (*e.g.*, soil vapour concentrations at source are higher than VISLs but sub-slab concentrations meet VISLs), and different lines of evidence may have different weighting based on the associated uncertainty. This highlights the need for the Site Professional to review the available data in a holistic manner to support their professional opinion.

4.0 REMEDIAL ACTIONS FOR VAPOUR INTRUSION

The following sections provide options for mitigating the risks associated with soil vapour intrusion by removing the source, pathway, or receptor.

4.1 Source Removal

Removal of the impacted subsurface material present at the site provides a permanent solution (USEPA, 2013b). Where it can be demonstrated that post-remediation site conditions do not represent unacceptable risk to human health via the inhalation pathway (see Section 2.5), post-remediation vapour sampling is not necessary. Following source removal, the site conditions may be suitable for Unconditional Closure under the Provincial Management process.

4.2 Engineered System

Engineered systems such as passive sub-slab venting, active sub-slab depressurization, and barrier products applied to the foundation may prevent vapours from entering an occupied building. Implementation of an engineered system may be considered a Conditional Closure. Consultation with Provincial regulatory officials is strongly recommended. Follow up and/or long-term monitoring may be required to demonstrate the effectiveness of the system.

4.3 Institutional Control

Institutional controls may be used to prevent people from being exposed. Examples include restrictions on land use (*e.g*. commercial use is suitable, but residential is not), and restrictions on placement of future buildings (*e.g*. "no-build" area in the inclusion zone). The Site Professional and the property owner will be expected to demonstrate how the property owner will ensure that the Institutional Control is maintained.

Implementation of an institutional control may be considered a Conditional Closure. Consultation with Provincial regulatory officials is recommended.

5.0 REPORTING

Although soil vapour assessments may be reported under various covers (*i.e*., as part of a Environmental Assessment Report, Remedial Action Plan, Closure Report, or as a stand-alone report), the following components should be included in the documentation.

- <u>Conceptual Site Model:</u> The CSM should identify sources, pathways, and receptors of concern, and provide sufficient details to justify the vapour sampling program.

- Screening: Screening consists of comparing soil and/or groundwater results to Tier II PSSLs for indoor air, and identifying which buildings, if any, are within the appropriate screening distance. At this point, the potential for vapour intrusion can be ruled out, or the need for further investigation, risk management, or remediation can be identified.
- Sampling Details: Sufficient details should be provided to justify the placement of each sampling location, including a description of the placement of probes relative to the source zone (laterally and vertically). The sampling schedule should be indicated, including justification for less than the default of a minimum of a fall/winter sample and a spring/summer sample, if applicable. Field details, including calibrated or calculated flow rates, sample duration, and residual vacuum (canisters only) should be provided.
- Data Quality: A discussion of the data quality should be included in the report, consisting of the results of laboratory and/or field duplicate analysis, laboratory QA/QC procedures, probe integrity testing, and field conditions. Upon review of the data quality assessment, the Site Professional must determine whether data limitations may affect the interpretation and decide whether or not data quality is sufficient to meet the assessment objectives.
- Tier III Approach (if applicable): Where Tier III SSTLs were calculated, provide the rationale for changing default parameters. For a Tier III assessment of chemicals other than PHCs, sources of toxicological information, and justification for the use of each source should be discussed.
- Data Analysis: A comparison of the measured vapour concentrations to the applicable VISLs or SSTLs.
- Interpretation and Recommendations: The interpretation section should include a discussion of whether the vapour results are consistent with the CSM and other site data. Based on the dataset, the Site Professional should provide recommendations regarding the next step in the Contaminated Sites Management Process. If Conditional Closure is recommended, include the conditions and potential follow-up sampling recommended.

6.0 REFERENCES

ASTM D 5466 Standard. Standard Test Method for Determination of Volatile Organic Chemicals in Atmospheres (Canister Sampling Methodology).

Atlantic PIRI, 2006 with 2012 Errata. 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.

Atlantic PIRI, 2015. Atlantic RBCA (Risk-Based Corrective Action) for Petroleum Impacted Sites in Atlantic Canada. Version 3. User Guidance. July 2012, revised January 2015.

Canadian Council of Ministers of the Environment (CCME). 2008. Canada-Wide Standard for Petroleum Hydrocarbons (PHC) in Soil. User Guidance.

Canadian Council of Ministers of the Environment (CCME). 2014. A Protocol for the Derivation of Soil Vapour Quality Guidelines for Protection of Human Exposures via Inhalation of Vapours.

CCME. 2016. Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment. Volumes 1-4 Guidance Manual. Contaminated Sites Division.

