Vapor Intrusion Technical Support Document

Remediation Division
Minnesota Pollution Control Agency

Minnesota Pollution Control Agency

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1.0 Introduction

This document provides technical support and guidance for assessing risks associated with the vapor intrusion pathway at sites administered under the following programs within the Minnesota Pollution Control Agency (MPCA) Remediation Division:

- Petroleum Remediation Program (PRP)
- Petroleum Brownfields Program (PBP)
- Superfund Program
- Resource Conservation and Recovery Act (RCRA) Corrective Action Program
- Voluntary Investigation and Cleanup Program (VIC)

The last three remediation programs address releases of non-petroleum hazardous substances and are referred to within this document as the Superfund, RCRA and Voluntary Cleanup (SRVC) programs.

1.1 Intent and scope of this document

This document provides supplemental technical support for the following two MPCA program-specific guidance documents pertaining to the vapor intrusion pathway:

- Risk-Based Guidance for the Vapor Intrusion Pathway, for sites in the SRVC programs (MPCA, 2008a).
- Vapor Intrusion Assessments Performed during Site Investigations, Guidance Document 4-01a, for sites under the regulatory oversight of the Petroleum Remediation Program and Petroleum Brownfields Program (MPCA, 2008b).

These program-specific documents may be updated as necessary; therefore, check for the most recent version

Program-specific Guidance

The programmatic guidance documents described above should be followed depending on which program has regulatory oversight. Some programmatic differences in this document are identified through the use of graphic “call-out boxes,” such as this. Programmatic differences are also discussed within the document narrative where appropriate.

1.2 Description of the vapor intrusion pathway

Vapor intrusion is an exposure pathway resulting from the migration of volatile chemicals from the subsurface into overlying buildings with human receptors. A vapor intrusion source, migration route, and a human receptor must be present for the pathway to be complete and pose a potential health risk. A vapor intrusion source is defined as contaminated soil, groundwater, or non-aqueous phase liquid (NAPL). A subsurface migration route is defined as soils in the unsaturated zone through which vapors are transported. A vapor intrusion receptor is defined as human occupants of buildings. In addition, the source of chemicals must be sufficiently volatile and toxic to cause a risk. Figure 1 provides a schematic illustration of the vapor intrusion pathway.

When chemicals are released into the environment, they have the capacity to volatilize from a non-aqueous phase liquid (NAPL), contaminants dissolved in water, or contaminants adsorbed to soil. Volatile compounds dissolved in groundwater enter into the vapor phase at the boundary between the saturated zone and the vadose zone. Volatile compounds may then migrate within the subsurface as soil gas vertically or laterally by diffusion or advection. Soil gas migration can occur radially or in any direction due to pressure gradients, variations in soil type, permeability and moisture content. Pressure gradients influencing soil gas migration can be the result of barometric pressure changes or pressure differences between a building's interior and the subsurface. Such gradients can cause shallow soil gas to enter buildings through foundation cracks, sumps, or other preferential pathways (ITRC, 2007a). Vapor intrusion can also result from the advective air movement within a building caused by thermal and air density variations between the building interior and the outside air which create vertical air flow through the building (i.e., via the chimney or other openings). This is known as the building stack effect. The stack effect is typically greatest during the winter months when heated interior air can depressurize a building's interior relative to the exterior and subsurface air pressure.

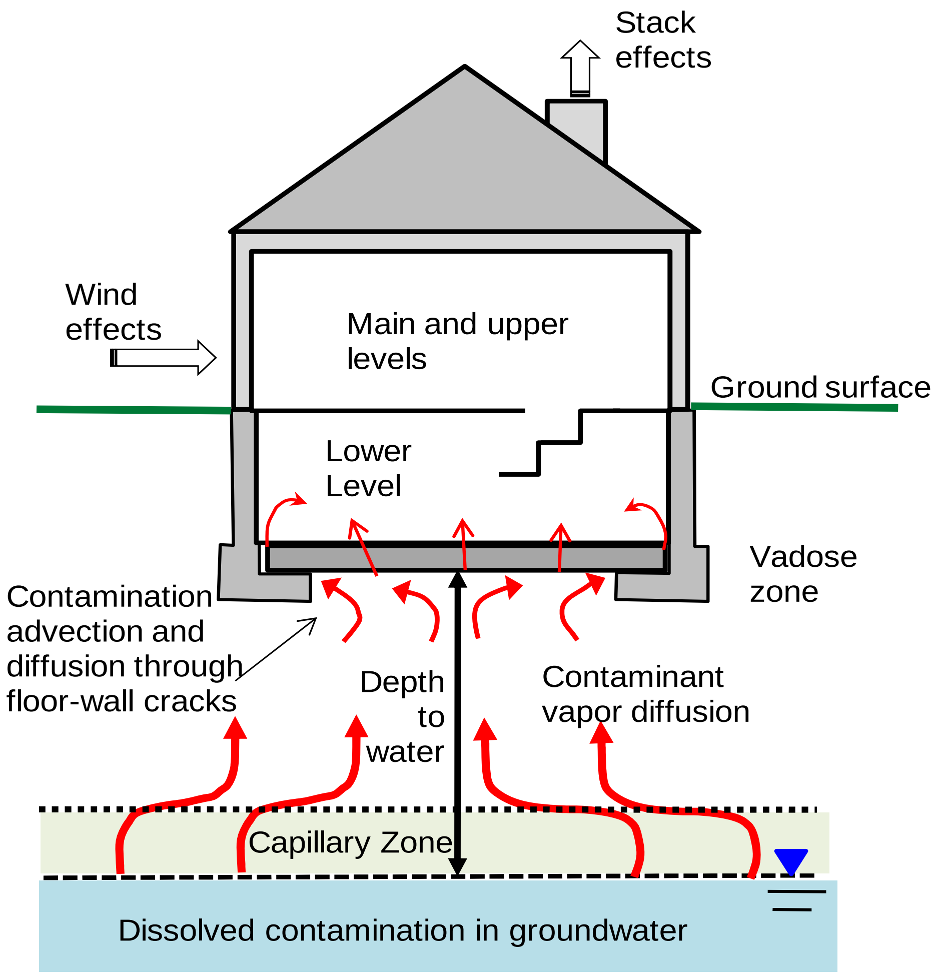

Figure 1: Simplified Model of Vapor Intrusion

2.0 Minnesota Pollution Control Agency's approach for vapor intrusion investigation

The MPCA's vapor intrusion investigative framework is based on a step-wise, risk-based approach emphasizing the use of empirical field data rather than fate and transport modeling to assess human health risks. The empirical approach begins by identifying vapor intrusion sources and determining if buildings with human receptors are at risk. If receptors are identified, subsurface vapor concentrations are evaluated near identified receptors, followed by determining if a building-specific investigation is required. Vapor intrusion data is interpreted through developing a site conceptual model which integrates qualitative and quantitative data sources collected throughout the investigative process.

2.1 Investigation decision framework

The purpose of vapor intrusion investigations is to evaluate whether a completed vapor intrusion pathway exists and, if so, to determine whether there is a risk to receptors in overlying structures. The four major investigation steps are summarized below and are discussed in Sections 3 through 6.

Step 1: Vapor intrusion screening and receptor evaluation

Review existing records and investigation results for the site to determine if the vapor intrusion pathway must be investigated or if it can be excluded as a pathway of concern. If it is determined that this pathway may pose a risk to nearby receptors, conduct preliminary soil gas sampling, and document the location of receptors relative to vapor sources. If vapor intrusion risks to nearby receptors are identified, proceed to Step 2.

Step 2: Soil gas investigations

Conduct or complete soil gas investigations to determine which receptors may be at risk and which buildings require a building-specific investigation.

Step 3: Building-specific investigations

Conduct a building-specific vapor investigation to evaluate risks posed to individual receptors which may involve sub-slab vapor, indoor air, and ambient air sampling. Use an accurate site conceptual model (see Section 2.2) and multiple lines of evidence to assess risks and determine whether response actions are necessary.

Step 4: Response actions

If necessary, evaluate and implement response actions to address unacceptable vapor intrusion risks. The term response actions is used broadly within this document to refer to corrective or remedial actions including building mitigation.

This step-wise framework has similarities to the framework outlined in the American Standard Testing Methods (ASTM) Standard E 2600 (ASTM, 2008) and to the tiered steps outlined in the Risk-Based Vapor Intrusion Guidance (MPCA, 2008a) developed for the SRVC programs. This framework is of a sufficiently high level to be applicable to most vapor-intrusion investigations, regardless of the type of site or the investigation strategies used.

When vapor intrusion risks are identified or suspected, the regulated party or property owner may conduct proactive remedial actions to reduce risks to receptors. Such proactive response actions should be closely coordinated with the MPCA project staff.

Sites with potential vapor intrusion pathway concerns can require an increased level of community involvement. This is particularly the case at Step 3 (Building-Specific Investigations) and Step 4 (Response Actions) when more invasive investigation techniques are employed to evaluate and mitigate risks at specific buildings. Additional resources to aid in determining the appropriate level of community involvement and strategies for risk communication, particularly for larger sites, can be found in the MPCA Risk-base Site Evaluation (RBSE) document, Guidelines for Community Involvement in Risk-Based Decision Making (MPCA, 1998), and the ITRC Vapor Intrusion Pathway: A Practical Guideline (ITRC, 2007a).

2.2 Using a site conceptual model

A Site Conceptual Model (SCM) for vapor intrusion provides a three-dimensional conceptual understanding of the:

- extent and magnitude of vapor sources
- confirmed or suspected preferential migration pathways
- spatial distribution of contaminant soil vapors and concentrations
- type and location of receptors relative to vapor sources

An accurate SCM is necessary to interpret site investigation results, determine whether additional investigation is required, document that site closure criteria have been achieved and provide support in selecting appropriate remedial actions. An SCM functions both as an interpretation and communication tool used to describe the site conditions and vapor intrusion pathway for a given site. As additional site information is collected, the SCM should continue to be refined in an iterative fashion.

The MPCA requires that the SCM be documented with vapor intrusion investigation reports both within the report narrative and by use of cross-sections, plan-view site figures, and data tables. Cross-sections should identify vapor sources and the interpreted site geology, and receptor locations as appropriate. Site maps should identify the spatial relationships between vapor sources, receptors, sample locations, and known or suspected locations of soil gas and groundwater plumes. Documentation of the SCM should be consistent with program specific reporting guidelines.

A checklist for developing an SCM is provided in Appendix A. Sites within the MPCA PRP or PBP should also utilize program documents 4-01a and 4-06 (2008a and 2008b) for guidelines on reporting SCM information. Other supporting resources include the ITRC guidance (2007a, Section 2.1) and the U.S. Environmental Protection Agency (EPA) draft guidance (2002a).

2.3 Screening values for the vapor intrusion pathway

Screening values for two building exposure scenarios are provided in this document: (1) residential; and (2) industrial. Commercial building exposure scenarios use the industrial screening values as they are based on the same exposure assumptions. Screening values and their corresponding sampled media are summarized in Table 2-1.

Intrusion screening values (ISVs) are compound-specific risk-based values used for evaluating indoor air results. The screening values for groundwater, soil gas, and sub-slab sampling results are referred to as media-specific screening values. Details regarding the basis and rationale for the screening values used in this guidance are provided in Appendix B. Vapor intrusion screening levels for soil-phase analytical results are not provided or supported by the MPCA due to the difficulties of accurately relating soil contaminant concentrations to soil gas concentrations. The application of screening values in making risk-based decisions is discussed in more detail in Sections 3, 4, and 5.

Table 2-1: Screening Values for the Vapor Intrusion Pathway

Sampling Locations	Applicable Screening Values
Within the interior space of a building	Intrusion Screening Values (ISVs)
Soil gas collected from the subsurface	Soil Gas Screening Values
Sub-slab vapor from beneath a building slab	Sub-slab Screening Values
Groundwater collected from near the top of the water table	Groundwater Screening Values

2.3.1 Intrusion screening values

The ISVs are compound-specific values used to evaluate contaminants in the indoor air environment derived from vapor intrusion sources. ISVs are not promulgated health values; rather they are intended to be used as screening criteria for evaluating risks posed to receptors using an accurate SCM.

ISVs for evaluating chronic risk are available for most of the compounds on the Minnesota Soil Gas List. The Minnesota Soil Gas List contains a standard list of compounds that are to be analyzed and reported from vapor intrusion investigation sampling (see Section 4.2.1 and Appendix C). A limited number of compounds on the Minnesota Soil Gas List also have ISVs for the evaluation of acute risks. Compounds currently without ISVs either do not have sufficiently supportable toxicity data or are not common compounds of concern for the vapor intrusion pathway.

The ISVs are available on spreadsheets in Microsoft Excel™ format that are maintained separately for the SRVC, programs and Petroleum Remediation and Petroleum Brownfield Programs and are posted on MPCA's Web site. The spreadsheets will be updated as new toxicity values are generated from the hierarchy of sources (see Appendix B-1). The ISV Spreadsheet for the SRVC programs enables calculation of additive health risk from exposure to multiple compounds identified in indoor air. For additional information regarding incorporation of additive health risks for indoor air samples, please refer to appropriate programmatic ISV Spreadsheet or consult with the MPCA project staff.

The PRP bases corrective action decisions by demonstrating that a completed exposure pathway exists. Based on information presented in a SCM, the detection of elevated petroleum constituents in subsurface vapor intrusion samples (i.e., sub-slab or near-slab soil gas) that are also present in indoor air samples will usually indicate a need for corrective action. Corrective actions may also be taken when other data sources or site conditions indicate a need to be protective of human health.

Program-specific guidance

The Intrusion Screening Values can be found on the following Web pages

- ISV Spreadsheet for Use in the SRVC Programs: http://www.pca.state.mn.us/publications/aq1-36.xls
- ISV Spreadsheet for Use in PRP and PBP: http://www.pca.state.mn.us/publications c-prp4-01c.xls

2.3.2 Media-specific screening values

Soil gas screening values and sub-slab screening values are used in the MPCA vapor intrusion guidance for evaluating the risk posed to nearby receptors, described further in Sections 4 and 5. These values are based on the conceptual model whereby contaminant vapor concentrations decrease from vapor sources in the subsurface upwards toward the surface and eventually into buildings. They are determined by back calculating from the compound-specific ISV and use of a conservative attenuation factor particular to that media. Both the soil gas and sub-slab screening values are based on an attenuation factor of 0.1 and 0.01. The use of attenuation factors allow the media-specific screening values to be presented as a factor of the ISVs, specifically ten times the ISV (10X-ISV) or one hundred times the ISV (100X-ISV). Both the 10X-ISVs and 100X-ISVs values are provided on the MPCA program-specific ISV Spreadsheets for reference.

Groundwater screening values for the vapor intrusion pathway (GWISVs) provide an additional, secondary screening tool for SRVC Programs and are calculated using both a media-specific attenuation factor (0.001) and the compound-specific Henry's Law constant. Refer to Section 3.2.3 for additional information regarding the use of GWISVs.

Program-specific guidance

Groundwater screening values are developed for use at sites in the SRVC Programs to provide an additional screening tool for groundwater plumes that are, on average, larger than groundwater plumes solely from petroleum releases. Tabulated values can be found on the MPCA's Risk-Based Site Evaluation Web page.

2.4 Field sampling and laboratory analysis

2.4.1 Field sampling

The term active sampling refers to collecting soil gas, sub-slab or ambient indoor air samples using an evacuated vacuum canister. Soil gas samples are sampled typically between three and eight feet below ground surface whereas sub-slab samples are collected just beneath the concrete slab of a building. Additional information regarding sampling procedures for active gas sampling is provided in Section 4.2 and Appendix D. Other sampling procedures, such as the use of passive (diffusion) soil gas sampling, are discussed in Appendix E.

Active soil gas sampling can be conducted using either from temporary or permanent soil gas monitoring point. Permanent soil gas monitoring points are recommended when multiple sampling events are necessary. In either case, the annular space around the sample device should be sealed off from the ground surface. Soil gas probes should be logged and a total organic vapor measurement recorded using either a flame ionization detector (FID) or a photoionization detector (PID) from each push probe location at the same depth interval from which the soil gas sample is collected.

2.4.2 Target analytes and analytical methods

The default method for the analysis of soil gas, sub-slab, and indoor air samples is EPA Method TO-15 (full scan). Method TO-15 is a gas chromatograph/mass spectrometry (GC/MS) method. Samples should be analyzed for the target analytes on the Minnesota Soil Gas List provided in Appendix C. The Minnesota Soil Gas List was developed by the MPCA and comprises an augmented VOCs list as compared with the analytes on the EPA Method TO-15 list (EPA, 1999). The use of other analytical methods will require prior MPCA staff approval. Alternative analytical methods available are summarized in Table D-3 of the ITRC Toolbox (ITRC, 2007a). Laboratory quality assurance and quality control expectations for vapor intrusion data submitted to the MPCA are provided Appendix F.

Samples may be subject to dilutions by the laboratory if VOCs concentrations are particularly elevated or if an insufficient volume of air was collected within a canister sample. Diluted samples will typically have higher reporting limits than the reporting limits specified for chemicals on the Minnesota Soil Gas List. Such situations should be discussed with MPCA project staff to determine if resampling will be necessary or if the diluted results provide the information required.

The ISV Spreadsheet includes values for some compounds that cannot be analyzed using method TO-15 [e.g., mercury and polychlorinated biphenyls (and are not found on the Minnesota Soil Gas List. If these compounds are suspected of posing a vapor intrusion risk, investigators should coordinate with MPCA staff to determine the appropriate analytical method and sampling procedures. In some cases, laboratory reporting limits for TO-15 compounds may be higher than the compound’s ISV or soil gas or sub-slab screening values. In such cases TO-15 SIM (Selected Ion Monitoring) may be needed to reach appropriate detection limits if this is necessary at the site to evaluate risks.

