Public Review Draft

Vapor Intrusion Guidance

WSC#-14-435

This document provides guidance on identifying, assessing and mitigating vapor intrusion pathways at disposal sites regulated under the Massachusetts Contingency Plan (MCP).

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REFERENCES

LIST OF ACRONYMS

AEPMM	Active Exposure Pathway Mitigation Measure
APH	Air-Phase Petroleum Hydrocarbon
AUL	Activity and Use Limitation
BTEX	Benzene, Toluene, Ethyl Benzene and Xylenes
CAM	Compendium of Analytical Methods
CEP	Critical Exposure Pathway
COC	Contaminant of Concern
CRA	Comprehensive Remedial Action
CSM	Conceptual Site Model
DNAPL	Dense Nonaqueous Phase Liquid
DPS	Downgradient Property Status
EPA or USEPA	United States Environmental Protection Agency
EPC	Exposure Point Concentration
EPH	Extractable Petroleum Hydrocarbon
FID	Flame Ionization Detector
GW-1	Groundwater-1 Category
GW-2	Groundwater-2 Category
HVAC	Heating, Venting and Air Conditioning
IDA	Inclusion Distance Approach
IH	Imminent Hazard
IRA	Immediate Response Action
IRAC	Immediate Response Action Completion Statement
LEL	Lower Explosive Limit
LNAPL	Light Nonaqueous Phase Liquid
LSP	Licensed Site Professional
MCP	Massachusetts Contingency Plan
MassDEP	Massachusetts Department of Environmental Protection
NAPL	Nonaqueous Phase Liquid
NSH	No Substantial Hazard
NSR	No Significant Risk
OHM	Oil or Hazardous Material
PCE	Tetrachloroethylene
PHC	Petroleum Hydrocarbon
PID	Photo-ionization Detector
PRP	Potentially Responsible Party
PVI	Petroleum Vapor Intrusion

RAM	Release Abatement Measure
RC	Reportable Concentration
RQ	Reportable Quantity
ROS	Remedy Operation Status
RMR	Remedial Monitoring Report
SSD	Sub-slab Depressurization (as in SSD system)
SRM	Condition of Substantial Release Migration
TCE	Trichloroethylene
TIAC	Typical Indoor Air Concentration
TPH	Total Petroleum Hydrocarbons
TO-15	Volatile Organic Compounds in Air Method
TV	Indoor Air Threshold Value
$TV_{c/i}$	Commercial/Industrial Indoor Air Threshold Value
TV_r	Residential Indoor Air Threshold Value
UST	Underground Storage Tank
VI	Vapor Intrusion
VOC	Volatile Organic Compound
VPH	Volatile Petroleum Hydrocarbon

DISCLAIMER

The Massachusetts Department of Environmental Protection (MassDEP) intends the information contained in this document solely as guidance. The guidance provides a technical framework, recommended and preferred by MassDEP, which is intended to be protective of health, technically defensible and promote a consistent approach to addressing vapor intrusion into indoor air. Parties should be aware that other technically equivalent procedures may exist, and this guidance is not intended to exclude alternative approaches. The regulatory citations in this document should not be relied upon as a complete list of the applicable regulatory requirements.

MassDEP generally does not intend the guidance to be overly prescriptive. Use of such words as “shall,” “must,” or “require,” however, indicates that the text is referring to a specific regulatory and/or statutory requirement, rather than a suggested approach and/or optional measure. Use of the words “should” or “recommend” indicates aspects of a method or approach that are considered appropriate and protective, based on MassDEP’s experience and/or sound technical practices, but do not correspond to a specific regulatory and/or statutory requirement.

The guidance is not a regulation, rule or requirement, and should not be construed as mandatory. Accordingly, this document does not create any substantive or procedural rights, and is not enforceable by any party in any administrative proceeding with the Commonwealth.

Vapor intrusion is a rapidly developing field of science and policy. This guidance is intended to aid in evaluating the potential for human exposure from this pathway given the state-of-the-science at this time. MassDEP will continue to study efforts being made to improve the state-of-the-science of this complex exposure pathway. It is anticipated that procedures and practices within this guidance will change as understanding of vapor intrusion evolves. Hence, this guidance is intended to be a living document subject to amendment as appropriate to accommodate refinements and advances in understanding of the vapor intrusion pathway.

Within the guidance may be references to specific brands. These references are for discussion purposes only and are intended to be illustrative. They should not be interpreted as endorsements by the Commonwealth of any particular company or its products.

While striving to be as useful and complete as possible, nothing in this document should be viewed as limiting or obviating the need for the exercise of good professional judgment.

1. INTRODUCTION

In Massachusetts, thousands of sites with releases of oil and/or hazardous materials (OHM), such as petroleum products, dry cleaning fluids, and industrial solvents, have impacted soil and groundwater. When this contamination occurs near buildings, volatilization of contaminants from the dissolved or pure phases in the subsurface can result in the intrusion of vapor-phase contaminants into indoor air. Although the vapor intrusion pathway has been a concern at a small percentage of the sites reported to the Massachusetts Department of Environmental Protection (MassDEP) each year, it is a problematic issue due to the difficulty in assessing the pathway and the potential risks associated with the presence of VOCs in the indoor air of occupied buildings.