Davis, R.V. 2009, Bioattenuation of petroleum hydrocarbon vapors in the subsurface update on recent studies and proposed screening criteria for the vapor-intrusion pathway, LUSTLine Report 61, May 2009, New England Interstate Water Pollution Control Commission (NEIWPCC), pp. 11-14.

Department of Defense (DOD). 2009. DOD Vapor Intrusion Handbook. Prepared By The Tri-Service Environmental Risk Assessment Workgroup. January 2009.

DiGiulio, D. 2003. Raymark Site Preliminary Results. Proceedings of US EPA workshop on draft vapor intrusion guidance, Atlanta, February, 2003.

Health Canada. October 2008. Federal Contaminated Site Risk Assessment in Canada. Part IV: Spreadsheet Tool. Spreadsheet designed and programed by Meridian Environmental Inc., under contract to Health Canada.

Interstate Technology & Regulatory Council (ITRC). 2007. Vapor Intrusion Pathway: A Practical Guideline. January 2007. http://www.itrcweb.org/documents/vi-1.pdf.

Interstate Technology & Regulatory Council (ITRC). 2014 Petroleum Vapor Intrusion Team. October 2014. Petroleum Vapor Intrusion. Fundamentals of Screening, Investigation, and Management. PVI-1. Washington, D.C.: Interstate Technology & Regulatory Council, Petroleum Vapor Intrusion Team. http://itrcweb.org/PetroleumVI-Guidance/.

Johnson, P. 2005. Identification of Application-Specific Critical Inputs for the 1991 Johnson and Ettinger Vapor Intrusion Algorithm. Ground Water Monitoring & Remediation 25, no. 1. pp. 63-78.

Lahvis, M. A., Hers, I., Davis, R. V., Wright, J., DeVaull, G. E. 2013. "Vapor Intrusion Screening at Petroleum UST Sites." Groundwater Monitoring & Remediation. no. 33 (2):53-67.

Sanders, P. and Hers, I. 2006. Vapor Intrusion in Homes over Gasoline-Contaminated Groundwater in Stafford, NJ. Ground Water Monitoring & Remediation 26, no. 1. pp.63-72.

United States Environmental Protection Agency (USEPA). 1997-2000. U.S. Environmental Protection Agency. Spreadsheets for the Johnson and Ettinger (1991) Model. Prepared by Environmental Quality Management, Inc.

United States Environmental Protection Agency (USEPA). 2004. Draft Standard Operating Procedure (SOP) for Installation of Sub-Slab Vapor Probes and Sampling Using EPA Method TO-15 to Support Vapor Intrusion Investigations, Dominic DiGiulio, Ph.D., U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Ground-Water and Ecosystem Restoration Division, Ada, Oklahoma.

United States Environmental Protection Agency (USEPA). 2010. Temporal Variation of VOCs in Soils from Groundwater to the Surface/Subslab. October 2010. APM 349. EPA/600/R-10/118.

United States Environmental Protection Agency (USEPA). 2012. Conceptual Model Scenarios for the Vapor Intrusion Pathway.,U Office of Solid Waste and Emergency Response. February 2012.

United States Environmental Protection Agency (USEPA). 2013a. Draft Final Quality Standard for Environmental Data Collection, Production, and Use by Non-EPA (External) Organizations (CIO 2106-S-02) External Standard. February 2013.

United States Environmental Protection Agency (USEPA). 2013b. OSWER Final Guidance for Assessing and Mitigation the Vapor Intrusion Pathway from Subsurface Sources to Indoor Air (External Review Draft). Office of Solid Waste and Emergency Response (OSWER). April 2013.

United States Environmental Protection Agency (USEPA). 2015. Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites. Office of Underground Storage Tanks (OUST). June 2015. EPA 510-R-15-001.

APPENDIX A

BUILDING INSPECTION AND OCCUPANT SURVEY FORM

(AFTER USEPA 2002 and ITRC 2007)

Building Inspection and Occupant Survey Form

Date: ____________________

Project Number: ____________________

Address: ____________________

____

Building Description

Age (Approximate): ____________________

Has the building ever had a fire? ❒ Yes ❒ No

Air Tightness: ❒ Tight ❒ Average ❒ Not tight

Type:
- ❒ Single Family
- ❒ Townhouse
- ❒ Duplex
- ❒ Apartment
- ❒ Mobile Home
- ❒ Commercial
- ❒ Other (Specify):

Construction:
- ❒ Wood
- ❒ Brick
- ❒ Block
- ❒ Concrete
- ❒ Other (Specify):

Foundation: ❒ Basement ❒ Slab on grade ❒ Crawl space

Foundation Material:
- ❒ Poured concrete
- ❒ Block
- ❒ Sealed
- ❒ Stone
- ❒ Other (Specify):