3.0 Step 1: Vapor intrusion screening

Step 1 is a screening-level assessment to determine whether the vapor intrusion pathway represents an exposure pathway of concern at a site under investigation. If during Step 1 or at any other investigation step information points to the potential for imminent health impacts, emergency assessment and response, as described in Section 3.1, may need to be considered. Initial site screening for the vapor intrusion pathway at sites where the need for emergency assessment and response is not required is presented in Section 3.2. Flowchart G-1 in Appendix G provides an illustrated decision tree for items discussed in this section.

3.1 Consider the need for emergency assessment and response

Emergency assessment and response may be required if an imminent health risk is suspected at any point during a vapor intrusion investigation. To address an imminent vapor intrusion risk, an interim emergency response action may need to be considered. The decision to conduct emergency assessment and response, however, should be made on a case-by-case basis and with prior approval from the MPCA project staff.

An emergency assessment and response action is appropriate if an imminent health risk is present or potential uncontrolled flammable/explosive conditions are present. Responsible parties are required to mitigate these conditions. If they or other regulated parties cannot or will not comply, the state will respond to protect public health, safety, and the environment.

Examples of situations that might require an emergency response include:

- odors in an occupied building with or without exposure symptoms to the occupants
- oil or chemical infiltration in a basement or sump in a building
- measured indoor air concentrations are near or above the acute ISVs
- uncontrolled potentially flammable or explosive conditions in a building, sewer, or utility conduit

When an acute or immediate hazard resulting from vapor intrusion is suspected, the immediate safety of the building occupants is the first priority. In such cases, call the local fire department by dialing 911 to activate a local response. Local authorities can typically evaluate the conditions quickly and provide an immediate short-term control measure. Then contact the Minnesota Duty Officer at 1-800-422-0798 or 651-649-5451 to report the situation and the appropriate MPCA project staff.

Several sampling techniques may be used to make an immediate decision. Depending on whether the type of release is known and which compounds of concern are present, an investigator may use a photoionization detector (PID), a combustible gas detector, or similar field screening devices to get a rapid on-site determination that volatile gases are present. In most cases, indoor air sampling using Method TO-15 or other laboratory methods will be a necessary follow-up activity.

Methane gas and gasoline pose a threat of fire and explosion if they enter a building, sewer, or utility conduit. Methane gas is odorless and explosive at a concentration of 50,000 parts per million (ppm) or five percent by volume in air, a value referred to as the lower explosive limit (LEL). The NIOSH Immediately Dangerous to Life and health (IDLH) value for methane is 5,000 ppm. When methane concentrations reach ten percent of the LEL, emergency procedures are warranted for two reasons: the health hazard and the explosion hazard. The odor threshold for gasoline is two ppm and may provide a warning well before a threat of explosion. The LEL for gasoline is 14,000 ppm or 1.4 percent. Ten percent of the LEL is 1,400 ppm. However, some of the compounds in gasoline have an IDLH which is even lower, in the range of 500-900 ppm. Therefore, emergency response actions can be warranted below ten percent the LEL due to health hazards. If a fire or explosion hazard is identified (based on combustible gas measurements or suspected based on strong odor), buildings should be evacuated immediately and safe ventilation of structures should begin by emergency response personnel, such as the local fire department, a state-contracted Chemical Assessment Team, or an emergency response contractor. Additionally, MPCA Emergency Response Team staff can be reached through the Minnesota Duty Officer and consulted with on responding to these types of conditions.

3.2 Vapor intrusion screening and receptor evaluation

3.2.1 Initial vapor intrusion screening considerations

Review available site records and information sources including historical records, chemical use history, site investigation data, Phase I and Phase II ESA investigations, and other program-specific site background information as applicable to assess whether the vapor intrusion pathway represents a potential concern.

Further evaluation of the vapor intrusion pathway is required when:

- the historical use of volatile compounds at the site is confirmed or suspected
- site investigations have identified evidence of volatile compounds in the soil or groundwater

Further evaluation of the vapor intrusion pathway is not required at sites when:

- there is evidence that the site has never used volatile compounds
- no volatile compounds have been identified during past or current soil or groundwater investigations

If further vapor intrusion investigation is required, soil vapor sampling should be conducted at or near locations of known or suspected volatile contaminant releases.

Program-specific guidance

The vapor intrusion pathway is evaluated at all sites in the Petroleum Remediation Program. Sites in this program would combine Steps 1 and 2 to determine if vapor intrusion receptors are present within 100 feet from a release source followed by completing a preliminary soil gas investigation near identified receptors within this screening area.

3.2.2 Vapor intrusion receptor survey

The purpose of a vapor intrusion receptor survey is to document the location of receptors within a 100 foot radius from vapor sources, defined as the preliminary screening area. A secondary objective is to determine the applicable building exposure scenarios (e.g. residential versus commercial/industrial) for receptors. The vapor intrusion receptor survey should also determine and document the location of buried utilities which can be preferential migration routes for vapors migrating from vapor sources to receptors. The vapor intrusion receptor survey represents an integral component of the SCM (Section 2.2), and should be explicitly documented as part of MPCA program-specific reporting requirements. At a minimum, the vapor intrusion receptor survey should include a site map of potential receptors and other relevant features with respect to the extent of known vapor sources, and information on the type of buildings present, their use, and their construction.

If the horizontal extent of vapor sources is defined the Vapor Intrusion Receptor Survey is evaluated as follows:

1. If receptors are not present within the 100 lateral foot preliminary screening area as described above, no further vapor intrusion investigation is required.
2. If receptors are present within 100 lateral feet of the preliminary screening area and the compounds of concern are sufficiently toxic and volatile, a soil gas investigation should take place to evaluate receptor risks.

If the horizontal extent of vapor sources is undefined the Vapor Intrusion Receptor Survey is evaluated as follows:

1. The extent and magnitude of vapor sources will require further characterization to evaluate vapor intrusion risks near receptors.
2. Once the extent of vapor sources has been defined an evaluation of receptors within the 100 foot preliminary screening area should take place as described above.

Select Appropriate Screening Values Based on Building Exposure Scenarios
Building exposure scenarios can vary widely and include residential, commercial and industrial.

Important note

At industrial facilities that manufacture or use chemicals of concern for the vapor intrusion pathway, and where workers have had right to know training, the ISV's are not intended to replace applicable OSHA occupational exposure concentrations. At other receptor locations, however, the ISVs and the other media-specific screening values will be used to evaluate risks posed by vapor intrusion.

Building occupancy information can be obtained from public records, maps, and available databases. However, occupancy should be verified by field visits and direct contacts. Either the residential ISVs or the industrial ISVs should be selected to determine the appropriate media-specific screening values (see Section 2.4.1). Residential screening values are appropriate for evaluating buildings with sensitive populations (e.g., schools, hospitals and day care facilities).

3.2.3 Screening using soil gas data

Soil gas data collected for screening purposes should be evaluated following the criteria described in Section 4.3; however, general guidelines to evaluate this screening data are provided below:

1. If soil gas concentrations collected near a receptor are less than 10X the applicable ISVs (residential or industrial), then the risk is considered low and no further vapor intrusion investigation is needed at those receptor locations.
2. If soil gas concentrations are equal to or greater than 10X the applicable ISVs (residential or industrial), a more thorough soil gas investigation is required as described in Section 4.

If it is not possible, based on the available data, to complete the assessment from items 1 or 2 above, then the MPCA recommends that a more thorough soil gas investigation or building-specific investigation (Section 5) be completed to collect additional site information.

3.2.4 Screening using groundwater data

Groundwater screening values (GWISVs) as used in SRVC Programs and represent an additional screening tool for sites in SRVC Programs when existing groundwater data is available. GWISVs are designed to be used as an additional line of evidence to help refine the SCM and to help determine the scope of further investigation, and should not be applied alone to screen out vapor intrusion risk at sites or for remedial action levels.

Groundwater analytical results evaluated using GWISVs should be from samples collected at or near the water table (or perched water). The use of GWISVs as a line of evidence during site evaluation is described below.

Groundwater data has been collected but soil gas data is limited

- If receptors are identified overlying a groundwater plume with concentrations at the water table that exceed GWISVs or within 100 lateral feet where GWISVs are exceeded then soil gas sampling should be conducted if this has not yet been conducted.
- GWISVs can be useful for estimating vapor intrusion risks at sites where multiple receptors are located within the footprint of a groundwater plume (e.g., higher VOC groundwater concentrations at the water table may be indicative of areas with comparatively higher vapor intrusion risks).

Groundwater data and soil gas data have been collected

- If soil gas investigation results near receptors are less than 10X-ISVs, and the receptors are also farther than 100 feet from where GWISVs are exceeded no additional action will be required to address vapor intrusion risks for that location. This determination may not be appropriate if groundwater plume stability has not been documented.
- If soil gas investigation results near receptors are less than 10X-ISVs, but receptors are within 100 lateral feet of where GWISVs are exceeded, consideration should be given for conducting verification soil gas sampling before concluding there are no vapor intrusion risks.

GWISVs are based on attenuation factor compiled from EPA-investigated sites (see Appendix B-2, and EPA, 2008a) and compound-specific Henry's Law constants. These values may be conservative at sites in which the groundwater table is more than 100 feet below ground surface and where clays and silts act as vertical barriers to vapor migration. Conversely, at sites with highly permeable soils and a shallow groundwater table, the values may be less conservative.

Another consideration when evaluating groundwater data is that the diffusivity for a volatile compound is approximately 10,000 times lower in water than in a gas phase (i.e., unsaturated soil gas). As a result uncontaminated groundwater overlying a contaminated groundwater plume can serve as a barrier for the upward migration of contaminant vapors. However, these situations should be interpreted using cautiously because (a) residual dissolved VOCs or NAPL may be present in the capillary or vadose zone associated with historical groundwater fluctuations and (b) vapors from nearby soil or groundwater contamination may migrate laterally

4.0 Step 2: Conducting soil gas investigations

Soil gas investigations are completed to identify if receptors are at risk from vapor intrusion and to determine if further building-specific assessment is needed.

This section focuses on the following aspects of soil gas investigations:

- consideration of investigation objectives and strategies appropriate for different types of sites
- sampling locations, depths and procedures
- use of screening values to evaluate soil gas data within the context of the SCM

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4.1 Identify objectives and strategy

Soil gas investigations should be based on clearly defined objectives consistent with both programmatic requirements and site-specific conditions. The type of vapor intrusion sites can also vary widely and can include leaking underground storage tank (LUST) releases; dry cleaner releases at commercial facilities (e.g., strip malls); surface releases of VOCs with associated shallow soil contamination; vapor intrusion concerns associated with a widespread VOC groundwater plume that may impact multiple receptors, and brownfield sites with proposed new construction or redevelopment (e.g., as discussed in ITRC, 2007b). Three generalized scenarios are provided below as examples of site specific conditions that may require different investigation objectives and strategies.

4.1.1 Vapor sources and receptors are limited in extent

A simplified soil gas investigation strategy for smaller sites involves identifying receptors within a 100 foot radius from the “worst-case” sample area; or the area of highest suspected contamination, accompanied by collecting soil gas samples as described in section 3.2.2. This approach is used in the PRP vapor intrusion guidance (MPCA 2008b) for investigating petroleum release sites and also has applicability for smaller sites in the SRVC Programs. At smaller sites with localized vapor intrusion concerns, the initial screening level evaluation (Step 1) and the soil gas investigation (Step 2) can typically be conducted during the same investigation phase.

4.1.2 Sites with area-wide vapor intrusion risks

Sites with area-wide contamination and numerous receptors can require multiple soil gas sampling events to determine the extent of vapor intrusion impacts and identify which receptors are at risk and require a building-specific investigation. Typical sites are those where widespread VOC groundwater plumes extend well beyond the original release areas or sites where area-wide groundwater impacts are associated with multiple VOC releases. An investigation option for such sites can include techniques designed to rapidly assess the area-wide extent of groundwater and soil gas impacts rather than stepping out from the release area to nearby receptors in a building-by-building phased approach. Investigation screening techniques to consider include the use of passive soil gas sampling with follow-up active soil gas sampling using Method TO-15 and the use of mobile laboratories for concurrently characterizing the extent of both groundwater and soil gas impacts. Passive soil gas sampling and the use of mobile laboratories are discussed further in Appendix E.

At larger sites it may not be practical to collect soil gas samples at each individual receptor location. This may be an option where well characterized trends of both soil gas and groundwater contamination allow the interpolation of vapor intrusion risks. The use of area-wide soil gas sampling will be site specific and requires careful coordination with the MPCA project staff.

4.1.3 Brownfield sites: undeveloped land/proposed redevelopment

MPCA Brownfield Programs (PBP and VIC) require consideration of potential vapor intrusion risk associated with property redevelopment or reuse. Investigation strategies for sites in these programs need to include assessment of vapor intrusion risks for future receptors in addition to current receptors.

Factors that should be considered when evaluating risks to future receptors include:

- current and proposed land use
- the proposed development plans and design for buildings (e.g., slab-on-grade, sub-grade living or working spaces, underground parking, etc.)
- whether vapor controls are proposed for the buildings

When the construction of future buildings is proposed, soil gas sampling locations should include areas beneath or near these future structures. Accurate development plans should be obtained, if possible, before completing the soil gas investigation to ensure that future redevelopment locations are properly represented for evaluating risks. At MPCA Brownfield sites where soil gas concentrations exceed 10X the ISVs at and beneath the locations of new buildings, MPCA program staff will likely recommended building controls to be installed at these buildings (see Section 6.2 for a discussion of building controls) to provide safeguards from future vapor intrusion risks.

4.2 Collecting representative soil gas samples

The number of soil gas samples needed and the overall investigation strategies for a soil gas investigation will depend upon the geometry of the vapor sources, the location of receptors, the size and complexity of the site, as well as specific program requirements for which the soil gas investigation is being completed.

Specific locations and methodologies for completing soil gas sampling may include but are not limited to:

- immediately above the identified "worst-case" vapor source area or the area of the highest documented concentrations in soil or groundwater
- adjacent to the base of an existing building foundation or basement (referred to as near-slab soil gas sampling)
- within the footprint of a future building location
- at or near the outer edges of a soil gas plume

In general, it is recommended that soil gas samples should be collected adjacent to specific buildings according to the following depth requirements:

- at least 2 feet above the water table and at least three feet below grade
- near the basement floor depth of a building being evaluated (typically to a total depth of eight to ten feet below grade for a typical house)
- three to five feet below grade adjacent to slab-on-grade buildings

Significant precipitation events can displace shallow soil gas and close off pore space pathways that if sampled may provide an inaccurate representation of ambient vadose zone soil gas conditions. The effects of precipitation on soil gas samples are generally less of a concern at depths greater than five feet below ground surface, under foundations, or from an area that is significantly covered by an impervious surface cover (ITRC, 2007a). Samples should not be collected from depths less than five feet below ground surface immediately following significant precipitation events. The effect of significant precipitation can be recognized by observing high vacuum readings, extended sample collection time, and visible moisture droplets within the sampling train during sample collection.

4.3 Evaluating soil gas data

Soil gas sampling results are used in the context of a well understood SCM to assess risks posed to receptors in buildings. In general, higher soil gas concentrations are indicative of higher risk to receptors if other site conditions are the same. The decision framework described below considers three broad levels of risk that are based solely on soil gas concentration ranges identified from investigation results as compared with soil gas screening values.

The recommendations described in sections 4.3.1 through 4.3.3 are based on the assumption that soil gas samples were collected as close as possible to an existing receptor or within the footprint of future building locations. Soil gas results that vary significantly spatially (either horizontally or vertically) may be an indication that verification sampling or multiple sampling events over time may be necessary to assess risks more accurately.

Decision flowcharts corresponding to the following sections (4.3.1 through 4.3.3) are located in Appendix G-2.

4.3.1 Soil gas results less than 10X ISVs

Soil gas concentrations less than 10X their respective ISV concentration represent a relatively low risk and typically no further investigation for vapor intrusion is necessary.

4.3.2 Soil gas results between 10X and 100X ISVs

Soil gas concentrations between 10X and 100X their respective ISVs will require further investigation. An appropriate recommendation for completing further assessment should be prepared and submitted to the MPCA using program-specific reporting procedures. Additional assessment of the vapor intrusion pathway may include confirmation soil gas samples, completion of an Interior Building Survey (described in Section 5.1), or sub-slab soil gas concentrations. Recommendations for no further investigation of the receptor must be strongly supported through the use of the SCM that shows the vapor intrusion pathway is either incomplete, or that the pathway may be complete but does not present a risk to building occupants based on additional pathway assessment information.

Buildings proposed at active MPCA Brownfield Program sites that are adjacent to and above locations where soil gas concentrations are greater than 10X ISV's must consider implementing appropriate vapor intrusion response actions accordance with the appropriate MPCA Brownfield program.

4.3.3 Soil gas results greater than 100X ISVs

Soil gas concentrations that exceed 100X their compound-specific ISV may indicate a comparatively higher vapor intrusion risk. In these situations, a building-specific investigation is required including the completion of a building survey and sub-slab vapor sampling (see Section 5.0).

5.0 Step 3: Building-specific investigations

Building-specific investigations (Step 3) are completed to assess risks posed by vapor intrusion to occupants in specific buildings. The results of a building-specific investigation are used to determine if unacceptable risks exist that require response actions.

Building-specific investigations include one or more of the following actions:

- conducting a thorough interior building survey using the appropriate form(s) in Appendix H
- conducting sub-slab vapor sampling using information obtained from the building survey
- taking appropriate action based on sub-slab sampling results, and if necessary, conducting indoor air sampling and outdoor ambient air sampling
- evaluating the need for corrective action throughout each phase of a building-specific investigation

5.1 Interior building survey

The Interior Building Survey is divided into two components – a physical building inspection and an indoor air quality survey. The physical building inspection involves collecting information about building use, construction, condition, occupancy, potential vapor entry locations, and other building features that can influence the potential for vapor intrusion risk. The physical building inspection should be conducted as part of every building specific investigation involving sub-slab sampling. The indoor air quality survey involves collecting information to evaluate the potential for background air contamination sources and is only required when indoor air sampling is conducted. The Interior Building Survey should be completed by an environmental professional with approval and assistance of the building owner or other representative.