Attached Garage? ❒ Yes ❒ No

Air handling is:

❒ Separate from main building ❒ Integrated ❒ None

Storage of gas powered equipment?
- ❒ Yes:
- ❒ No
- ❒ N/A
- ❒ Lawn mower
- ❒ ATV
- ❒ Other (specify):

Basement Details ❒ **N/A**

Is the basement finished?
- ❒ Yes
- ❒ No
- ❒ Utility/Furnace Room
- ❒ Rec. Room
- ❒ Bedrooms ___________)
- ❒ Other (Specify):

Basement occupancy? ❒ >2 hours/day ❒ 1-2 hours/day ❒ < 1 hr/day

Lowest depth below grade:		
Basement floor?	❒ Concrete ❒ Tile/linoleum ❒ Dirt	❒ Wood ❒ Carpet ❒ Other (Specify):
Moisture/dampness problems?	❒ Yes ❒ > 3 times/ year ❒ 1-2 times/ year ❒ < 1 time/year	❒ No
Flooding?	❒ Yes ❒ > 3 times/ year ❒ 1-2 times/ year ❒ < 1 time/year	❒ No
Potential Vapour Entry Points:	❒ Floor cracks	Extent:
	❒ Wall cracks	Extent:
	❒ Water/utility ports	Number:
	❒ Sumps	Number: Construction: Water present?
	❒ Floor drains	Describe:
	❒ Other openings	Describe:

Mechanical/Heating Systems and Appliances

Home Heating Type:	❒ Natural gas ❒ Wood ❒ Other (Specify):	❒ Electric ❒ Coal	
	❒ Fuel Oil	Fuel Tank is: ❒ AST ❒ Indoor Location:	 ❒ UST ❒ Outdoor
Heat Distribution:	❒ Forced hot air ❒ Forced hot water ❒ Baseboard ❒ Wood stove	❒ Fireplace ❒ Other Specify:	
Air Conditioning?	❒ Yes ❒ Central ❒ Window mounted ❒ Open Windows ❒ Other (Specify):	❒ No	
Water Heater?	❒ Natural gas ❒ Electric ❒ By furnace ❒ Other (Specify):	Location:	
Clothes Dryer?	❒ Yes ❒ Vented outdoors Location:	❒ No ❒ Not Vented outdoors	

Stove exhaust hood? ❐ Yes ❐ No
❐ Vented outdoors ❐ Not Vented outdoors

Location: ______

Household Activities

Basement Storage Activities?

(Basement Storage Cont'd)

	Type/Quantity
❐ 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 or new upholstered furniture, drapes, or carpeting (within last 6 months)?

❐ Yes ❐ No

Describe (where, when):

Indoor home hobbies?
- ❒ Yes
- ❒ No
- ❒ Welding
- ❒ Model glues
- ❒ Painting
- ❒ Wood finishing
- ❒ Soldering
- ❒ Other (Specify): ____________________

Conducted Where: ____________________

____

____

____

Smoking in the home?
- ❒ Yes
- ❒ No
- ❒ Cigarettes
- ❒ Cigars
- ❒ Pipe
- ❒ Other

Specify: ____________________

Do building occupants smoke? ❒ Yes ❒ No

Do building occupants use solvents at work? ❒ Yes ❒ No
(*e.g.*, chemical manufacturing or laboratory, auto mechanic or auto body shop, painting, fuel oil delivery, boiler mechanic, pesticide application, cosmetologist

If yes, what types of solvents are used? ____________________

____

If yes, are their clothes washed at work? ❒ Yes ❒ No

Do any of the building occupants regularly use or work at a dry-cleaning service?

- ❒ Yes, use dry-cleaning regularly (weekly)
- ❒ Yes, use dry-cleaning infrequently (monthly or less)
- ❒ Yes, work at a dry-cleaning service
- ❒ No
- ❒ Unknown

Is there a radon mitigation system for the building?	❒ Yes Date Installed: ______	❒ No
Is the system active or passive?	❒ Active ❒ Don't know	❒ Passive

______

______

Use of Consumer Products

	Frequency of Use				
Product	Never	Rare	Occasional	Regular	Frequent
Air Fresheners	❒	❒	❒	❒	❒
Insecticides	❒	❒	❒	❒	❒
Disinfectants	❒	❒	❒	❒	❒
Window Cleaners	❒	❒	❒	❒	❒
Oven Cleaners	❒	❒	❒	❒	❒
Nail Polish Removers	❒	❒	❒	❒	❒
Hair Spray	❒	❒	❒	❒	❒
Aerosol Deodorizers	❒	❒	❒	❒	❒
Toner (fax, printer, copier)	❒	❒	❒	❒	❒
Other:	❒	❒	❒	❒	❒

Household Cleaning

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

Rare:	Less than once per month
Occasional:	Approx. once per month
Regular	Approx. once per week
Frequent	More than once per week

Additional Comments:

Please attach a Site Plan identifying building layout, sample locations, and potential sources.

APPENDIX B

VAPOUR INTRUSION SCREENING LEVEL (VISL) TABLE

Table B.1 - Tier II Vapour Intrusion Screening Levels for Petroleum Hydrocarbons (mg/m^3)

Compound of Concern	Indoor Air		Sub-Slab		Soil Vapour (> 1 m from foundation)	
	Agricultural/ Residential	Commercial/ Industrial	Agricultural/ Residential	Commercial/ Industrial	Agricultural/ Residential	Commercial/ Industrial
Benzene	0.003	0.025	0.100	2.5	57	1300
Toluene	3.8	13	63	690	21,000	370,000
Ethylbenzene	1.0	3.6	16	180	20,000	100,000
Xylenes	0.18	0.65	3.0	32	1,900	18,000
mTPH sub-fractions						
Aromatic >C_8-C_{10}	0.20	0.73	6.6	73	5,000	46,000
Aromatic >C_{10}-C_{12}	0.20	0.73	6.6	73	5,000	46,000
Aromatic >C_{12}-C_{16}	0.20	0.73	6.6	73	5,000	46,000
Aliphatic >C_6-C_8	18.4	67	610	6,700	460,000	4,200,000
Aliphatic >C_8-C_{10}	1.0	3.6	33	360	25,000	220,000
Aliphatic >C_{10}-C_{12}	1.0	3.6	33	360	25,000	220,000
Aliphatic >C_{12}-C_{16}	1.0	3.6	33	360	25,000	220,000
IAR Check [1]	1	1	1	1	1	1

Notes:

1 Index of Additive Risk (IAR) assesses potential health risk from inhalation of mTPH. The IAR is calculated by dividing the measured concentration (numerator) of each mTPH subfraction by its appropriate screening level guideline for protection of vapour inhalation risk (denominator) to calculate a hazard index for each mTPH subfraction, and then summing the hazard indices for the entire mTPH mixture. See Appendix D for example calculation.

APPENDIX C
EQUATIONS USED FOR THE DERIVATION OF HEALTH-BASED VISLS

EQUATIONS USED FOR THE DERIVATION OF HEALTH-BASED VISLS

The following equations and values were used in the calculation of the Tier II VISLs. Chemical-specific values as well as default values for exposure scenarios, building characteristics, and soil properties were obtained from Version 3 of the Atlantic RBCA Toolkit, and are summarized in Tables C.1 and C.2.

Tier II/III limitations have been placed on some parameters to minimize inadvertent unreasonable input assumptions, which commonly lead to unreasonable outputs (Johnson, 2005). These equations can be used on sites that do not meet default conditions by applying non-default values for a Tier III assessment. These equations were also used to derive default attenuation factors for different depths, which are provided in Table C.3.

These equations may also be used for contaminants of concern for which there are no VISLs; however, the Site Professional must provide full references and rationale for the chemical-specific values used in the derivation.

VISLs for Indoor Air

For threshold contaminants:

$$VISL_{indoor\ air} = \frac{TC}{ET} \qquad \text{Equation C.1}$$

$$ET = D_1 \cdot D_2 \cdot D_3 \qquad \text{Equation C.2}$$

For non-threshold contaminants:

$$VISL_{indoor\ air} = \frac{RsC}{ET} \qquad \text{Equation C.3}$$

$$RsC = \frac{10^{-5}}{IUR} \qquad \text{Equation C.4}$$

$$ET = D_1 \cdot D_2 \cdot D_3 \cdot D_4 \qquad \text{Equation C.5}$$

Where:		**Units**
$VISL_{indoor\ air}$	= guideline for indoor air quality	mg/m^3
TC	= tolerable concentration or reference concentration (chemical specific)	mg/m^3
RsC	= risk-specific concentration for 1-in-100,000 incremental increased cancer risk (chemical specific)	mg/m^3
IUR	= inhalation unit risk (chemical specific)	$(mg/m^3)^{-1}$
ET	= exposure term	unitless
D_1	= hours per day exposed/24 hours per day	unitless
D_2	= days per week exposed/7 days per week	unitless
D_3	= weeks per year exposed/52 weeks per year	unitless
D_4	= total years exposed/life expectancy	unitless