The form provided in Appendix H should be used to conduct and document the Interior Building Survey. Part 1 of the form should be used to document the physical building inspection along with grids that can be used to document basic floor plan layouts. Part 2 of the form should be used to document the indoor air quality survey and should be completed at least two weeks before indoor air samples are collected in order to identify and potentially remove background sources of indoor building contamination (paints, varnishes, fuels, etc.). The use of a physical building inspection and an indoor air quality can be used as a line of evidence in evaluating vapor intrusion risk is discussed further in Section 5.4.2.

5.2 Sub-slab sampling

Sub-slab sampling involves collecting soil gas samples directly below a building's foundation. Sub-slab sampling results can provide a more direct line of evidence of the risk from vapor intrusion than soil gas samples as these samples may not be located immediately near a building. Sub-slab vapor sampling along with completing part 1 of the Interior Building Survey can help determine if a complete exposure pathway is present. Sub-slab vapor sampling may be conducted concurrently with indoor air sampling; however, the MPCA recommends that sub-slab vapor sampling be conducted first to determine if indoor air sampling is necessary.

In cases where access difficulties limit obtaining sub-slab samples, near-slab sampling conducted directly adjacent to the building at the depth of the lower level can provide a means to approximate soil gas concentrations that may be found beneath the building slab. Although near-slab samples should not be viewed as directly comparable to a sub-slab sample, they are an option that may be considered when direct sub-slab samples cannot be collected.

5.2.1 Sub-slab vapor sampling procedures

The investigator needs to take into consideration the potential for sub-slab contaminant concentrations to vary both spatially and temporally when planning and conducting sub-slab vapor sampling. The MPCA recommends that sub-slab vapor be sampled during the winter heating season and another season if possible (e.g., summer).

For buildings with crawl spaces, the collection of crawl space air samples using the indoor air sampling methodologies discussed in Section 5.3 may be required, in addition to or instead of sub-slab vapor sampling.

To adequately assess the potential for spatial variations in sub-slab vapor samples, a recommended minimum of one sub-slab vapor sample should be collected for every 1,000 square feet of building footprint or for every section of a building separated by footings or foundations at different levels. For larger buildings (i.e., >5,000 square feet), a minimum of five sub-slab vapor samples should be collected and spaced throughout the building footprint. If the results from these initial samples are greater than the 10X-ISVs another phase of sub-slab sampling should be conducted to provide better coverage throughout the building footprint.

5.2.2 Evaluation of sub-slab vapor results

Sub-slab soil gas results should be used in the context of a well understood SCM for assessing risks posed to receptors in buildings. This helps ensure that the investigation considers and uses all quantitative and qualitative site investigation results, including the Interior Building Survey. In general, higher sub-slab concentrations are indicative of higher potential risk to receptors if other site conditions are the same. It is important that the investigator use all appropriate lines of evidence collected during the site investigation for risk-based decision making. Two important lines of evidence that should be considered when interpreting sub-slab sampling results include the results of the Interior Building Survey and site-wide spatial and temporal data trends of vapor sources and soil gas.

The recommendations below are based on the assumption that a minimum of two consecutive sub-slab vapor samples were collected during different seasons and that Part 1 of the Interior Building Survey has been conducted to identify possible vapor entry points. Samples collected during a both sub-slab sampling events should be collected in individually certified canisters.

Recommendations and options based on a sub-slab vapor evaluation results are discussed below and are depicted schematically in flow chart G-3 of Appendix G.

Sub-slab results less than 10X ISVs

Sub-slab concentrations less than 10X their respective ISV concentration represent a relatively low risk and typically no further investigation for vapor intrusion is necessary.

Sub-slab results between 10X and 100X ISVs

Sub-slab concentrations at or greater than 10X-ISVs will require further investigation to determine whether a completed pathway exists. Typical investigation options for sub-slab results in this range are depicted in Flowchart G-3 and include:

- conducting additional sub-slab verification sampling
- paired sub-slab vapor samples and indoor air samples to document contaminants present both in the sub-slab and indoor air environments

Recommendations for no further investigation at the building under investigation must be strongly supported through the use of a SCM documenting that the vapor intrusion pathway is either incomplete, or that the pathway may be complete but does not present a risk to building occupants based on additional pathway assessment information.

Sub-slab results greater than 100X ISVs

Sub-slab vapor concentrations that exceed 10X the ISVs will require one of the following options:

- conducting paired sub-slab and indoor air sampling to document contaminants present in the sub-slab and indoor air environments
- conducting proactive mitigation

If sub-slab soil gas is greater than 100X ISV's and proactive mitigation is not pursued, paired sub-slab and indoor air samples should be collected to verify if a completed pathway is present and mitigation is necessary.

5.3 Sampling indoor air and outdoor ambient air

Indoor air sampling can be used to help determine if there is a completed vapor intrusion pathway. The MPCA recommends that indoor air samples be collected only after soil gas or sub-slab sampling results and other site investigation results have been evaluated and indicates a need. Collecting sub-slab, indoor air, and outdoor air samples together can be an additional line of evidence indicating whether indoor air contaminants are derived from vapor intrusion or background sources of contamination (see 5.4). In situations where soil gas or sub-slab samples cannot be collected, consultation with the MPCA project staff should occur to determine if direct indoor air sampling is an appropriate course of action. Outdoor ambient air sampling should also be conducted when indoor air samples are collected. The concurrent indoor air and ambient air sampling results, as well as the results of the Interior Building Survey, are used collectively to help distinguish indoor air contaminants resulting from vapor intrusion versus those originating from other background contaminant sources.

Indoor air samples and outside ambient air samples should be collected over a 24-hour period. Both indoor air and outdoor ambient air sampling require the use of certified clean individual canisters. Situations may exist where collecting a grab sample is appropriate; however, this requires prior approval from the MPCA project staff.

Indoor air samples should be collected under representative conditions of the structure, (i.e., doors open or closed, depending on their typical condition and the heating system is in use if it is winter). HVAC systems should be operating under normal operating conditions to provide representative ventilation conditions during the sampling. In summer months, windows should be closed to minimize the contribution of outdoor air. General guidelines for collecting representative indoor air samples include:

- Collect the samples from the basement or lowest level near suspected vapor entry points to assess the worst-case exposure.
- Place the evacuated canister in the breathing zone, approximately three to five feet from the floor.
- Collect the samples away from windows or other sources of exterior air leakage.
- If direct preferential pathways are identified (e.g., earthen floors, unsealed crawl spaces, sumps), indoor air samples should be collected from those areas.

When indoor air sampling is deemed appropriate, the MPCA recommends at a minimum two consecutive indoor air sampling events be conducted during different seasonal conditions for evaluation purposes. Indoor air sampling during the winter (peak heating season) may be required by the MPCA staff. Samples collected from the lowest habitable level and from each occupied building floor should be conducted initially and may be sufficient for a typical single-family home. Multiple indoor air sample locations will be necessary for multifamily residential units and larger commercial or retail buildings.

Results of the indoor air quality survey should be used to identify chemicals that may interfere with the proposed sampling, and to prepare the building for the sampling process by temporarily removing potential background substances. The MPCA recommends that the indoor air quality survey (Part 2 of Appendix H) be completed at least two weeks prior to collecting indoor air samples. The MPCA recommends that prior to conducting indoor air sampling that the building owners or occupants follow the instructions provided in Appendix I to help minimize the potential for indoor air background contamination. All indoor air sampling results should be accompanied by a completed or updated survey as well as details of the modifications that the occupants were requested to make and to what extent they complied with the request.

An appropriate number of outdoor ambient air samples should be collected based on the size of the investigation area and the number and location of potential background sources. A minimum of one ambient outdoor sample is required when indoor air samples are collected at a building. For a larger investigation area, at least two outdoor ambient samples for each city block should be collected. As is the case with indoor air sampling, consecutive multiple outdoor air sampling events may be required to clearly establish the localized ambient air conditions for a given site.

Outdoor ambient air samples should be collected from a representative upwind location, away from wind obstructions (e.g., trees or buildings), and at a height above the ground to represent breathing zones (i.e., three to five feet). A representative sample is typically one that is not biased toward obvious sources of volatile chemicals (e.g., automobiles, lawnmowers, oil storage tanks, gasoline stations, industrial facilities, etc.). In some cases outdoor ambient air sampling biased for one or more ambient sources of contamination, however, can provide important information, but should be coordinated in advance with MPCA project staff.

5.4 Evaluating the need for response actions

5.4.1 Using multiple lines of evidence

The use of vapor intrusion receptor surveys and screening values to evaluate soil gas, sub-slab, and indoor air sampling results have been discussed previously. This section discusses other important lines of evidence to consider when interpreting investigation results.

Spatial and Temporal Variations of Data Trends

The site-wide spatial distribution of vapor sources and concentration trends relative to receptor locations can be important qualitative information regarding risks especially at larger sites. Information regarding whether vapor sources are stable or attenuating is needed to understand whether sampling results are representative of future conditions near receptors. Such qualitative risk considerations are based on the recognition that actual three-dimensional migration patterns of vapors can be complex and vary spatially and temporally.

Physical Building Inspection

A physical building inspection (Section 5.1, Part 1 of the Interior Building Survey in Appendix H) provides qualitative information regarding the likelihood that subsurface soil gas proximal or beneath a building will enter the building through preferential pathways such as cracks, sumps, earthen floors, drain tiles, utility penetrations or other openings. Examples of other lines of evidence for risk evaluation include the condition of the building foundation, the long-term integrity of the building structure and the magnitude of sub-slab concentrations.

The presence of obvious preferential pathways along with elevated soil gas and sub-slab results can indicate that a completed pathway is likely, depending on nearby soil gas or sub-slab results and in such cases identified entry points should be sealed if possible (see Section 6.2.1). Effective building ventilation systems, new slab-on-grade construction, and tight building foundation construction can contribute to lowering the risk for vapor intrusion. Mechanical ventilation systems can influence vapor intrusion by the amount of ventilation (e.g., air exchanges) provided and how the systems modify the interior building pressure. For example, frequent air exchanges and positive pressurization of a building can minimize the risk for vapor intrusion.

Distinguishing COCs for vapor intrusion from background contaminant sources

The lines of evidence discussed below concern distinguishing whether compounds detected in the indoor air are derived from vapor intrusion or from other background sources. Contaminant sources not resulting from vapor intrusion are referred to as background contaminant sources. Identifying the sources of indoor air contamination can be difficult; however, the efforts made to distinguish between vapor intrusion and background sources represent a critical component of interpreting indoor air results.

Interior air quality survey and outdoor ambient air sampling results

An interior air quality survey (Section 5.1, Part 2 of the Interior Building Survey in Appendix H) and outdoor ambient air sampling (Section 5.3) should be conducted whenever indoor air samples are collected to help determine whether there may be background contaminant sources contributing to indoor air contamination that is not due to vapor intrusion. Compounds detected in the indoor air that do not correspond to the site COCs found in subsurface samples, such as sub slab or soil gas, are likely due to indoor or outdoor ambient air background sources and should be clearly identified as such.

Common sources for background contamination

Many common COCs such as solvents and petroleum compounds can also be derived from common household products, paints, varnishes, household hobbies, building materials, the use of tobacco products, and chemicals stored in basements or in attached garages. Low levels of several common petroleum compounds and other VOCs are present in outdoor ambient air especially in urban locations. Nearby point source emission sources may also contribute to outdoor ambient air contamination. Outdoor ambient air contaminants, if present, are also likely to be found in indoor air of buildings at varying levels.

Indoor and outdoor background sources of contamination typically originate from the types of sources listed in Table 5-1.

Table 5-1. Common Background Sources of Indoor Air Contaminants

Source Type	Category	Examples
Indoor air background sources	Consumer products	Household cleaners, dry-cleaning chemicals (i.e., PCE), clothing recently dry cleaned, air fresheners, aerosols, mothballs, scented candles, insect repellents
	Building materials, or building sources	Carpets, insulation, paint, varnishes, wood finishing products, PVC pipe cleaners and glue; municipal drinking water as a contributor of volatile disinfection products from tap water; contaminated domestic drinking water
	Combustion processes	Smoking, cooking, home heating
	Occupant activities	Craft hobbies, woodworking, home repair activities using glues, paints, solvents, etc.; fuels or chemicals stored in attached garages either in storage containers or equipment
	Commercial or industrial workplace chemicals	Can vary widely depending on past and current use
	Residual past chemical use or spills in building	Can vary widely depending on past use
Outdoor ambient air sources	Urban mobile petroleum sources	Cars, trucks, airplanes, boats, construction equipment
	Stationary industrial sources	Nearby chemical or fuel spills, bulk fuel storage or distribution

Several studies have been published in recent years on the subject of background concentration of VOCs in indoor air which document the widespread occurrence of a large number of VOCs that are consistently found in residential indoor air due to background sources rather than from vapor intrusion (e.g., Kurtz and Folkes, 2002; Dawson and McAlary, 2009). The results of such studies emphasize the importance of conducting building surveys and collecting outside ambient air samples as an integral part of all indoor air site investigations.

Use of constituent ratios between sub-slab and indoor air sample results

Comparison of constituent ratios involves comparing the concentrations from one sampled medium to another. Examples include comparing chemicals in the soil gas or sub-slab vapor to the same chemicals detected in indoor air. Constituent ratio analysis for evaluating indoor air sampling results is based on the expectation that chemicals, ideally would be at a greater concentration in the sub-slab environment than in the indoor air and that the compound ratios would be similar in both the sub-slab and the indoor air sample results. Substantially different constituent ratios between indoor air and sub-slab vapor could represent evidence that background indoor air sources are contributing to the indoor air results. Comparison of constituent ratios should be made carefully with consideration for other lines of evidence, particularly since soil gas concentrations can vary over space and time. Refer to Section 3.7.3 of ITRC (2007a) for additional information.

Use of indicator and tracer compounds

Another tool in evaluating constituent ratios is the use of indicator compounds. For example, the compound 1, 1-dichloroethylene is not typically found as part of household products or building materials and its presence in indoor air is often indicative of vapor intrusion. Additional compounds can be used as tracers for evaluating infiltration rates or flux between sub-slab and indoor air. Both sulfur hexafluoride (SF6) and radon have been used as tracer compounds in vapor intrusion investigations and are chemically inert, not derived from indoor background sources, and can be detected accurately at relatively low concentrations.

5.4.2 Vapor intrusion risk evaluation

Vapor intrusion risks are evaluated at each investigation step as new information is collected. The use of vapor source characterization, and media-specific screening values to evaluate risks have been discussed in previous sections of this document. Both qualitative and quantitative data sources need to be used collectively when evaluating risk to receptors.

The identification of unacceptable vapor intrusion risks based on paired sub-slab and indoor air sampling results or elevated sub-slab or near-slab results supported by results from the Interior Building Survey and other lines of evidence require appropriate response actions to eliminate the completed pathway, remediate the source contamination, or otherwise reduce or eliminate risks. Evaluating risks associated with indoor air sampling results require careful consideration of whether indoor air contamination is due to vapor intrusion of identified site COCs, background sources or perhaps a combination of both. Site COCs should be limited to the compounds comprising the vapor sources and their degradation products.

An evaluation of vapor intrusion risk at a particular receptor location typically results in one of the following conclusions:

1. A completed vapor intrusion pathway and unacceptable risks requiring remedial action have been identified based on an evaluation of all data sources.
2. A completed vapor intrusion pathway exists but the site COCs have not been identified in indoor air or, if they have been identified are below health-based exposure levels. Overall risks based on multiple lines of evidence provide support that response actions are not required.
3. A completed vapor intrusion pathway does not exist and the conclusions drawn from using multiple lines of evidence support that the risks are sufficiently low to support recommendations for no further action at the building.
4. A completed vapor intrusion pathway and the risk posed to receptors at the building cannot be confirmed without conducting further investigation.

6.0 Step 4: Response actions

Response actions for the vapor intrusion pathway are necessary when there is evidence of a completed pathway and the risks posed to human health are deemed unacceptable. The term response action is used in this document to refer to all means of mitigating vapor intrusion risk through remedial actions. Remedial actions completed for PRP sites seeking eligible reimbursement costs should be termed as corrective actions.

A response action can include one or more of the following measures:

- remediation of the source of the vapor contamination
- preventing vapor intrusion at the receptor using building control technologies
- controlling vapor intrusion risks through institutional controls, long-term monitoring, engineering controls or other long-term risk-management tools

The primary remedial objective is to eliminate risks to receptors but the specific remedial objectives required to achieve this goal may be site specific and should be established early during the evaluation of remedial actions and in coordination with the MPCA project staff.

Regulated parties and environmental consultants should consult the specific MPCA Remediation program to determine the programmatic submittal, approval, and other reporting requirements associated with response actions.

The following sections 6.1 though 6.3 provide supporting information and general recommended practices for response actions most commonly used to eliminate vapor intrusion risks. The MPCA, however, acknowledge that there may be other acceptable response actions and risk reduction strategies for vapor intrusion beyond those discussed in this section. Section 6.4 discusses operation, and maintenance of constructed remedies and long-term monitoring that may be required to ensure remedial objectives are achieved.

6.1 Source-area remediation

Source-area remediation refers to the response actions conducted to address contaminated soil, groundwater, or NAPL that serves as the source for vapors. Examples of response actions that target source contamination include:

- soil excavation and landfill disposal
- soil vapor extraction (SVE)
- multi-phase extraction (MPE)
- air sparging
- groundwater treatment and containment technologies
- bioremediation, including natural attenuation

Source-area remediation alternatives have varying degrees of effectiveness in addressing immediate vapor intrusion risks, either due to the length of time to implement the remedy or the time required for the remediation to reduce contaminant levels. The investigator should consult program-specific guidelines and requirements for evaluating and conducting response actions as risk-management approaches vary programmatically.

6.2 Building controls for vapor mitigation

Building controls refers to the use of technologies to eliminate completed vapor intrusion pathways at a building. Building control technologies may be necessary to respond to unacceptable risks to receptors in buildings when source-area remedies would take too long or may not be possible to implement. Many building control technologies are similar to methods used for many years in the radon mitigation industry.

The most common building control design and installation recommendations are discussed in Sections 6.2.1 through 6.2.6 and include:

- sealing building leaks
- sub-slab depressurization
- sub-slab membrane depressurization
- venting systems for new building construction
- passive vapor barriers at new building construction
- building pressurization and ventilation

6.2.1 Sealing building leaks

A completed vapor intrusion pathway can result if contaminated soil vapor enters into a building through leaks and openings in the building envelope. This is more likely to occur if the building's interior air pressure is lower than that of the vadose zone air pressure beneath it. When this pressure differential exists, even a small leak in the building envelope can enable vapor intrusion.

Common building locations where leaks and openings can occur include:

- foundation and basement wall cracks
- floor sumps
- floor drains
- floor or wall slab joints
- cinder blocks and mortar joints
- penetrations from piping, wiring, and ducts
- crawl spaces

6.2.2 Sealing building leaks

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Common building locations where leaks and openings can occur include:

- foundation and basement wall cracks
- floor sumps
- floor drains
- floor or wall slab joints
- cinder blocks and mortar joints
- penetrations from piping, wiring, and ducts
- crawl spaces

If such pathways are identified during the physical building inspection and a completed pathway is confirmed or likely then vapor entry points should be sealed by:

- using caulk or expanding foam to seal openings and cracks
- repairing damaged concrete slabs
- covering and sealing areas of exposed earth or pits
- placing air-tight sump covers on existing sumps

Sealing of leaks can be especially important when considering the use of active sub-slab depressurization systems since building leaks, depending on their location, can reduce the effective extent of mitigation (see 6.2.2). Leaks in building foundations and floor slabs can often be identified during a physical building inspection or by conducting pre-mitigation diagnostic pressure field extension tests (see Section 6.2.2).

6.2.3 Sub-slab depressurization systems

Sub-slab depressurization (SSD) systems prevent vapor intrusion into buildings by lowering the air pressure in the soils directly beneath the buildings' floor slabs relative to indoor air pressure. This is accomplished by installing vertical piping into a cavity known as a suction pit that is dug within the lower level floor slab and by exhausting the collected vapors to the atmosphere above the building's roof line by using a low-wattage fan. The MPCA recommends that all SSD systems be constructed as active systems that use a low-wattage fan. As used in the MPCA guidance, the term SSD system implies the use of an active SSD system.

SSD systems are considered among the most effective vapor intrusion mitigation strategy for existing or new buildings and have been documented to achieve vapor concentration reductions of 90 to 99 percent (EPA, 1993, Folkes, 2002). SSD systems can be used to mitigate both existing residential as well as larger commercial/industrial buildings where a concrete slab directly overlies soil.

Many best management practices developed and documented within the radon mitigation industry for diagnostic testing, design, and installation of SSD systems are applicable to SSD systems designed for vapor intrusion. Guidance discussing SSD construction can be found at the following sources: "Standard Practice for Installing Radon Mitigation Systems in Existing Low Rise Residential Buildings" ASTM Standard E2121 (2003); the "Radon Reduction Techniques for Existing Detached Houses – Technical Guidance" SEPA, 1993), which provides design considerations for SSD systems in residential homes; and the "Radon Prevention in the Design and Construction of Schools and Other Large Buildings (EPA, 1994b), which provides design considerations for systems designed for larger buildings.

When multiple suction pits are required, multiple vertical risers can be manifolded together and connected to a single fan to minimize the number of roof openings. The collected vapors are discharged to the atmosphere from exhaust vent openings that must be located above the breathing zone and above all ambient air intake elevations, generally more than 12 inches above the roof peak.

A sub-slab diagnostic test should be conducted prior to installing the SSD to document the operational design needed to successfully mitigate the building. The primary purpose of sub-slab diagnostic testing is to simulate a completed SSD system to determine the number and location of suction pits required to obtain sufficient pressure field extension beneath the slab. Detailed guidelines for conducting a sub-slab diagnostic test can be found in "Radon Reduction Techniques for Existing Detached Houses – Technical Guidance" (EPA, 1993) and an overview is provided in Appendix E.

A 2007 statute (Minnesota Stat. § 326B.106, subd. 6) specifies that radon controls must be adopted within the State Building Code for new residential buildings. Minnesota Residential Energy Code in Minn. R. 1322.2100 states that a passive radon venting system (i.e., passive SSD system) will be required for new residential buildings as modified from Appendix F in the International Residential Building Code. This statute and rule is intended to provide for a viable sub-slab depressurization infrastructure to be in place in the event that radon mitigation is required. This passive radon mitigation system could also provide the infrastructure in the event that mitigation was needed for vapor intrusion from environmental releases.

Table 6-1. SSD Design Considerations

Suction Pits ▪ Determine the number of required suction pits based on the results of a sub-slab diagnostic test. ▪ Remove sufficient volume of soil (about 12 gallons) from each suction pit location to improve air flow to the vent.	**Fans** ▪ Fans used for depressurization should be installed in a portion of the building that is not living space such as in an attic, on the roof or on the outside wall of the building. ▪ Fans should be sized for proper flow rates and vacuum levels based on site specific conditions to provide the required pressure field extension to meet mitigation objectives.
Vent Piping ▪ A manometer or other pressure measuring gauge should be installed in piping to allow system effectiveness to be checked by inspectors and building owners. ▪ In some cases, other piping material may be required to meet building codes in multifamily or commercial buildings.	**Sampling Ports** ▪ Sampling ports installed in the vertical riser above the suction pit and/or within the floor slab (i.e., for larger commercial and industrial buildings) allow the collection of differential pressure measurements (interior and sub-slab) or for collecting vapor samples for laboratory analysis.
Material Safety and Compatibility ▪ System equipment and piping should be chemically resistant to the specific chemicals of concern at the site. ▪ Intrinsically safe equipment may be necessary if vapors are potentially combustible or flammable.	**Additional Considerations** ▪ USEPA (2008) recommends that the pressure differential between sub-slab and indoor air achieved by the SSD system be at least 0.02 inch of water or within a range of 3–5 pascals. ▪ It is good practice to clearly label system infrastructure components (e.g., piping, electrical boards) for building owners and maintenance personnel.

6.2.4 Sub-slab membrane depressurization

Sub-slab membrane depressurization (SMD) systems can be used to mitigate vapor intrusion in existing buildings where earthen floors, such as crawl spaces, provide a vapor entry location. SMD systems use a synthetic membrane to seal the opening in the floor and like SSD systems, typically require a continuously operated fan to vent vapors from beneath the installed membrane to the atmosphere. Due to the difficulties of sealing the openings and potential for tearing and damage to the membrane, permanently sealing the earthen floor or crawl spaces with a more permanent covering may be a better alternative to SMD systems. Membranes installed must be well maintained to ensure effectiveness and therefore SMD systems may require more long-term maintenance than an SSD system.

6.2.5 Venting systems for new building construction

A venting system design commonly used for newly constructed buildings involves installing a horizontal perforated piping system (e.g., PVC) within a granular aggregate layer beneath the foundation slab (ITRC, 2007a). Vertical piping is connected to the sub-slab horizontal piping network through the floor slab allows pressure relief and venting of contaminant vapors collected within the piping to the atmosphere above the roof line. These systems can be designed provide active venting by using continuously operating fans installed within the vertical risers, or to provide for passive venting. The MPCA recommends that passive venting systems always be designed to be converted into an active venting system with a minimum of structural and design alterations.

Additional design considerations include: a) selecting the appropriate granular aggregate material capable of both allowing air flow and minimizing potential of clogging of the slotted piping; b) the horizontal piping configuration and lateral spacing; c) the contingent use of a passive barrier (Section 6.2.5) to further inhibit the potential for vapor intrusion; and c) installing that vapor or pressure sampling ports that can be accessed easily for conducting remedial verification.

6.2.6 Passive vapor barriers - new building construction

Passive vapor barriers are flexible synthetic membranes installed beneath the slab of a new building to prevent or minimize the migration of subsurface vapors into the building. Passive vapor barriers are most commonly used to supplement passive or active venting systems or SSD systems for vapor intrusion mitigation.

The performance and effectiveness of various vapor barrier products can be described in part by performance testing data including information regarding the membrane's ability to inhibit diffusion or vapor permeation, puncturing and tearing; and the chemical resistance of the membrane.

Fluid-applied membranes are cold-spray-applied directly to substrates or proprietary fabric layers and to building penetrations (footings, grade beams, etc.). If installed properly by a contractor who has been trained and approved by the membrane provider, fluid-applied membranes can result in a well adhered and seamless membrane. Fluid-applied membranes typically achieve a thickness of approximately 60 mil.

A sheet membrane comes in rolls of varying materials and sizes. In the event that a vapor barrier is proposed to serve as the sole vapor intrusion remedy for a building, it is recommended that the membrane be 30 mil or more in thickness, installed with a high level of quality control. Some thinner (15 to 30 mil) membranes may also have applicability as a vapor barrier if the material testing results for the barrier material support low permeability of vapor through the membrane, high puncture resistance, and high tensile strength. Membranes less than 15 mil thick, however, are not recommended due to the greater potential for puncturing and tearing. Care must be taken during installation to prevent damage to the vapor barrier, as it will render the barrier ineffective. Small tears, punctures, or other gaps in a membrane can create a pathway for vapor entry into buildings, and any pathways that result and are identified must be sealed. Penetrations through the membrane (utility conduits, piping, etc.) that could result in openings for vapor entry into the building must be properly sealed. Sheet membrane seams during installation must also be sealed in accordance with the manufacturer's recommendations. Sheet membranes must also be properly sealed where they lap onto footings or grade beams.

Appropriate testing methods should be incorporated as part of the project's quality control procedures. The use of a smoke test on a synthetic membrane can be one effective method to test for the presence of leaks. A smoke test involves the use of a generator or blower to introduce an inert, nontoxic smoke with sufficient pressure beneath a membrane to visually identify leaks.

6.2.7 Building pressurization and ventilation using HVAC

Heating, ventilation, and air conditioning (HVAC) systems in commercial and industrial buildings can help minimize or prevent vapor intrusion into buildings by providing positive pressure and ventilation. Building pressurization is achieved by having greater air inflow than outflow, resulting in positive pressure differential of the indoor environment relative to the sub-slab environment. Building pressurization can prevent vapor intrusion from the subsurface if this pressure differential between indoor air and sub-slab environment can be established and maintained for interior spaces.

HVAC system air exchange rates for buildings undergoing vapor mitigation should be evaluated and compared with industry standards to ensure they are appropriate for the building size, the building use, any sensitive population, and occupancy rates. Requirements for HVAC systems, as developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ANSI/ASHRAE Standard 62.2, 2007), are designed to achieve minimum levels of air circulation for occupant health and comfort. These minimum ventilation rates alone may not be sufficient to address all indoor air risks, depending upon site-specific conditions. Air exchange rates for existing HVACs or other air-exchange systems should be included as part of the physical building inspection conducted for vapor intrusion investigations or as part of documentation to support the effectiveness of HVAC operation (See Appendix H). These rates can be obtained from a building operations manager for a commercial or industrial facility or by contacting the equipment manufacturer.

Larger commercial or industrial buildings may be less susceptible to poor indoor air quality resulting from vapor intrusion due to the larger building air volume, higher building pressures, and higher air exchange rates. Open buildings areas with a high degree of natural ventilation (such as with some warehouses and buildings with open bay doors), may be less likely to have concerns related to interior vapor accumulation, although pressurization in other portions of the building would need to be considered independently.

Underground parking garages are required to use mechanical ventilation and are likely to result in environmental vapor intrusion risks that are lower than comparable risks or concerns from carbon monoxide and automobile fuel vapors. Unless an enclosed parking garage is adjacent to or near a significant subsurface source of VOC vapors, it is unlikely that the additional risks associated with short-term exposure from vapors introduced by an environmental release would be significant. In situations where elevated subsurface vapors are identified, the MPCA recommends that the ventilation rate and design for the structure be documented and this information be evaluated to assess risks.

Use of HVAC as a remedial option requires appropriate documentation to demonstrate its effectiveness. One means of documentation or remedial verification can involve collecting pressure measurements in spaces to verify that the system is capable of providing differential positive pressures in all of the occupied spaces and especially in lower-level areas in direct contact with the subsurface environment.

6.2.8 Other building controls used for mitigation

Several other building control technologies have been used, particularly in the radon mitigation industry, and although less common, may be an option in some situations.

Sub-slab pressurization

A sub-slab pressurization system involves the use of a fan to pressurize the sub-slab air rather than depressurizing this space. This technique can be used with existing buildings or for new construction. This method does not prevent airflow vapors from the sub-slab from entering homes through cracks and other openings; however, it can dilute the soil gas concentrations beneath the foundation, and divert gases from the foundation. This technology may be most effective in situations where the sub-slab soils have high air permeability, which could result in establishment of a negative sub-slab pressure field extension around the entire building perimeter. While this technique is not commonly used at vapor-intrusion sites, it is an option at existing buildings or for new construction.

Block wall depressurization

Block wall depressurization is a mitigation technique that mechanically depressurizes the void network within a block wall foundation by drawing air from inside the wall using an electric fan and venting the collected vapors to the outside. As with other depressurization systems, sub-slab diagnostic testing should be conducted to ensure uniform depressurization can be achieved.

Drain tile depressurization

Drain tile depressurization is a mitigation technique that can be used at a building that has perforated drain tile installed along the inside or outside of its foundation. If the drain piping discharges to a sump pit, the negative pressure field should be applied to the sealed sump pit. If the drain piping discharges to an outdoor location, the negative pressure field should be applied to the terminal end of the drain loop at an outdoor location or to the permeable aggregate material surrounding the drain tile.

6.3 Institutional controls

Institutional controls are not themselves considered a remedy but can provide an administrative or legal control to help manage ongoing or future risks or to supplement other response actions. Institutional controls can be used as a component of response actions at remediation sites administered under the Minnesota Environmental Response and Liability Act to limit unacceptable exposure for either long-term risk management or until site remediation or natural attenuation reduces exposure concentrations to acceptable levels. In situations where response actions may take a considerable amount of time or cannot effectively eliminate long-term vapor intrusion concerns, institutional controls can help manage long-term risks.

Institutional controls as defined in Minn. Stat. §115B.02, subd. 9a include legally enforceable restrictions, conditions, or controls on the use of real property, groundwater, or surface water located at or adjacent to a facility where response actions are taken that are reasonably required to assure that the response actions are protective of public health or welfare or the environment. Such controls include real property affidavits and enforceable environmental covenants and easements. Environmental covenants and easements are defined in Minnesota's Uniform Environmental Covenants Act (UECA), Minn. Stat. §114E (Supp. 2007). The MPCA requires that sites that use environmental covenants provide an annual reporting documenting the status of the institutional control.

Potential uses for an environmental covenant as a component of a response action to address vapor intrusion risks include:

- requiring the use of building controls (either ongoing use or future use) to address vapor intrusion risks to on-site or off-site properties
- controlling the type of property use (e.g., residential, commercial/industrial) at a property where vapor intrusion risks are considered likely

Real property affidavits provide notice of environmental conditions on a property deed and are required under the conditions specified in Minn. Stat. § 115B.16, subd. 2. Real property affidavits are not legally enforceable; however, they may be needed to document existing or residual contamination at a property.

6.4 Remedial verification, monitoring, and closure

Remedial verification, monitoring, and closure criteria will vary depending on site specific conditions and program-specific requirements. Additional guidelines for conducting remedial verification sampling, monitoring, and system maintenance are provided below.

6.4.1 Remedial verification sampling

Mitigation systems must be inspected after they are installed and during their initial use to ensure they are working effectively. Post-installation verification procedures for SSD systems and active and passive venting systems should, at a minimum, include the collection of differential pressure measurements to verify that sub-slab soils have been sufficiently depressurized below that of the indoor air. Ports installed in the floor slab to facilitate differential pressure measurements are recommended if conditions enable this as a practical option. The number and frequency of such measurements will be site and program specific.

Remedial verification of active systems may also involve collecting initial and follow-up pressure measurements from a pressure gauge (i.e., U-tube manometer) installed in the system's vertical exhaust piping in locations that are accessible to the owner. Inspections should also be conducted and documented for building sealing activities or for other improvements made to building floors or walls if conducted as components of a remedy. Information to support that the system is effective can include follow-up sub-slab sampling or follow-up indoor air sampling.

Remedial verification sampling of the indoor air quality may also be required based on MPCA program requirements, although the potential for background sources of contamination within indoor air samples must be considered. In many cases, concurrent indoor air and sub-slab vapor sampling may be required two to four weeks after a mitigation system is operational to verify system performance and effectiveness. Indoor air sampling is especially warranted if pre-mitigation sampling results confirmed elevated concentrations either in the sub-slab vapor or indoor air.

Remedial verification sampling may need to be conducted during seasons when the potential for interior depressurization is greatest (i.e., winter months to early spring). Verification results that are above indoor air screening values after the consideration of background sources may require system modifications or considerations of other response actions.