VISLs for Sub-Slab and Soil Vapour Probe Samples

For threshold contaminants:

$$VISL_{sub\text{-}slab,\ soil\ vapour} = \frac{TC \cdot AF}{\alpha \cdot ET} \qquad \text{Equation C.6}$$

$$ET = D_1 \cdot D_2 \cdot D_3 \qquad \text{Equation C.2}$$

For non-threshold contaminants:

$$VISL_{sub\text{-}slab,\ soil\ vapour} = \frac{RsC}{\alpha \cdot ET} \qquad \text{Equation C.7}$$

$$RsC = \frac{10^{-5}}{IUR} \qquad \text{Equation C.4}$$

$$ET = D_1 \cdot D_2 \cdot D_3 \cdot D_4 \qquad \text{Equation C.5}$$

Where:		**Units**
$VISL_{sub\text{-}slab}$	= guideline for sub-slab samples that is protective of indoor air quality	mg/m^3
$VISL_{soil\ vapour}$	= guideline for soil vapour samples that is protective of indoor air quality	mg/m^3
TC	= tolerable concentration or reference concentration (chemical specific)	mg/m^3
AF	= allocation factor (chemical specific)	unitless
α	= soil vapour to building air attenuation factor	unitless
RsC	= risk-specific concentration for 1-in-100,000 incremental increased cancer risk (chemical specific)	mg/m^3
IUR	= inhalation unit risk (chemical specific)	$(mg/m^3)^{-1}$
ET	= exposure term	unitless
D_1	= hours per day exposed/24 hours per day	unitless
D_2	= days per week exposed/7 days per week	unitless
D_3	= weeks per year exposed/52 weeks per year	unitless
D_4	= total years exposed/life expectancy	unitless

The VISLs for sub-slab samples were calculated using the CCME (2014) recommended default attenuation factor (α) of 0.01 for commercial properties or 0.03 for residential properties. These same default attenuation factors may also be used for soil vapour samples (i.e., samples collected > 1 m from a building foundation) if site conditions do not meet generic criteria (e.g., presence of a dirt floor, the building is taller than 4 floors, residence does not have two floors, there are preferential pathways present). In other words, sub-slab VISLs may be applied to soil vapour probe sample results on sites where the default conditions do not apply.

For soil vapour probe samples collected greater than 1 m from the building foundation, the attenuation factor (α) used to derive the $VISL_{soil\ vapour}$ is calculated using the Johnson and Ettinger (1991) model (or J&E model), which is represented by the following equations.

Attenuation factor calculation

$$\alpha = \frac{\left[\left(\frac{D_T^{eff} A_B}{Q_B\ L_T}\right) \exp\left(\frac{Q_{soil}\ L_{crack}}{D_{crack}\ A_{crack}}\right)\right]}{\exp\left(\frac{Q_{soil}\ L_{crack}}{D_{crack} A_{crack}}\right) + \left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) + \left(\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right)\left[\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) - 1\right]} \div BAF \qquad \text{Equation C.8}$$

Where:		**Units**
α	= soil vapour to building air attenuation factor	unitless
D_T^{eff}	= effective porous media diffusion coefficient through soil	cm^2/s
A_B	= building area	cm^2
Q_B	= building ventilation rate	cm^3/s
L_T	= distance from the contaminant source to the foundation	cm
Q_{soil}	= volumetric flow rate of soil gas into the building	cm^3/s
L_{crack}	= thickness of the foundation	cm
D_{crack}	= effective vapour pressure diffusion coefficient through the crack	cm^2/s
A_{crack}	= area of cracks and openings through which contaminant vapour enter the building	cm^2
BAF	= bioattenuation factor	unitless

Effective Porous Media Diffusion Coefficient Calculation

$$D_T^{eff} = D^{air} \cdot \frac{\theta_a^{3.33}}{\eta^2} + \left(\frac{D^{water}}{H'}\right) \cdot \left(\frac{\theta_w^{3.33}}{\eta^2}\right) \qquad \text{Equation C.9}$$

Where:		**Units**
D_T^{eff}	= overall effective porous media diffusion coefficient through soil	cm^2/s
D^{air}	= diffusion coefficient of chemical in air	cm^2/s
D^{water}	= pure component molecular diffusivity in water (chemical specific)	cm^2/s
H'	= dimensionless Henry's Law constant (chemical specific)	unitless
θ_a	= soil-vapour-filled porosity	unitless
η	= soil total porosity	unitless
θ_w	= water-filled porosity	unitless

Effective Porous Media Diffusion Coefficient Calculation in Floor Cracks

$$D_{crack} \approx D^{air} \cdot \left(\frac{\theta_{acrack}^{3.33}}{\eta_{crack}^{2}}\right) \qquad \text{Equation C.10}$$

Where:		**Units**
D_{crack}	= effective vapour-pressure diffusion coefficient through the crack	cm^2/s
D^{air}	= diffusion coefficient of chemical in air	cm^2/s
$\theta_{a\ crack}$	= air-filled porosity of soil-filled foundation crack	unitless
η_{crack}	= total soil porosity in foundation crack	unitless

For D_{crack}, it is assumed that a coarse, granular material is used as the base for the floor and footings and therefore that the cracks are filled with dry coarse soil, even if the native soil is fine grained.