6.4.2 Long-term maintenance and monitoring

In addition to post-remediation verification sampling, long-term maintenance and monitoring may be necessary at some sites to ensure the system is still operating effectively or to verify that conditions have not changed. Long-term monitoring plans will be site-specific and need to follow the appropriate program requirements. The need for long-term operation, monitoring, and maintenance plans is greater at sites where:

- long-term monitoring is needed to verify remedial effectiveness
- the remedial system requires periodic adjustments and maintenance
- risks to receptors would result if the system fails or if site conditions change
- the conditions that would trigger specific contingent responses require ongoing monitoring

At sites with ongoing post-construction and remedial actions, the remedial action plans should clearly specify the necessary post-remedial monitoring, the maintenance activities to be conducted, the person responsible for conducting these activities, and applicable ongoing reporting requirements to the MPCA. Some site remedial systems may also require the use of an MPCA-approved contingency plan or similar corrective action document approved by the MPCA to identify conditions that may trigger the need for additional maintenance, collection of additional data, modifications of monitoring frequency, or other responses to ensure the remedy remains effective. Conditions that might trigger additional responses could be based on monitoring results, facility or system inspections, operational problems of the remedial system, or other information that may indicate that the remedial objectives are not being met.

6.4.3 Remedial closure

Remedial closure for vapor intrusion mitigation systems will be program- and site-specific. In general, closure criteria and conditions should be determined when the response or corrective action plan is developed and, if possible incorporated into these plans for MPCA review and approval. Remedial closure generally means that the MPCA has made an administrative decision that no further response actions are needed for a particular release; that the vapor intrusion exposure pathway is no longer deemed a risk; or that the remedial system shutoff has been approved by the MPCA. In cases where a remedial system or passive venting system continues to operate either voluntarily by the owner or as an MPCA recommendation, closure plans may recommend continued system operation without requiring further MPCA reporting requirements unless conditions change. The individual remediation programs should be consulted for specific requirements for remedial closure.

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Appendix A: Site conceptual model checklist for vapor intrusion

Constructing a site conceptual model (SCM) for vapor intrusion requires the integration of important site characteristics to assist in understanding and evaluating the potential impacts that vapor intrusion risks pose to potential receptors. The following items are some of the site characteristics and factors that should be considered when developing an SCM for the vapor intrusion pathway. The items in the SCM checklist are typically collected during different phases in a site's overall investigation.

Source Area:

- Identify known or potential vapor sources at the site including:
  - soil contamination
  - groundwater contamination
  - non-aqueous phase liquid (NAPL)
  - soil vapor
- Identify the potential and actual vapor phase compounds of concern for the vapor intrusion pathway.
- Describe the potential and documented vapor migration pathways associated with all vapor sources and potential receptors.
- Describe the spatial and temporal characteristics of the vapor sources such as whether source contamination (i.e., groundwater plume) is expanding, stable, or attenuating and reference supporting data for these conclusions.

Geology/hydrogeology:

- Describe site geology and hydrogeology and its potential controls on source area and associated vapor fate and transport.
- Identify and describe soil types or geologic units that may facilitate or inhibit vapor migration.
- Describe the depth to groundwater and perched water units and aquifers that have the potential to serve as vapor sources.

Utilities:

- Describe and document locations of all utility and subsurface structures that are present near soil and groundwater impacts. In particular, identify all utilities that are proximal to vapor sources that could potentially serve as vapor migration pathways to receptors.

Receptors/buildings:

- Identify the locations and the occupancy types of existing and future buildings (e.g., residential, commercial, etc.).
- Identify the proximity of potential receptors to vapor sources.
- Through visual observations, describe the construction type of the building (one-story, two-story, single family, etc.).
- Describe the approximate age and type of building construction.
- Building type (single-family home, multi-level apartment, commercial, school, office, mixed use, etc.)
  - foundation floor construction (basement, half-basement, slab-on-grade, monolithic, multiple slabs with cold joints, carpeted covered floor, etc.)
  - foundation construction materials (brick, stone, masonry block, precast concrete, limestone, etc.)
  - depth below grade of lower-level floor
  - building foundation and floor depths in relation to groundwater or vapor plume
- Describe ventilation systems that may be present within possible impacted receptors.
  - forced air, radiant furnace, heat pump, etc.
  - source of return air (inside air, outside air, combination)
  - heating, ventilation and air condition (HVAC) system use and description
  - system design as related to indoor air pressure (positive or negative pressure)

- Describe potential entry points observed during the physical building inspection
    - Concrete slab cracking
    - Concrete slab cold joints
    - Utility ports
    - Floor drains or sumps
    - Earthen floor areas
    - No obvious vapor entry ways observed
- Describe any sub-slab depressurization ventilation systems or moisture barriers on existing buildings.

Site Characteristics:

- Provide an estimate for the distance from the edge of vapor sources to potential receptors.
- Describe the surface cover between potential vapor source areas and potential impacted receptors.

Appendix B: Screening values for the vapor intrusion pathway – supplemental information

This appendix provides additional background and technical support regarding the basis for the MPCA screening values for the vapor intrusion pathway. Details regarding the development of the ISVs and the toxicity sources for the ISVs are provided in Appendix B-1. Appendix B-2 provides conceptual background and rationale for the media-specific screening values introduced in Section 2.4.2 of this guidance. Both the ISVs and media-specific screening values represent risk-based screening criteria that should be interpreted within the decision-making framework presented in this guidance including based on a well understood site conceptual model.

The ISVs can be found at the following web sites:
Intrusion Screening Values spreadsheet (02/09) for the SRVC programs:
http://www.pca.state.mn.us/publications/aq1-36.xls.

Intrusion Screening Values spreadsheet (10/08) for the Petroleum Remediation Program and Petroleum Brownfields
http://www.pca.state.mn.us/publications/c-prp4-01c.xls.

Appendix B-1: Toxicity source hierarchy for the ISVs

The ISVs were developed by MPCA risk assessors in the Environmental Analysis and Outcomes (EAO) Division. The Minnesota Soil Gas List was developed by the MPCA Remediation Division and EAO staff in consultation with private laboratories, and represents an augmentation of the standard USEPA Method TO-15 analyte list. EPA Method TO-15 is the laboratory analytical method commonly recommended for analysis of chemicals in vapor intrusion samples (see Section 4.2).

The sources of toxicity values used for development of the ISVs, in order of preference by the MPCA are: the Minnesota Department of Health (MDH), United States Environmental Protection Agency (EPA) Integrated Risk Information System (IRIS), the EPA National Center for Environmental Assessment (NCEA) Provisional Peer Reviewed Toxicity Values (PPRTVs), the California Environmental Protection Agency, the Agency for Toxic Substances and Disease Registry (ATSDR), and other EPA guidance.

The use of this hierarchy of preference was applied for the majority of the compounds for which ISVs were developed; however, for several compounds there may be only one toxicity value available. This hierarchy is similar to the EPA's revised hierarchy for Superfund (EPA, 2003), with the exception that the MDH HRVs or other MDH guidance precedes the use of IRIS toxicity values unless more updated peer-reviewed toxicity values from IRIS are available. This hierarchy is also similar to that used for the MPCA Air Emissions Risk Analysis (AERA) procedures, with the exception that the AERA process does not use the PPRTVs as a data source.

The Health Risk Values (HRVs) are inhalation risk values promulgated in rule as health guidelines by the MDH in 2002. This rule sets maximum values for concentrations of chemicals or defined mixtures of chemicals emitted to air that are unlikely to pose a significant risk of harmful effects when humans are exposed to those concentrations over a specified time. HRVs have been developed using public health protection practices that advocate the protection of the most sensitive portion of the population, including but not limited to children, pregnant women and their fetuses, individuals compromised by pre-existing diseases, and elderly persons. Because HRVs are guidelines, the MDH acknowledges that their application will be utilized within a risk management framework, and the rule does not specify specific applications of the values. The 2002 HRV list is also not inclusive of all potential compounds of concern. The HRVs can be found on the MDH Web site (accessed at http://health.state.mn.us/divs/eh/risk/rules/hrvrule.html).

The Office of Research and Development/National Center for Environmental Assessment/Superfund Health Risk Technical Support Center (STSC) developed the PPRTVs for the EPA's Superfund Program and the EPA supports their use for applications at remediation sites, especially in the absence of updated IRIS values.

Exceptions to the stated hierarchy of toxicity sources is minimal and is based on professional judgment by the MPCA and in consultation with MDH in order to utilize the highest quality toxicity data that is currently available.

Examples of exceptions to the hierarchy include the use of more recent data, choosing not to use route-to-route extrapolated data, and based on concerns that may exist regarding data quality or confidence associated with specific toxicity studies. MDH was consulted for compounds for which the hierarchy was not used. For chemicals that are risk drivers, it may be appropriate to request further consideration of toxicity values.

Appendix B-2: Media-specific screening values

Media-specific screening values used in this guidance are designed to be used for the screening of pathway-specific vapor results obtained from subsurface soil gas or sub-slab sampling within the decision-making framework outlined in this guidance.

Media-specific screening values are based on the recognition that contaminant concentrations typically undergo a significant reduction in concentration as vapors migrate from their source upwards towards the surface. The principal basis for the screening values used in this guidance is published empirical documentation of the ratios between indoor air concentration and media-specific measured concentrations. These dimensionless ratios are referred to as attenuation factors, typically denoted by the symbol alpha (α), and can be generically represented by the following relationship:

$$\alpha_{media} = C_{IA}/C_{media}$$

C_{IA} is the measured concentration in indoor air, C_{media} is the measured concentration at the media- or pathway-specific endpoint, and αmedia is the media-specific attenuation factor.

Default media-specific attenuation factors for the evaluation of subsurface soil gas contaminant concentrations (CSG), sub-slab vapor contaminant concentrations (CSS), and dissolved groundwater contaminant concentrations (CGW) along with their respective default attenuation factors proposed for use in this guidance are summarized in Table B-2a.

Table B-2a: Media-Specific Attenuation Factors

Description	Calculation	Default Dimensionless Factor
Subsurface soil gas attenuation factor, α_{SG}	$\alpha_{SG} = C_{IA}/C_{SG}$	0.1 to 0.01
Sub-slab attenuation factor, α_{SS}	$\alpha_{SS} = C_{IA}/C_{SS}$	0.1 to 0.01
Groundwater attenuation factor, α_{GW}	$\alpha_{GW} = C_{IA}/[C_{GW} \times H_{cc}]$	0.001

Measured attenuation factors can be used in a predictive manner to estimate potential risks posed by concentrations measured in the different media at other sites. To accomplish this, specific conservative attenuation factors were selected for use in the MPCA guidance to identify situations where a potential risk to indoor air may exist, and by substituting the indoor air screening criteria (i.e., the ISV) for CIA. The media-specific screening value is determined as follows:

$$\text{Media specific screening value} = ISV/\ \alpha_{media}$$

The default media-specific attenuation factors used in this guidance are based on conservative values that have been recommended by EPA (2002) or have been selected using the EPA Vapor Intrusion Database "Preliminary Evaluation of Attenuation Factors, March 4, 2008," (EPA, 2008) as a summary resource for measured attenuation factors. The default subsurface soil gas and sub-slab screening values are chosen as 0.1 and are approximately equivalent to the 95th percentile in the EPA Vapor Intrusion Database.

Table B-2b summarizes the media-specific screening value calculations and ranges relative to the ISVs. Both the subsurface soil gas and sub-slab attenuation factors and corresponding screening values use a range from 0.1 to 0.01

(representative of 10X to 100X of the ISVs) to provide flexibility in making site decisions when site-specific factors that support less conservative scenarios are appropriate and justified.

The groundwater attenuation factor of 0.001 is also based on data documented in USEPA (2008).This value corresponds with the 95th percentile attenuation factor based on 1229 groundwater and indoor air samples from 36 different sites.

Table B-2b: Media-Specific Screening Values

Description	Calculation
Soil gas screening values (µg/m³)	ISV / α_{SG} = *10x to 100x*
Sub-slab screening value (µg/m³)	ISV / α_{SS} = *10x to 100x*
Groundwater intrusion screening value (µg/L)	GWISV = ISV/[α_{GW} *x (1000 Liters/meters³) x Hcc]*

The GWISVs for the guidance, which uses the compound-specific ISV, was calculated by using the relationship provided in Table B-2a, and the dimensionless the default groundwater attenuation factor, the dimensionless compound- and temperature-specific Henry's Law constant, and a factor to convert the volume units of cubic meters to liters.

Henry's Law Constants are a function of temperature. Therefore, because the application of these values was designed for the state of Minnesota, a temperature other than typically reported values at standard conditions (20°C) was employed. A temperature of 10°C was chosen to represent a conservative mean annual groundwater temperature; this is more reflective of Minnesota groundwater conditions. If site-specific conditions indicate that 10°C is not sufficiently conservative for screening purposes (e.g., facilities with buried stream pipes), the GWISV can be recalculated using a Henry's Law Constant representative of site-specific groundwater temperatures.

The source of the temperature-corrected Henry's Law Constants, used to develop the GWISVs, were obtained from used the following hierarchy of sources: a) the EPA online calculator available at http://www.epa.gov/athens/learn2model/part-two/onsite/esthenry.htm, or b) calculated by the MPCA staff using the procedures outlined in the EPA Fact Sheet (June 2001), "Correcting the Henry's Law Constant for Soil Temperature." Physical constants required for recalculation of Henry's Law Constants using these procedures were obtained from a variety of sources including the Hazardous Substances Data Bank (HSDB), the California Air Resources Board chemical database, and from the Agency for Toxic Substances and Disease Registry (ATSDR). The HSDB is part of the National Library of Medicine's Toxicology Data Network (TOXNET) (http://toxnet.nlm.nih.gov/index.html).

The 10º C temperature value used for the temperature-adjusted Henry's Law Constants was chosen to represent a conservative upper bound long-term average value for shallow groundwater temperature based on the groundwater temperature map provided in Collins (1925).

Appendix C: Minnesota soil gas list

COMPOUND	CAS No.
Acetone	67-64-1
Benzene	71-43-2
Benzyl chloride	100-44-7
Bromodichloromethane	75-27-4
Bromoform	75-25-2
Bromomethane (Methyl Bromide)	74-83-9
1,3-Butadiene	106-99-0
2-Butanone (Methyl ethyl ketone, MEK)	78-93-3
Carbon disulfide	75-15-0
Carbon tetrachloride	56-23-5
Chlorobenzene	108-90-7
Chloroethane (Ethyl chloride)	75-00-3
Chloroform	67-66-3
Chloromethane (Methyl chloride)	74-87-3
Cyclohexane	110-82-7
Dibromochloromethane	124-48-1
1,2-Dibromoethane (Ethylene dibromide)	106-93-4
1,2-Dichlorobenzene	95-50-1
1,3-Dichlorobenzene*	541-73-1
1,4-Dichlorobenzene	106-46-7
1,1-Dichloroethane	75-34-3
1,2-Dichloroethane	107-06-2
1,1-Dichloroethene (DCE)	75-35-4
cis-1,2-Dichloroethene	156-59-2
trans-1,2-Dichloroethene	156-60-5
Dichlorodifluoromethane (Freon 12)	75-71-8
1,2-Dichloropropane	78-87-5
cis-1,3-Dichloropropene	10061-01-5
trans-1,3-Dichloropropene	10061-02-6
Dichlorotetrafluoroethane (Freon 114)	76-14-2
Ethanol	64-17-5
Ethyl acetate	141-78-6
Ethylbenzene	100-41-4
4-Ethyltoluene	622-96-8
n-Heptane	142-82-5
Hexachloro-1,3-butadiene	87-68-3
n-Hexane	110-54-3
2-Hexanone (Methyl Butyl Ketone)	591-78-6
4-Methyl-2-pentanone (Methyl isobutyl ketone)	108-10-1
Methylene Chloride (Dichloromethane)	75-09-2

COMPOUND	CAS No.
Methyl-tert-butyl ether (MTBE)	1634-04-4
Naphthalene	91-20-3
2-Propanol (isopropyl alcohol)	67-63-0
Propylene (Propene)	115-07-1
Styrene	100-42-5
1,1,2,2-Tetrachloroethane	79-34-5
Tetrachloroethylene (PCE)	127-18-4
Tetrahydrofuran	109-99-9
Toluene (Methylbenzene)	108-88-3
1,2,4-Trichlorobenzene	120-82-1
1,1,1-Trichloroethane (Methyl chloroform)	71-55-6
1,1,2-Trichloroethane	79-00-5
Trichloroethylene (TCE)	79-01-6
Trichlorofluoromethane (Freon 11)	75-69-4
1,1,2-Trichlorotrifluoroethane (Freon-113)	76-13-1
1,2,4-Trimethylbenzene	95-63-6
1,3,5-Trimethylbenzene	108-67-8
Vinyl acetate	108-05-4
Vinyl chloride	75-01-4
m&p-Xylene	108-38-3
o-Xylene	95-47-6

Appendix D: Field methods and procedures

This appendix summarizes recommended field methods and procedures for active soil gas, sub-slab, indoor air, and outdoor air monitoring. While it is understood that different practitioners will employ various methods based on their experience and equipment, it is expected that due care will be taken to ensure integrity of the samples and data quality. The procedures recommended here may be varied or changed with MPCA approval depending on site-specific conditions or emerging technologies and methodologies. In all cases, the methodologies used in the field must be thoroughly described and documented in the final report accompanying the sampling results.

D.1 Active soil gas sampling procedures

These procedures demonstrate how to install and sample soil gas monitoring points. Soil gas can be monitored using temporary or permanent soil gas monitoring points. The specific methodology used may be varied, but should be clearly specified in work plans, if required by the MPCA program, and within the documentation of the soil gas investigation. These procedures are for active soil gas monitoring.

D.1.1 Installing temporary soil gas monitoring points

Temporary soil gas monitoring points are used for one-time measurement of soil gas concentrations.

The following procedures describe how to install temporary soil gas monitoring points:

1. Advance the soil gas monitoring point to the necessary depth (see Table D-1) using direct push technology or, if site conditions permit, a hand-driven manual auger.
2. Place a material such as bentonite around the probe rod and the ground surface to seal the borehole and prevent sample short-circuiting to the atmosphere.
3. Fit the soil gas monitoring points with inert tubing (e.g., nylon, polyethylene, stainless steel, or Teflon®) of the appropriate size.
4. Collect a sample using the procedure in D.1.3.

Table D-1. Soil gas sample collection depths

Soil gas Sample	Sample collection eepth
Worst-case soil gas samples	8-10 feet below grade, minimum of 2 feet above the water table. Minimum depth of 3 feet. If water table or bedrock does not permit collection at minimum 3 feet, sample does not need to be collected.
Receptor building-specific soil gas sample	Buildings with basements: 8-10 feet below grade. Buildings with slab-on-grade or crawl space: 3-5 feet below grade. Minimum depth of 3 feet. If water table or bedrock does not permit collection at minimum 3 feet, sample does not need to be collected.

Note: If site conditions prevent the collection of samples at three feet and greater depths, MPCA staff may request other means of assessing vapor intrusion.

D.1.2.1 Permanent soil gas monitoring points

Permanent soil gas monitoring points may be installed when multiple sampling events are necessary at a site. A permanent soil gas monitoring point can be installed using either (1) a buried soil gas implant probe or (2) a screened monitoring probe (See Table D-2). Both the implant probe and screened monitoring probe can be installed as a single or nested probe installation. Single and nested probe installations are illustrated on Figure D-1

Table D-2. Permanent soil gas monitoring methods

Permanent soil gas sampling method	Description
Buried soil gas implant probe	Drill hole using push probe, hollow stem auger, hand augers, etc. Bury inert tubing (Teflon, stainless steel, etc.) attached to soil gas implant (i.e., drive point with gas inlet perforations, or other perforated screen or mesh inlet device). See Section D.4.2 of ITRC (2007a)
Screened soil vapor well	Similar to SVE vapor monitoring well construction using non-flexible tubing or well casing with slotted screen instead of a soil gas implant probe

D.1.2.2 Installation of a permanent soil gas monitoring probe

1. Advance the soil gas sampling point to its necessary depth using direct push technology or manual probes if site conditions permit.
2. Fit the soil gas monitoring points with inert tubing (e.g., polyethylene, Teflon®, stainless steel, etc) of the appropriate size and length along with an inert screen material approximately 6 inches long comprised of stainless steel, slotted polyethylene, or polyethylene mesh (indicated as probe tip in Figure D-1).
3. Install a polyethylene check valve on the surface end of the inert tubing. Use a check valve that will not allow ambient air to enter the tubing.
4. Place an artificial filter pack in the annular space between two to four inches below the screen tip to six inches above the screened interval.
5. Grout the remaining annular space to the surface using bentonite or other appropriate material.
6. Fit the monitoring point with at-grade covers or above-grade protective casings set in place with cement.
7. Wait 30 to 60 minutes before purging and sampling if a sample is to be collected during the installation mobilization.
8. Collect a sample following the procedures in section D.1.3.

D.1.2.3 Installing nested sampling ports

1. Complete steps 1 through 4 as listed above.
2. Use a seal of at least two feet of bentonite between individual screened intervals.
3. Step 4 should again be completed to set the second sampling screen in filter pack.
4. Repeat steps 2 and 3 as needed for the number of nested points required.
5. Cut the protruding lengths of tube successively shorter so the deepest screened interval tube is the longest length and the shallowest screened interval is the shortest. Label each tube clearly upon completion.
6. Complete the surface ends of each tube with an airtight check valve or cap to prevent ambient air from entering each tube.
7. Wait 30 to 60 minutes before purging and sampling if a sample is to be collected during the installation mobilization.
8. Collect a sample following the procedures in section D.1.3.

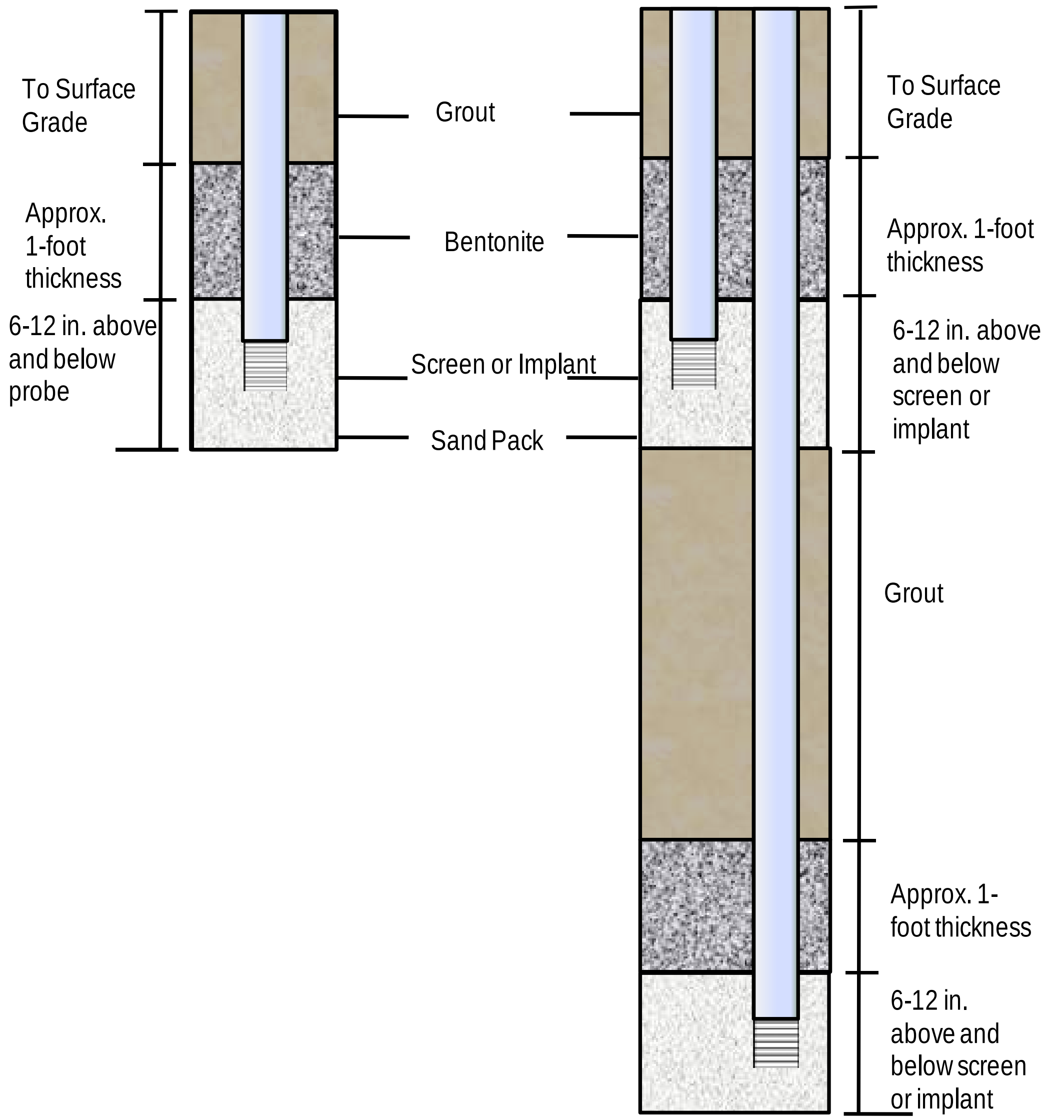


Figure D-1. Single and nested soil gas probe construction

D.1.3 Sampling soil gas monitoring points

Whether temporary, permanent, a single probe installation or nested probes, soil gas is sampled as follows:

1. Before collecting the sample, purge a minimum of two volumes (i.e., total volume of the monitoring point and tube) to ensure samples are representative of soil gas. Purging can be completed accurately using a graduated syringe. (See Table D-3 if using a vacuum pump for purging.)
2. Install an in-line particulates filter to trap particles and prevent moisture from entering the evacuated canister.
3. Collect a sample by attaching the top end of the tubing to an evacuated canister instrumented with a vacuum gauge.
4. Note and record the initial vacuum gauge reading, open the evacuated canister valve, and monitor the vacuum gauge to check progress of canister filling.
5. Close the evacuated canister valve after the time required to collect an adequate volume of soil gas has elapsed or the vacuum gauge indicates that the canister is full. Sampling with a vacuum gauge is recommended as the most effective way of ensuring an adequate volume of sample was collected. Without an adequate sample volume, the laboratory may not be able to meet the reporting limits needed to determine if the compound-specific action levels are being exceeded. If reporting limits prove to be consistently higher than the screening levels, a decision regarding vapor intrusion risk may not be possible and re-sampling may

be required. Consult with the laboratory supplying the canisters to obtain the vacuum gauge readings corresponding to an acceptable canister volume.

6. Record the time required for sampling and the final pressure onto the reporting form and chain-of-custody form.
7. Connect the inert tubing that was used to fill the canister to a field instrument and record the organic vapor measurement onto the chain-of-custody form and sample log sheet.
8. Submit the canisters for laboratory analysis.

Purge time calculation for one probe volume

$$\frac{D^2 \times P_d \times 9.27}{P_r} = P_t$$

D = Diameter of probe, inches
P_d = Probe depth, feet
P_r = pump rate, liters per minute
P_t = Purge time for one probe volume, seconds

Figure D-2. Recommended purge volumes for sampling with vacuum pumps

D.2 Sub-slab vapor monitoring procedures

Sub-slab vapor is monitored to characterize the nature and extent of soil gas contamination immediately beneath the building footprint. Sub-slab vapor is monitored after soil gas characterization or other sampling results (e.g., soil or groundwater characterization) indicate a need.

Temporary or permanent sub-slab monitoring points can be installed; however, all points should be constructed in the same manner at all sampling locations during the investigation to minimize possible discrepancies. The following two subsections describe how to construct temporary and permanent sub-slab vapor monitoring points.

D.2.1 Installing temporary sub-slab vapor monitoring ports

A temporary monitoring port may be constructed if only one sub-slab sample is intended to be collected from the port. A temporary sub-slab vapor monitoring port is illustrated on Figure D-3.

The following procedures outline sub-slab sampling point construction protocols for temporary monitoring ports:

1. Before installing the sub-slab port, inspect the building floor and record any penetrations (cracks, floor drains, utility perforations, sumps, etc.) to identify the best location for the installation.
2. Install sub-slab probes:
   a. In a central location away from foundation footings.
   b. Where the potential for ambient air infiltration via floor penetrations is minimal.
   c. To the depth of the soil or aggregate immediately below the basement, at-grade slab, or slab-on-grade.
3. Temporarily seal significant floor penetrations if they exist near the sampling location to avoid short circuiting during sample collection.
4. Advance a boring into the sub-slab material using a rotary hammer drill or other device.
5. Fit vapor monitoring probes with inert tubing (e.g., polyethylene, stainless steel, or Teflon®) of the appropriate size.
6. Insert a vapor monitoring point into the material immediately below the slab.
7. Add coarse sand or glass beads to cover the point tip.
8. Seal the boring at the surface with grout, cement, or other non-VOC-containing and non-shrinking products to prevent infiltration of ambient air.
9. Collect the sub-slab vapor sample following the procedures in section D.2.3.

D.2.2 Installing permanent sub-slab monitoring points

A permanent sampling port should be constructed if multiple sub-slab vapor samples are needed from one sampling port location. A permanent sub-slab vapor monitoring port is illustrated on Figure D-3.

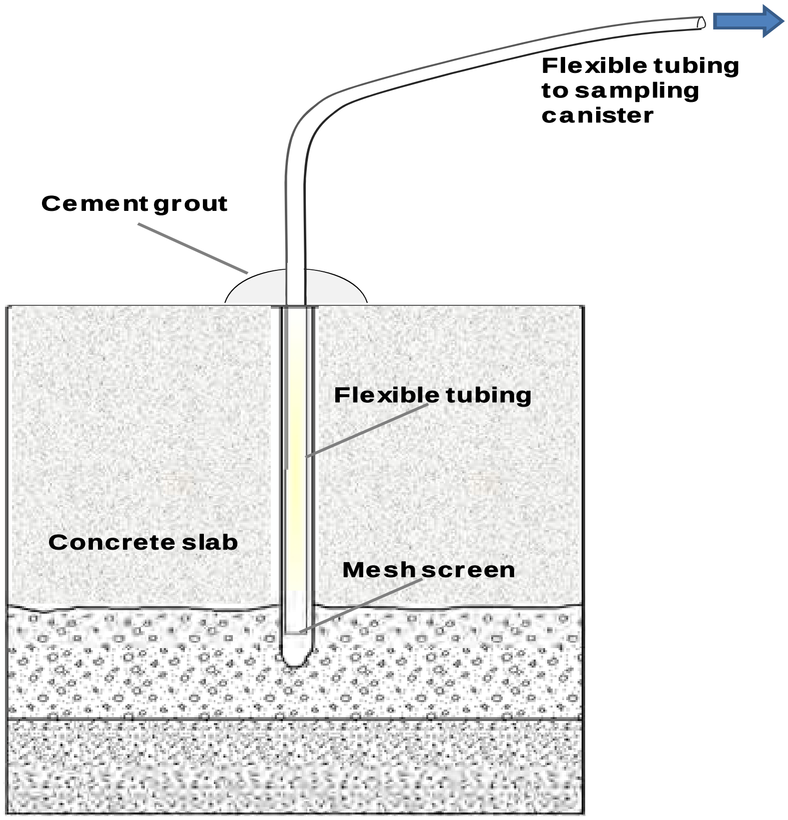


Figure D-3. Temporary sub-slab vapor monitoring point

The following procedures demonstrate how to construct a permanent sub-slab vapor monitoring port (see Figure D-4):

1. Advance a boring through the concrete slab and approximately two – three inches into the sub-slab soil material using a rotary hammer drill or other similar device.
2. Install sub-slab vapor monitoring points through an approximately 1- to 1½-inch diameter hole. The upper portion of the borehole should be a slightly wider diameter to allow a metal coupling to fit onto the probe.
3. During drilling of the borehole, control dust using a vacuum cleaner.
4. Fit the sub-slab vapor monitoring probes with inert metal tubing (e.g., stainless steel, brass, or copper) with a threaded end to enable a threaded cap to be attached to the probe. Size the length of the probe so that, after it is installed into the underlying sub-slab soil approximately two – three inches inches, the top of the capped probe is flush with or slightly recessed below the cement slab.
5. Insert the vapor monitoring point into the material immediately below the slab.
6. If needed, cover the point tip with coarse sand or glass beads. Fit the end of the probe with an inert plastic or metal mesh screen to prevent plugging of the sampling probe.
7. Attach a brass, steel, or copper threaded coupling with a metal cap to the top of the metal probe.
8. Seal the annular space around the port using bentonite, cement or other non-VOC-containing and non-shrinking products to prevent infiltration of ambient air from above the slab.
9. After the cement has cured (approximately 48 hours), collect a vapor grab sample through the monitoring point following the procedures in section D.2.3.

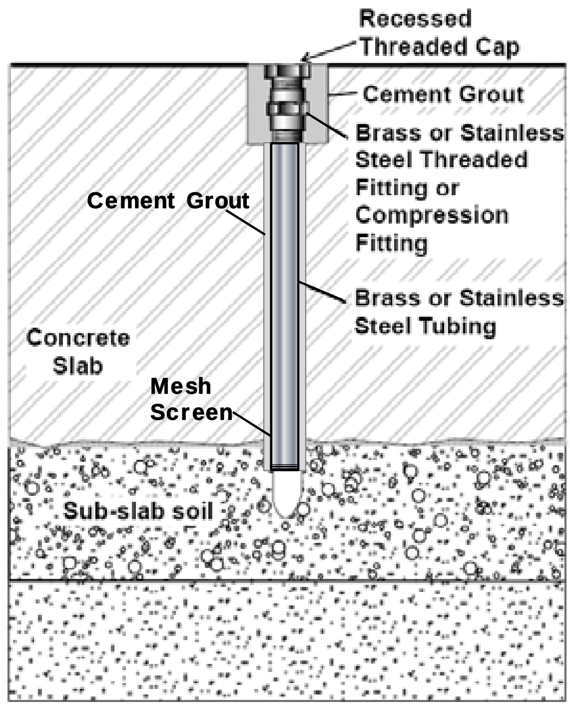


Figure D-4. Permanent sub-slab vapor monitoring point (adaptead from A. DiGiulio)

D.2.3 Sampling sub-slab vapor sampling points

1. Before collecting the sub-slab vapor sample, purge a minimum of two volumes (i.e., the volume of the sample point and tube) with a graduated syringe or other device (see Table D-3 if using a vacuum pump for purging).
2. Install an in-line particulates filter to prevent particles and moisture from entering the evacuated canister. Limit the canister filling rate to a maximum flow rate of 200 milliliters per minute (mL/minute) using a flow controller (see section D.4).
3. Collect a sample by attaching the top end of the tubing to an evacuated canister instrumented with a vacuum gauge.
4. Open the value of the evacuated canister and monitor the vacuum gauge to check progress of canister filling for the same reasons as listed above.
5. After an adequate volume of soil gas has been collected, close the canister valve and record the final canister pressure and time required for sampling on the chain-of-custody form and sample sheets.
6. After an adequate volume of soil gas has been collected, submit the canister for laboratory analysis.
7. Connect the inert tubing that was used to fill the canister (or sampling port probe for a permanent monitoring point) to a field instrument and record the measurement onto the chain-of-custody form and sample log sheet.
8. For permanent monitoring points, seal the monitoring point tight using a hex wrench that is designed to remain in place to allow follow-up sampling.
9. After the sampling activities are completed, properly seal the sub-slab monitoring point drill hole opening.

D.3 Additional items for consideration with active soil gas sampling

In addition to the installation and sampling procedures listed in sections D.1 and D.2, an inflow controller can be considered to minimize short circuiting air flow from the surface. Also, leak detection compounds can be used to ensure a proper seal during construction of soil gas monitoring points.

D.3.1 Flow rate and vacuum

To minimize the potential for short circuiting air flow from the surface and desorption of contaminants from the soil under saturated conditions, techniques to control and minimize the flow and vacuum applied to the soil should be employed. In such cases, use of an in-line flow controller set at a flow of 200 mL/minute and vacuum less than 15 percent of atmosphere (≈ 5 inches of Hg) should be used.