Calculation of Building Ventilation Rate

$$Q_B = \frac{A_B \cdot H_B \cdot ACH}{3{,}600} \qquad \text{Equation C.11}$$

Where:		**Units**
Q_B	= building ventilation rate	cm^3/s
A_B	= area of building foundation	cm^2
H_B	= building height, including basement	cm
ACH	= air exchanges per hour	h^{-1}
3,600	= conversion factor	s/h

Tier II/III Limitation: ratio of Q_{soil}/Q_B must be within the range of 0.01 – 0.0001*

Volumetric Flow Rate of Soil Gas into the Building

$$Q_{soil} = \frac{2\pi \cdot \Delta P \cdot k_v \cdot X_{crack}}{\mu \cdot \ln\left(2 \cdot \frac{Z_{crack}}{r_{crack}}\right)} \qquad \text{Equation C.12}$$

Where:		**Units**
Q_{soil}	= volumetric flow rate of soil gas into the building	cm^3/s
ΔP	= air pressure differential between soil gas and indoor air	$g/cm\text{-}s^2$
k_v	= soil vapour permeability	cm^2
X_{crack}	= floor-wall seam perimeter	cm
μ	= viscosity of air	g/cm-s
Z_{crack}	= crack depth below grade (basement depth)	cm
r_{crack}	= equivalent crack radius	cm

Tier II/III Limitation: ratio of Q_{soil}/Q_B must be within the range of 0.01 – 0.0001*

Equivalent Crack Radius

$$r_{crack} = \frac{A_{crack}}{X_{crack}} \qquad \text{Equation C.13}$$

Where:		**Units**
r_{crack}	= equivalent crack radius	cm
A_{crack}	= area of cracks and openings through which contaminant vapour enter the building	cm^2
X_{crack}	= floor-wall seam perimeter	cm

Table C.1 – Chemical-Specific Properties

Compound of Concern	Tolerable Concentration TC mg/m^3	Inhalation Unit Risk IUR (mg/m^3)$^{-1}$	Risk-Specific Concentration RsC mg/m^3	Diffusivity in Air D^{air} cm^2/s	Diffusivity in Water D^{water} cm^2/s	Henry's Law Constant H' unitless	Allocation Factor AF unitless	Bioattenuation Factor BAF unitless
Benzene	-	0.0033	0.003	0.088	9.8E-06	0.225	-	10
Toluene	3.8	-	-	0.087	8.6E-06	0.274	0.5	10
Ethylbenzene	1.0	-	-	0.075	7.8E-06	0.358	0.5	10
Xylenes	0.18	-	-	0.070	7.8E-06	0.300	0.5	10
mTPH sub-fractions								
Aromatic >C_8-C_{10}	0.20	-	-	0.050	1.0E-05	0.48	1	10
Aromatic >C_{10}-C_{12}	0.20	-	-	0.050	1.0E-05	0.14	1	10
Aromatic >C_{12}-C_{16}	0.20	-	-	0.050	1.0E-05	0.053	1	10
Aliphatic >C_6-C_8	18.4	-	-	0.050	1.0E-05	50	1	10
Aliphatic >C_8-C_{10}	1.0	-	-	0.050	1.0E-05	80	1	10
Aliphatic >C_{10}-C_{12}	1.0	-	-	0.050	1.0E-05	120	1	10
Aliphatic >C_{12}-C_{16}	1.0	-	-	0.050	1.0E-05	520	1	10