D.3.2 Leak check compounds

To ensure that valid soil gas samples are collected with no atmospheric breakthrough down the probe rod's annular space, a tracer compound can be applied at the base of the probe rod and near all connections in the sampling train. Seal integrity is then confirmed by analyzing for the leak check compound.

Several compounds can be used as leak check compounds during soil gas collection. Gaseous compounds using shrouds or liquids applied to paper towels can be used. Isopropyl alcohol, pentane, isobutene, and helium are some common compounds used in tracer analysis for soil gas samples. Additional information regarding leak check compounds can be found in ITRC (2007a, Section 4).

Soil gas samples with concentrations of the leak check compound greater than five percent of the initial concentration (equal to 100 percent for gaseous compounds and to the partial pressure for liquid compounds) should not be considered reliable.

D.4 Monitoring indoor air and outdoor ambient air

Sample collection

Indoor air and outside ambient air sampling should be conducted as a time-weighted sample over a 24-hour period using an evacuated canister. Instructions for using the evacuated canister and flow regulator and for collecting the samples should be obtained from the canister supplier or laboratory. In general, 24-hour indoor air samples should be collected in the following manner:

1. Place a sampling canister in the appropriate sampling location.
2. A flow controller must be affixed to the canister prior to sampling. The flow controller must be preset by the laboratory to collect the sample over a 24-hour period.
3. Install an in-line moisture trap to prevent moisture from entering the canister.
4. Open the valve on the canister to begin sample collection.
5. After approximately 24 hours have passed, close the valve on the canister and record the time on the chain-of-custody form.
6. The canister(s) and flow controller(s) are then to be transported to the laboratory.
7. If the MPCA requires that a grab sample be collected, the same procedure should be followed without the use of a flow controller.

The following additional information regarding the sampling conditions and methodologies should be documented and reported to the MPCA along the sampling results during indoor air sampling:

- floor plot sketches identifying sampling locations and noteworthy features observed during the sampling especially potential vapor entry locations
- pertinent observations during sampling such as odors or field instrument readings, and ventilation conditions (e.g., heating system active and windows closed)

The following actions should be taken to document conditions during outdoor air sampling and ultimately to aid in the interpretation of the sampling results:

1. Outdoor plot sketches should be drawn that include the building site, area streets, outdoor air sample locations (if applicable), location of potential interferences (e.g., gasoline stations, factories, lawn movers, etc.), and compass orientation (north).
2. Weather conditions (e.g., precipitation, indoor and outdoor temperature, and barometric pressure) and ventilation conditions (e.g., heating system active and windows closed) must be recorded.
3. Any pertinent observations such as odors, field instrument readings, and significant activities in the vicinity (e.g., operation of heavy equipment or dry cleaners) should be recorded.

Appendix E: Other investigation methodologies

E.1 Passive soil gas sampling

Passive soil gas sampling requires the burial of an adsorbent in the shallow ground subsurface that is retrieved after a given period of time for chemical analysis. Passive soil gas samplers rely on the diffusion of volatiles within the subsurface to adhere to the adsorbent material. Passive sampling methods provide a general mass of the diffusing chemical with reporting units relative to mass (e.g., micrograms). Passive methods provide a quick and relatively inexpensive way to determine vapor source areas and potential pathways of concern in a qualitative fashion for large contaminant plumes.

Field studies and methods to calibrate passive sampling results to active soil gas concentrations are too limited to provide accurate validation for use in quantitative assessments (ITRC, 2007a). For this reason, many states including the MPCA will not accept passive sampling results as a stand-alone data source for defining risk from the vapor intrusion pathway. These results cannot be accurately and consistently converted to vapor concentrations (µg/m3) required for quantitative risk evaluation; however; the results do provide valuable qualitative information regarding the likely extent and magnitude of potential vapor intrusion risks.

E.2 Use of mobile laboratories

Another method that may be available in some situations for screening purposes is the use of mobile laboratories for the analysis of subsurface soil gas samples. The quality assurance and control for mobile laboratories analyzing volatile compounds using EPA Method 8260 may not be sufficient to allow use of these data for quantitative risk evaluations at vapor intrusion sites; however, if used for screening purposes, this technique can help facilitate rapid delineation of subsurface soil gas plumes at larger, more complex sites. If used, twenty percent of samples collected during a mobile laboratory sampling event should also be analyzed at a private laboratory using EPA Method TO-15. Use of mobile laboratories for soil gas sampling analysis requires prior MPCA staff approval, and may not be allowed in some remediation programs.

E.3 Emission flux chambers

Emission Flux Chambers are apparatuses placed directly on the ground surface, or lowest level of a potentially impacted building, for a period of time to measure contaminant flux between the subsurface and the ambient environment within enclosure building. Assuming that the measured flux is constant from time zero to the end of the designated measurement period and is consistent over the entire area of the floor, an estimated concentration can be calculated. This method of measurement has been used for other regulatory applications such as measuring trace emissions from natural soils, however its use in vapor intrusion investigations is somewhat limited (ITRC, 2007a). There are two primary methods of conducting flux chamber assessments, 1) the static-chamber or the 2) dynamic-chamber test method. With the static-chamber method, contaminants are trapped in a stagnant chamber volume and the contaminant concentration builds up over time and provides a time-integrated sample, analogous to a vacuum chamber collecting gas over a specified period of time.

One of the advantages of the static-chamber method is that the equipment required is much simpler compared to the dynamic-chamber method. One disadvantage of the static-chamber method is that higher subsurface concentrations can result in a decrease in the flux into the chamber as an effect of Fick's Law.

Dynamic-chamber testing utilizes a sweep gas to maintain a concentration gradient across the surface under examination. Emissions gases are then collected using canisters for analysis. Dynamic-chamber testing has the advantage of eliminating much of the concern that the chamber concentration will reach levels high enough to cause flux reduction.

Flux chambers are best suited for buildings or structures where bare soils or dirt floors or crawlspaces are apparent. Flux chamber analysis can be used as an additional qualitative line of evidence to identify and pin point entry points into a suspect building at risk for vapor intrusion. For additional information relating to flux chambers refer to (Hartman, 2003).

E.4 Sub-slab diagnostic testing

Sub-slab diagnostic testing can be used to simulate a completed sub-slab depressurization system to determine the number and location of suction points to obtain sufficient pressure field extension beneath the slab. This technique can also be used to indirectly identify significant vapor entry point locations in a floor slab so they can be sealed. Detailed specifications as described in EPA (1993) should be used for completing sub-slab diagnostic testing.

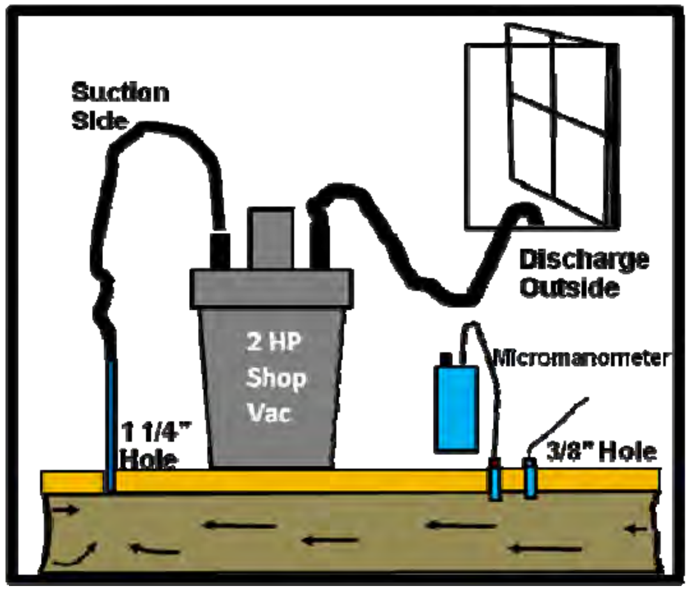


Figure E1: Schematic of typical communication test design
(Adapted from Midwest Universities Radon Consortium course notes, 2006)

The general process involves creating a suction point within the floor slab and a vacuum is applied within the suction point (Figure E1). Differential pressure measurements are then collected at measurement point locations drilled through the floor slab at successive distances from the suction pit. The differential pressure measurements should be collected using a digital micro-manometer capable of reading in increments of 0.25 pascal, or 0.001 inch water column. Small pressure differentials can be estimated qualitatively using non-thermal smoke (i.e., smoke pencils), although quantitative differential pressure readings are preferred. This testing should be conducted under conditions simulating maximum interior building depressurization if possible.

Portable vacuum sources such as Shop-Vac's® can be used as the vacuum source during sub-slab diagnostics testing, although the design can be tested more effectively by using actual system fans. Although a Shop-Vac® may produce higher vacuum and air flow than the actual system fan, it can overcome the absence of a true suction pit with a significant open volume (i.e., up to ten cubic feet). Cracks, leaks and openings in the floor slab that are identified during the testing will result in a reduced pressure field extension between the suction point and successive measurement points. These openings should be completely sealed, if possible to reduce air leakage. Even if a tight building envelope can be confirmed or has been established by sealing openings in ground contact rooms, other sub-slab features such as grade beams, footings and foundation walls that penetrate the slab into footings can easily restrict the pressure field extension. These features may result in the need for multiple suction points in a final system's design.

Appendix F: Required laboratory quality assurance and quality control

Each laboratory analyzing samples by method TO-15 shall follow the method as defined by the USEPA in the EPA/625/R-96/010b dated January 1999 or subsequent updates or revisions.

1. The laboratory shall supply the following data with each report:
   a. Method blank (Zero canister): All results from analysis of the method blank should be less than the reporting limits. If concentrations are reported above the reporting limits, the laboratory will document this occurrence within the narrative and flag any concentration reported above the reporting limit for this compound up to ten times the level measured in the blank. The area responses for the internal standards (IS's) must be within ± 50 percent of the area response of the ISs in the mid-point standard of the most recent initial calibration. The RT for each IS must be within ± 0.33 minutes between the blank and the most recent calibration. Method blanks shall be run every 20 environmental samples or once per day, whichever is more frequent.
   b. Laboratory Control Sample: The laboratory will report the percent recoveries from all analytes spiked into the Laboratory Control Sample (LCS). One LCS will be run within each 24-hour period of TO-15 samples analyzed.
   c. The narrative of the laboratory report will define if the initial calibration curve, continuing calibration check sample (when appropriate), and internal quality assurance (such as internal standards, blanks, etc.) met the method requirements for each report.
   d. The chromatogram for each analysis will be submitted with the data and have the compounds identified in Appendix C clearly labeled on the chromatogram.
   e. The laboratory shall report the results using the field sample ID and the associated laboratory sample number.
   f. The laboratory shall report all compounds in units of µg/m3.
   g. The laboratory report must contain the following information: Coversheet with signature of a laboratory supervisor or designee, a narrative discussing the sample results and any irregularities that were found during the analysis, chain of custody and sample condition upon receipt forms, tables containing the VOC compounds, CAS number of each reported compound, measured concentration in µg/m3, reporting limit, date of analysis, labeled sample chromatograms, method blank data for the batch, and a summary of applicable quality control.
2. The laboratory is required to maintain the data for a minimum of ten years with the ability to reconstruct the data either via a computer or paper.
3. Laboratories must verify their reporting limits by running a standard at the reporting limit once every month. The recovery of the reporting limit shall be +/- 40 percent of the true value.
4. Laboratories shall verify their calibration curve a minimum of every 24 hours. The 24 hour clock will begin at the injection of a standard for tuning the instrument (bromofluorobenzene (BFB) is the suggested tuning standard). The calibration verification standard must be at the midpoint (or lower) of the calibration curve. The standard must meet TO-15 or laboratory generated limits for the compounds of interest/target compounds (as identified on the chain of custody), not a set of continuing calibration check compounds. If no direction is given to the laboratory for check compounds, then the laboratory SOP shall be followed.
5. Laboratories should run ten percent laboratory duplicates. Duplicate samples should have less than or equal to 25 percent Relative Percent Difference or corrective action should be initiated.
6. The MPCA accepts a holding time of 14 days for the TO-15 analysis.

7. Reporting Limits: The MPCA expects that for the following compounds: benzene, toluene, the xylenes, ethylbenzene, the trimethylbenzenes, trichloroethene, and vinyl chloride will have reporting limits between 0.2-0.4 ppbv (reported as µg/m3). The other compounds on the Minnesota Soil Gas List (Appendix C) should have reporting limits between 0.5-1.0 ppbv (reported as µg/m3). The MPCA does recognize that some compounds will have issues with chromatography or interferences that will prevent the expected reporting limits from being met. Laboratories should clearly document these cases within their SOPs and on reports as necessary.
8. Canisters: The laboratory providing summa canisters shall verify each batch of 20 canisters by analyzing one container after cleaning. The canister chosen for post-cleaning analysis shall be the canister with the highest recorded VOC concentration from prior analyses. The container shall be verified by charging the canister with clean zero air, analyzing the container by TO-15, and verifying no compounds are found above the reporting limits required by the MPCA. Additionally, the supplier of summa canisters is expected to verify the operability of the canisters. The TO-15 SOP (or equivalent) should describe the preventative maintenance performed on the canisters. 100 percent certified canisters may be required upon request.
9. Whenever a high concentration sample is analyzed (sample with concentrations outside the calibration curves), a Zero canister analysis should be performed to check for carryover. If carry over is detected, column bake out shall be performed.
10. Tentatively Identified Compounds: The MPCA requires each TO-15 analysis to include the reporting of the top ten Tentatively Identified Compounds (TICs) greater than 5 ppbv that are not attributed to column breakdown, as compared to response of the nearest IS, when using full scan mode of the mass spectrometer. The laboratory will also report within the narrative if a hump is seen within the chromatogram such as is typical for gasoline, fuel oil, mineral spirits, etc. The laboratory is not required to quantify this as part of the analysis, although this may be requested of the laboratory at a later date for an additional cost.
11. Lab Certification: At this time certification is available for the TO-15 method through the Minnesota Department of Health (MDH) Laboratory Certification Program. The MPCA requires that TO-15 analytical results submitted be completed by an MDH certified laboratory.
12. MDL studies must be performed at least annually. The MDLs should be ≤0.5 ppbv for all target analytes.
13. Field samples can be analyzed after successfully meeting all criteria established for instrument performance checks, calibrations, and blanks. All target analyte peaks should be within the initial calibration range. The RT for each IS must be within ± 0.33 minutes of the IS in the most recent calibration. The area response for the IS's must be within ± 50 percent of the area response of the ISs in the mid-level standard of the most recent initial calibration.
14. Daily check standard must be analyzed every 24 hours. This standard is at the mid-point of the calibration curve (ten ppbV suggested). The %D must be within ± 30 percent for each target analyte. Control charts should be maintained for the %D values.
15. Internal standard (IS) A suggested internal standard mixture of bromochloromethane, chlorobenzene-d5, and 1,4-difluorobenzene will be added to each sample as standard. The resulting concentrations are at ten ppbV (suggested).

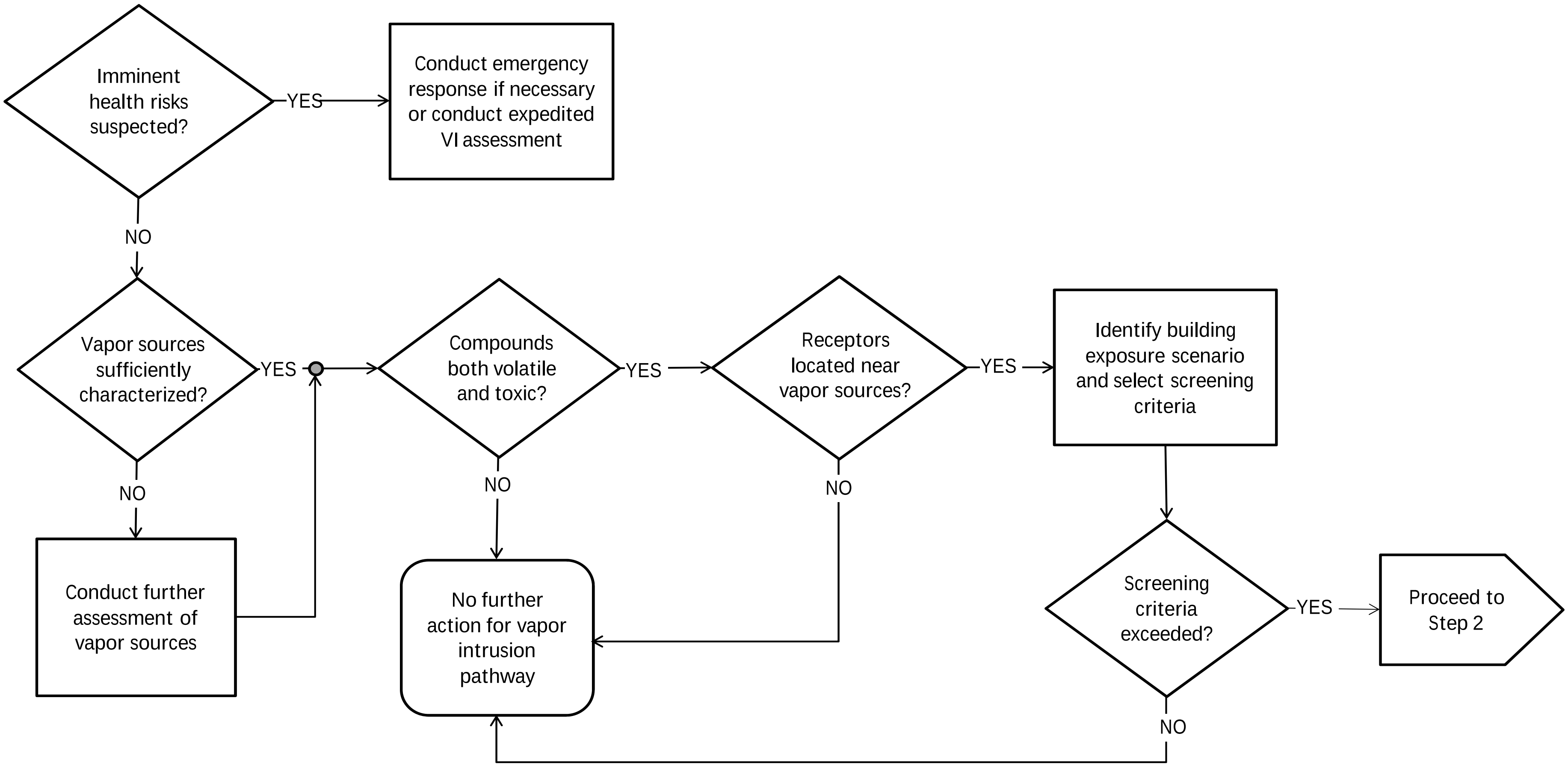
Appendix G: Vapor intrusion decision flowcharts