Table C.2 – Atlantic RBCA Default Values for Soil and Building Parameters

Parameter	Default Value	
	Coarse-grained soils	Fine-grained soils
Soil Column Parameters		
soil vapour permeability, k_v (cm^2)	5.0×10^{-8}	1.0×10^{-9}
soil total porosity, η (unitless)	0.36	0.47
water-filled porosity, θ_w (unitless)	0.119	0.168
soil-vapour-filled porosity, θ_a (unitless)	0.241	0.132
air-filled porosity of soil-filled foundation crack, $\theta_{a\ crack}$ (unitless)	0.36 (assumes same as dry, coarse soil)	
total soil porosity in foundation crack, η_{crack} (unitless)	0.36 (assumes same as dry, coarse soil)	
Building Parameters	**Agricultural/Residential**	**Commercial/Industrial**
building height, including basement, H_B (m)	360	300
area of building foundation, A_B (cm^2)	1.6×10^6	3.0×10^6
floor-wall seam perimeter, X_{crack} (cm)	4900	7000
foundation crack fraction, f_{crack} (unitless)	0.00067	0.00062
area of cracks and openings in foundation, A_{crack} (cm^2)	1005	1860
building air exchange rate per hour, ACH (1/h)	0.5	0.9
thickness of the foundation, L_{crack} (cm)	11.25	
crack depth below grade (depth to bottom of foundation), Z_{crack} (cm)	11.25	
air pressure differential between soil gas and indoor air, ΔP ($g/cm/s^2$)	40	20
Exposure Parameters	**Agricultural/Residential**	**Commercial/Industrial**
hours per day exposed/24 hours per day, D_1 (unitless)	24/24	10/2
days per week exposed/7 days per week, D_2 (unitless)	7/7	5/7
weeks per year exposed/52 weeks per year, D_3 (unitless)	52/52	48/52
total years exposed/life expectancy, D_4 (unitless)	80/80	35/80

Table C.3 – Summary of Attenuation Factors for Petroleum Hydrocarbons Based on Default Values for Coarse Grain Soil Characteristics

Depth, L_T (m)	Attenuation Factor α (unitless)	
	Residential	Commercial
1	5.3E-05	1.9E-05
2	3.7E-05	1.5E-05
3	2.8E-05	1.3E-05
4	2.3E-05	1.1E-05
5	1.9E-05	9.6E-06

APPENDIX D
SAMPLE CALCULATIONS

Sample Calculation - Index of Additive Risk

In addition to comparing PHC sub-fraction concentrations to the applicable VISLs, the Index of Additive Risk (IAR) must also be assessed to account for the cumulative effects of the PHC mixture. The IAR calculation consists of comparing the ratio of the concentration of each sub-fraction to its applicable VISL and summing these ratios to calculate the IAR.

Consider the following example of indoor air data on a residential site:

Table D.1 IAR Calculation

PHC Fraction	Agricultural/Residential Indoor Air VISLs (mg/m^3) [1]	Site Concentration (mg/m^3) [2]	[2] / [1] (unitless)
Aromatic >C_8-C_{10}	0.20	0.130	0.65
Aromatic >C_{10}-C_{12}	0.20	<0.041	0.10*
Aromatic >C_{12}-C_{16}	0.20	0.150	0.75
Aliphatic >C_6-C_8	18.4	0.610	0.03
Aliphatic >C_8-C_{10}	1.0	0.310	0.31
Aliphatic >C_{10}-C_{12}	1.0	0.100	0.10
Aliphatic >C_{12}-C_{16}	1.0	0.200	0.20
		Sum (IAR)	**2.14**

*****Where results are less than the detection limit, conduct calculations on ½ the detection limit.

Although the concentration of each individual sub-fraction is below its respective VISL, the cumulative effects of exposure to this mixture are deemed unacceptable since the sum of the hazard quotients (2.14) exceeds the IAR check value of 1.0.

Sample calculation – Derivation of VISLs for Benzene on an Agricultural/Residential Site with coarse-grained soil

VISL for Indoor Air for benzene (non-threshold substance)

$$ET = D_1 \cdot D_2 \cdot D_3 \cdot D_4$$

D_1	= hours per day exposed/24 hours per day (unitless) = 1
D_2	= days per week exposed/7 days per week (unitless) = 1
D_3	= weeks per year exposed/52 weeks per year (unitless) = 1
D_4	= total years exposed/life expectancy (unitless) = 1

ET = exposure term (unitless) = 1

$$RsC = \frac{10^{-5}}{IUR}$$

IUR	= inhalation unit risk ($(mg/m^3)^{-1}$) = 0.0033

RsC = risk specific concentration (mg/m^3) = 0.003

$$VISL_{indoor\ air} = \frac{RsC}{ET}$$

RsC	= risk specific concentration (mg/m^3) = 0.003
ET	= exposure term (unitless) = 1

$VISL_{indoor\ air}$ = guideline for indoor air quality (mg/m^3) = 0.003

VISL for sub-slab for benzene (non-threshold substance)

$$VISL_{sub\text{-}slab} = \frac{RsC}{\alpha \cdot ET}$$

RsC	= risk specific concentration (mg/m^3) = 0.003
ET	= exposure term (unitless) = 1
A	= soil vapour to building air attenuation factor (unitless) = 0.03

$VISL_{sub\text{-}slab}$ = guideline for sub-slab samples that is protective of indoor air quality (mg/m^3) = 0.100

VISL for soil vapour for benzene (non-threshold substance)

$$r_{crack} = \frac{A_{crack}}{X_{crack}}$$

A_{crack}	= area of cracks and openings through which contaminant vapour enters the building (cm^2) = 1005
X_{crack}	= floor-wall seam perimeter (cm) = 4900

r_{crack} = equivalent crack radius (cm) = 0.205 cm

$$Q_{soil} = \frac{2\pi \cdot \Delta P \cdot k_v \cdot X_{crack}}{\mu \cdot \ln\left(2 \cdot \frac{Z_{crack}}{r_{crack}}\right)}$$

ΔP	= air pressure differential between soil gas and indoor air ($g/cm\text{-}s^2$) = 40
k_v	= soil vapour permeability (cm^2) = 5.0×10^{-8}
X_{crack}	= floor-wall seam perimeter (cm) = 4900
μ	= viscosity of air (g/cm-s) = 0.00018
Z_{crack}	= crack depth below grade (basement depth) (cm) = 11.25
r_{crack}	= equivalent crack radius (cm) = 0.205

Q_{soil} = volumetric flow rate of soil gas into the building (cm^3/s) = 72.8

$$Q_B = \frac{A_B \cdot H_B \cdot ACH}{3{,}600}$$

A_B	= area of building foundation (cm^2) = 1500000
H_B	= building height, including basement (cm) = 360
ACH	= air exchanges per hour (h^{-1}) = 0.5
3,600	= conversion factor (s/h)

Q_B = building ventilation rate (cm^3/s) = 75000

Check: Q_{soil}/Q_B = 0.0097, therefore within the range of 0.01 – 0.0001

$$D_{crack} \approx D^{air} \cdot \left(\frac{\theta_{acrack}^{3.33}}{\eta_{crack}^2}\right)$$

D^{air}	= diffusion coefficient of chemical in air (cm^2/s) = 0.088
$\theta_{a\ crack}$	= air-filled porosity of soil-filled foundation crack (unitless) = 0.36
η_{crack}	= total soil porosity in foundation crack (unitless) = 0.36

D_{crack} = effective vapour-pressure diffusion coefficient through the crack (cm^2/s) = 0.0225

$$D_T^{eff} = D^{air} \cdot \frac{\theta_a^{3.33}}{\eta^2} + \left(\frac{D^{water}}{H'}\right) \cdot \left(\frac{\theta_w^{3.33}}{\eta^2}\right)$$

D^{air}	= diffusion coefficient of chemical in air (cm^2/s) = 0.088
D^{water}	= pure component molecular diffusivity in water (cm^2/s) = 0.0000098
H'	= dimensionless Henry's Law constant (unitless) = 0.225
θ_a	= soil-vapour-filled porosity (unitless) = 0.241
η	= soil total porosity (unitless) = 0.36
θ_w	= water-filled porosity (unitless) = 0.119

D_T^{eff} = overall effective porous media diffusion coefficient through soil (cm^2/s) = 0.00591

$$\alpha = \frac{\left[\left(\frac{D_T^{eff} A_B}{Q_B\ L_T}\right)\ \exp\left(\frac{Q_{soil}\ L_{crack}}{D_{crack}\ A_{crack}}\right)\right]}{\exp\left(\frac{Q_{soil}\ L_{crack}}{D_{crack} A_{crack}}\right) + \left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) + \left(\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right)\left[\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) - 1\right]} \div BAF$$

D_T^{eff}	= effective porous media diffusion coefficient through soil (cm^2/s) = 0.00591
A_B	= building area (cm^2) = 1500000
Q_B	= building ventilation rate (cm^3/s) = 75000
L_T	= distance from the contaminant source to the foundation (cm) = 100
Q_{soil}	= volumetric flow rate of soil gas into the building (cm^3/s) = 72.8
L_{crack}	= thickness of the foundation (cm) = 11.25
D_{crack}	= effective vapour pressure diffusion coefficient through the crack (cm^2/s) = 0.0225
A_{crack}	= area of cracks and openings through which contaminant vapour enter the building (cm^2) = 1005
BAF	= bioattenuation factor (unitless) = 10

α = soil vapour to building air attenuation factor (unitless) = 0.0000533

$$VISL_{soil\ vapour} = \frac{RsC}{\alpha \cdot ET}$$

RsC	= risk specific concentration (mg/m^3) = 0.003
ET	= exposure term (unitless) = 1
α	= soil vapour to building air attenuation factor (unitless) = 0.0000533

$VISL_{soil\ vapour}$ = guideline for soil vapour samples (mg/m^3) = 57