The flowcharts provide a conceptualized summary of decision making steps discussed in more detail in the document. Flowchart G-1, G-2 and G-3 correspond, respectively to the following vapor intrusion investigation steps and sections of the document:

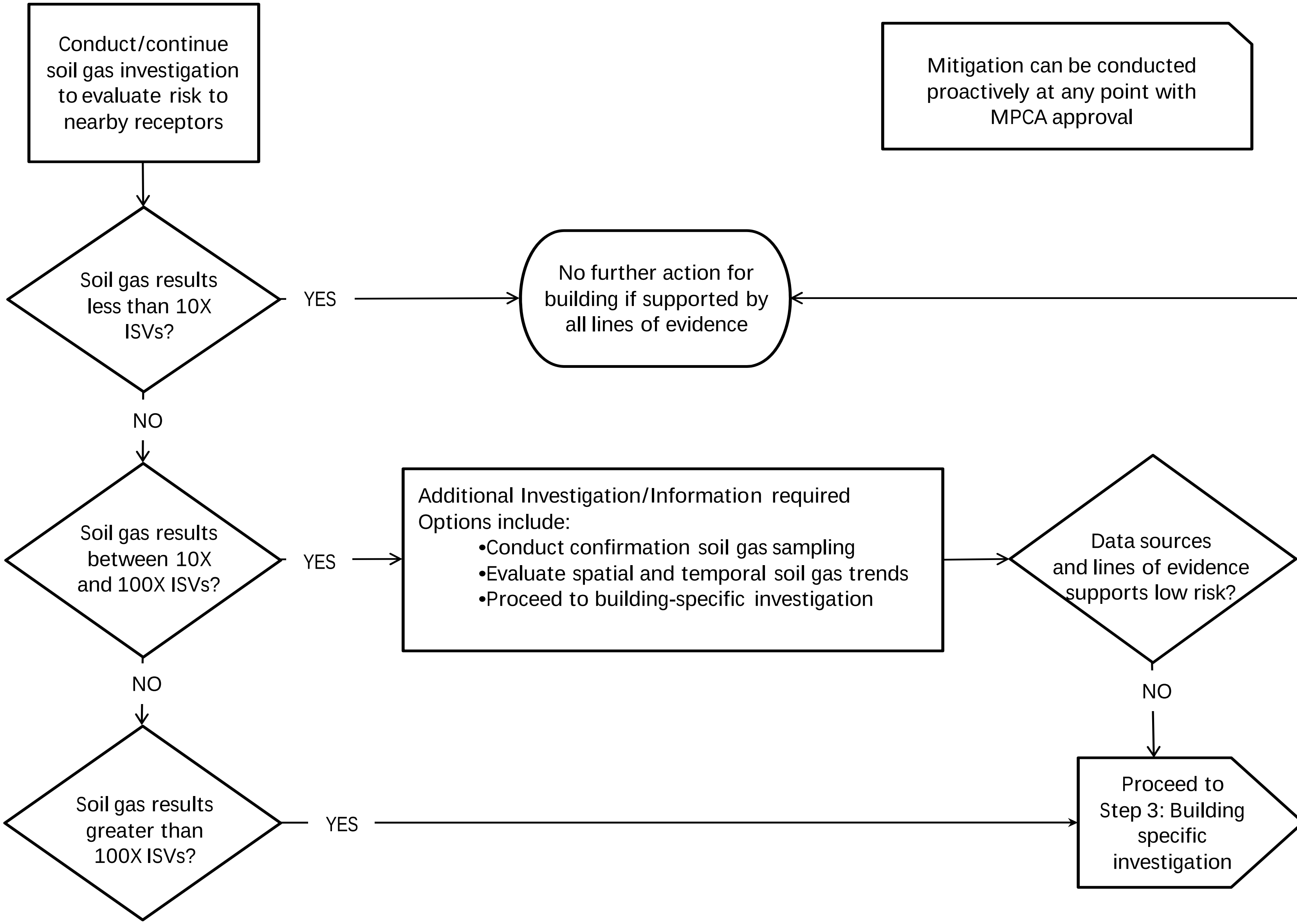
Vapor intrusion steps	Flowchart	Document Reference
Step 1: Vapor intrusion screening and receptor evaluation	G-1	Section 3
Step 2: Soil gas investigations	G-2	Section 4
Step 3: Building-specific investigations	G-3	Section 5
Step 4: Response actions	Flowchart Not provided	Section 6

The MPCA guidance emphases the use of multiple lines of evidence interpreted within an accurate Site Conceptual Model. The variety of site specific conditions to be considered when conducting vapor intrusion investigations cannot be described in detail in the flowcharts and the user is directed to the corresponding sections of the document for supporting guidance.

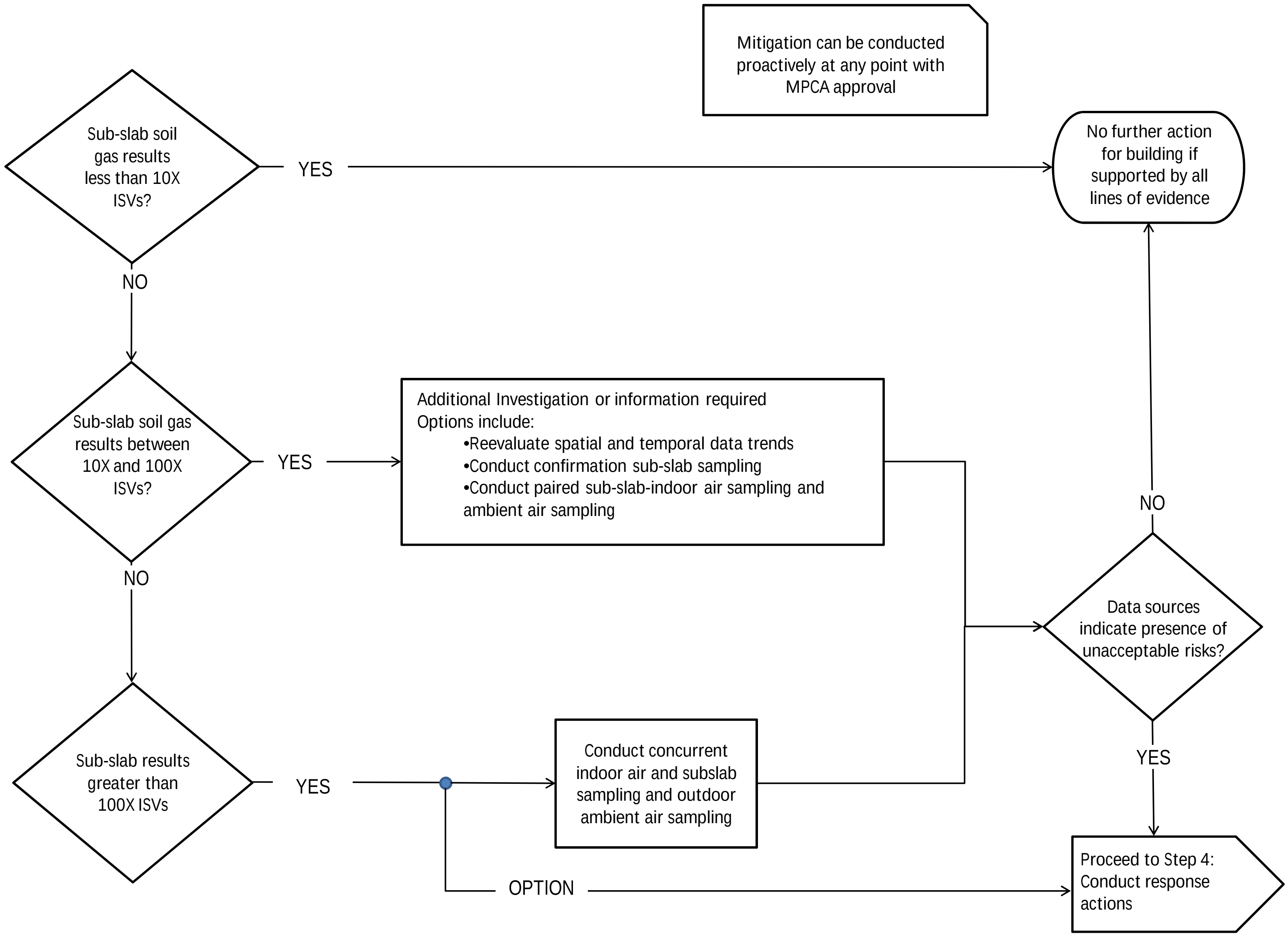
Flowchart G-1: Step 1 - Vapor intrusion screening and receptor evaluation



Flowchart G-2: Step 2 - Soil gas investigation



Flowchart G-3: Step 3 - Building-specific investigations



Minnesota Pollution Control Agency
520 Lafayette Road North
St. Paul, MN 55155-4194

Vapor Intrusion Interior Building Survey Form

Remediation Program

Doc Type: Site Inspection Information

Part 1: Physical Building Inspection

Preparer's name: ____________________ Date/Time prepared: ____________________

Affiliation: ____________________ Phone number: ____________________

1. Occupant information

Occupant name(s): ____________________ Interviewed: ☐ Yes ☐ No

Mailing address: ____________________

City: ____________________ State: __________ Zip code: __________

Phone: __________ Fax: __________ E-mail: ____________________

Number of occupants at this location: __________ Age range of occupants: ____________________

2. Owner/Landlord information (Check if same as occupant: ☐)

Occupant name(s): ____________________ Interviewed: ☐ Yes ☐ No

Mailing address: ____________________

City: ____________________ State: __________ Zip code: __________

Home phone: ____________________ Office phone: ____________________

3. Building type (Check appropriate response)

☐ Residential ☐ Industrial ☐ School ☐ Church ☐ Commercial/Multi-use

☐ Other (specify): ____________________

If the property is residential, what type? (Check appropriate response)

☐ Ranch rambler ☐ Raised rambler ☐ Townhouses/Condos ☐ Duplex ☐ Modular ☐ 2-Family

☐ Split level ☐ Contemporary ☐ Apartment house ☐ Cape cod ☐ Log home ☐ 3-Family

☐ Colonial ☐ Mobile home ☐ Other (specify): ____________________

4. Building description

If the property is commercial or industrial, describe the business use(s):

____

____

____

Indicate the number of floors and general use of each floor of the building beginning with lowest level:

____

____

____

If there are multiple residential units, indicate how many units: ______ When was building constructed: __________

Type of insulation used in building: ____________________ Elevators or lifts: ☐ Yes ☐ No

Basement/Lowest level depth below grade: ____________________ (feet)

Observed basement characteristics (Check all that apply)

Is basement/lowest level occupied:	☐ Full time	☐ Occasionally	☐ Almost never		
Basement type:	☐ Full	☐ Crawlspace	☐ Slab	☐ Other:	
Floor materials:	☐ Concrete	☐ Dirt	☐ Stone	☐ Other:	
Floor covering:	☐ Uncovered	☐ Covered	☐ Covered with:		
Concrete floor:	☐ Unsealed	☐ Sealed	☐ Sealed with:		
Foundation walls:	☐ Poured	☐ Block	☐ Stone	☐ Other:	
Basement finished:	☐ Unfinished	☐ Finished	☐ Partially finished		
Basement wetness:	☐ Wet	☐ Damp	☐ Seldom	☐ Moldy	
Sump pump present:	☐ Yes ☐ No	If yes, was water present: ☐ Yes ☐ No			

Indicate sources of water supply sources (i.e., drinking, irrigation, etc.) and type of sewage disposal (Check all that apply)

Water supply:	☐ Public water	☐ Drilled well	☐ Driven well	☐ Dug well
Sewage disposal:	☐ Public sewer	☐ Septic tank	☐ Leach field	☐ Dry well:

5. Heating, venting, air conditioning, or other building controls (Check all that apply)

Type of heating system(s) used in this building (Check all that apply)

☐ Hot air circulation ☐ Space heaters ☐ Electric baseboard ☐ In-floor heating ☐ Heat pump

☐ Steam radiation ☐ Wood stove ☐ Hot water baseboard ☐ Radiant floor ☐ Outdoor wood boiler

☐ Other (specify): ____________________ **Primary type:** ____________________

Primary type of fuel used (Check appropriate response)

☐ Natural gas ☐ Fuel oil ☐ Kerosene ☐ Electric ☐ Propane

☐ Solar ☐ Wood ☐ Coal

If hot water tank present, indicate fuel source: ____________________

Boiler/furnace is located in:	☐ Basement	☐ Outdoors	☐ Main floor	☐ Other:
Type of air conditioning:	☐ Central air	☐ Window units	☐ Open windows	☐ No mechanical system

Are there air distribution ducts present: ☐ Yes ☐ No

Describe the supply and cold air return ductwork and its condition where visible, including whether there is a cold air return and the tightness of duct joints. Indicate the locations on the floor plan diagram.

____

____

____

Describe the type of mechanical ventilation systems used within or for the building (e.g., air-to-air exchangers, HVAC, etc.). Indicate whether the interior spaces of the building use separate ventilation systems and/or controls. Provide information on any existing building mitigation system (e.g., radon mitigation, passive venting systems, etc.). If available, provide information on air exchange rates for any existing mechanical ventilation systems currently in use.

____

____

____

____

____

6. Grid plans

Use grid plans to describe floor plans, locate potential soil vapor entry points (e.g., cracks, utility ports, drains); and if applicable, identify sample locations (sub-slab, indoor air, outdoor air sampling).

Floor plan for basement or lowest level:

Floor above lowest level:

Outdoor grid plot (Include if outdoor ambient air samples collected):

Insert sketch (or attach separate document) of the area outside the building and locate outdoor air sample locations.
If applicable, provide information on spill locations, potential air contamination sources, locations of wells, septic system, etc., and PID meter readings. Indicate wind direction and speed during sampling.

Part 2: Indoor Air Quality Survey

Complete if indoor air sampling is conducted (use grids in Part 1 for labeling sampling locations).

Factors that may influence indoor air quality:

Is there an attached garage: ☐ Yes ☐ No

Are petroleum-powered machines or vehicles stored in the garage (e.g., lawn mower, ATV, car): ☐ Yes ☐ No Please specify: ____________

Has the building ever had a fire: ☐ Yes ☐ No When: ____________

Is a kerosene or unvented gas space heater present: ☐ Yes ☐ No Where & type: ____________

Is there smoking in the building: ☐ Yes ☐ No How frequently: ____________

Have cleaning products been used recently: ☐ Yes ☐ No When & type: ____________

Have cosmetic products been used recently: ☐ Yes ☐ No When & type: ____________

Has painting/staining been done in the last 6 months: ☐ Yes ☐ No Where & when: ____________

Has any remodeling or construction occurred in the last 6 months: ☐ Yes ☐ No Where & when: ____________

Is there new carpet, drapes, or other textiles: ☐ Yes ☐ No Where & when: ____________

Have air fresheners been used recently: ☐ Yes ☐ No When & type: ____________

Is there a clothes dryer: ☐ Yes ☐ No If yes, is it vented outside: ____________

Are there odors in the building: ☐ Yes ☐ No If yes, please describe: ____________

Do any of the building occupants use solvents at work: ☐ Yes ☐ No

If yes, what types of solvents are used: ____________

Do any of the building occupants regularly use or work at a dry-cleaning service: ☐ Yes ☐ No

If yes, indicate approximately how frequent: ____________

Product inventory form (Add additional rows if needed)

Make and model of field instrument used: ____________

List specific products identified in the building that have the potential to affect indoor air quality:

Location	Product description*	Comments	Instrument readings if taken and units

* Describe the condition of the product containers as Unopened (UO), Used (U), or Deteriorated (D).
Include photographs of product containers as appropriate to document products and ingredients.

Appendix I: Instructions for occupants

The instructions provided below are intended to help minimize the potential for background indoor air compounds to be detected during indoor air sampling event. If possible, please follow these instructions beginning at least 48 hours prior to the beginning of and during the time that indoor air sampling will be conducted. Ventilation of the building should be conducted as is typical for this time of year with the exception that open windows be closed. Following these instructions may not completely eliminate the potential for background air contamination but may help minimize their effects. Please indicate to the field sampling personnel when they arrive for sampling whether these instructions could be completed.

- Do not open windows, fireplace dampers, openings, or vents.
- Do not use air fresheners, scented candles, or odor eliminators.
- Do not smoke in building.
- Do not use wood stoves, fireplaces, or auxiliary heating equipment (e.g., kerosene heater).
- Do not use paint or varnishes.
- Do not use cleaning products such as bathroom cleaners, furniture polish, appliance cleaners, all-purpose cleaners, floor cleaners.
- Do not use cosmetics such as hair spray, nail polish, nail polish remover, perfume, cologne, etc.
- Do not partake in hobbies that use solvents or other volatile chemicals.
- Do not store containers of gasoline, oil, or petroleum-based or other solvents within the house.
- Do not conduct lawn mowing, snow blowing, or paving with asphalt.
- Do not use caulk or roofing tar.
- Do not operate or store automobiles in an attached garage.