The assessment and remediation of sites contaminated by releases of OHM, including sites with vapor intrusion issues, are governed by Massachusetts General Laws, Chapter 21E (M.G.L. c. 21E) and the Massachusetts Contingency Plan (MCP or 310 CMR 40.0000).

Vapor intrusion that results in indoor air exposures is of concern because:

- People spend most of their time inside of buildings;
- The lungs are an efficient mass-transfer mechanism for introducing air contaminants into the body; and
- While it is possible to avoid exposure to contaminated soils and groundwater at a site, it is not possible to avoid breathing the air within an affected occupied structure.

Of particular concern are indoor air exposures to sensitive receptors, especially pregnant women and young children, in places where these parties spend long periods of time (e.g., schools, daycare facilities, and homes). Exposures in commercial and/or industrial buildings are usually of shorter duration, but can also pose a risk to workers and other occupants.

1.1 Purpose

The MCP is a performance-based set of regulations that provides the framework for conducting response actions and achieving closure. MassDEP has developed this guidance document to assist parties conducting response actions and their Licensed Site Professionals (LSPs) to comply with the requirements of the MCP. To that end, the guidance document outlines MassDEP’s recommendations for best practices that will meet the current regulatory requirements. PRPs and their LSPs may meet the regulatory requirements in ways other than those specified in this document, providing that the technical justification for their approach is documented and supported by adequate data.

The purpose of this document is to:

- Clarify when evaluation of the vapor intrusion pathway is required pursuant to the MCP (Section 1);

- Provide guidance on conducting assessments to determine if the vapor intrusion pathway at a site is complete and likely to be of concern (Section 2);
- Provide guidance on conducting exposure and risk assessments at sites where the vapor intrusion pathway has been determined to be complete (Section 2);`
- Recommend vapor intrusion mitigation strategies (Section 3); and
- Outline the MCP requirements relative to sites at which a potential or known vapor intrusion pathway exists (Section 4).

1.2 Regulatory Basis of this Guidance

Regulatory requirements related to the vapor intrusion pathway are found throughout the MCP. This guidance specifically addresses many of these requirements, including:

- Reporting obligations;
- Immediate Response Actions (IRAs), including Critical Exposure Pathways (CEPs);
- Comprehensive Response Actions;
- Risk Characterization; and
- MCP Closure at Sites with Vapor Intrusion Pathways.

Regulatory citations in this document should not be relied upon as a complete list of applicable regulatory requirements.

1.3 When to Evaluate the Vapor Intrusion Pathway

The MCP (310 CMR 40.0925) requires that all exposure pathways that are probable must be identified and described in the risk characterization for a site. When VOCs are released to the subsurface near occupied buildings and/or structures or migrate through the subsurface to the area around occupied buildings and/or structures, initiation of an assessment of vapor intrusion is therefore required. In some cases, the existence of a vapor intrusion pathway is obvious, due to odors and/or site conditions and events. In other cases, the impact is not apparent, but may be confirmed after the generation of investigational data.

VOCs are defined in the MCP (310 CMR 40.0006) as an “organic compound with a boiling point equal to or less that 218°C that are targeted analytes in EPA Method 8260B and other purgeable organic methods specified in the Department’s Compendium of Analytical Methods.” This definition includes the Volatile Petroleum Hydrocarbon fractions C_5 through C_8 Aliphatic Hydrocarbons, C_9 through C_{12} Aliphatic Hydrocarbons, and C_9 through C_{10} Aromatic Hydrocarbons.

Under certain circumstances, the MCP Method 1 GW-2 Groundwater Standards, developed by MassDEP for use at sites contaminated by releases of OHM, can be used to determine whether vapor intrusion is likely to occur. Method 1 GW-2 Standards were developed based upon a consideration of volatilization from groundwater to indoor air. Pursuant to 310 CMR 40.0932(6), these Standards apply to groundwater that is considered a potential source of indoor air contamination.

The recommended use of Method 1 GW-2 Standards in determining whether to evaluate the vapor intrusion pathway is presented in more detail below.

Method 1 Soil Standards, however, were *not* developed with a consideration for the potential vapor intrusion pathway and cannot be used to draw any conclusions about the potential for indoor air impacts from VOC contamination in soil. This is addressed in more detail in Section 1.3.2.

It should be noted, and is further clarified below, that pursuant 310 CMR 40.0942(1)(b) and 40.0971(1), if VOC-contaminated soil and/or groundwater is likely to result in a significant impact to indoor air, then a Method 1 risk characterization, including the GW-2 Standards and distance criteria, is not applicable. Groundwater assessments and vapor intrusion evaluations should consider this possibility, and document and affirm that the vapor intrusion pathway has been ruled out whenever Method 1 is used to characterize risk at a disposal site.

Some specific conditions that are likely to result in the discharge of vapors to buildings require 2- or 72-hour notification to MassDEP pursuant to 310 CMR 40.0300 and therefore require that an IRA be conducted pursuant to 310 CMR 40.412 to expedite the assessment of the potential pathway, and if necessary, perform remedial action to prevent or mitigate potential impacts to receptors and the environment. These notification requirements are discussed in detail in Sections 4.1 and 4.2 of this guidance document.

Figure 1-1 illustrates a process for the evaluation of site information and conditions in determining whether additional evaluation of the vapor intrusion pathway is warranted. The different components of this process are presented in more detail below.

1.3.1 VOCs in Indoor Air

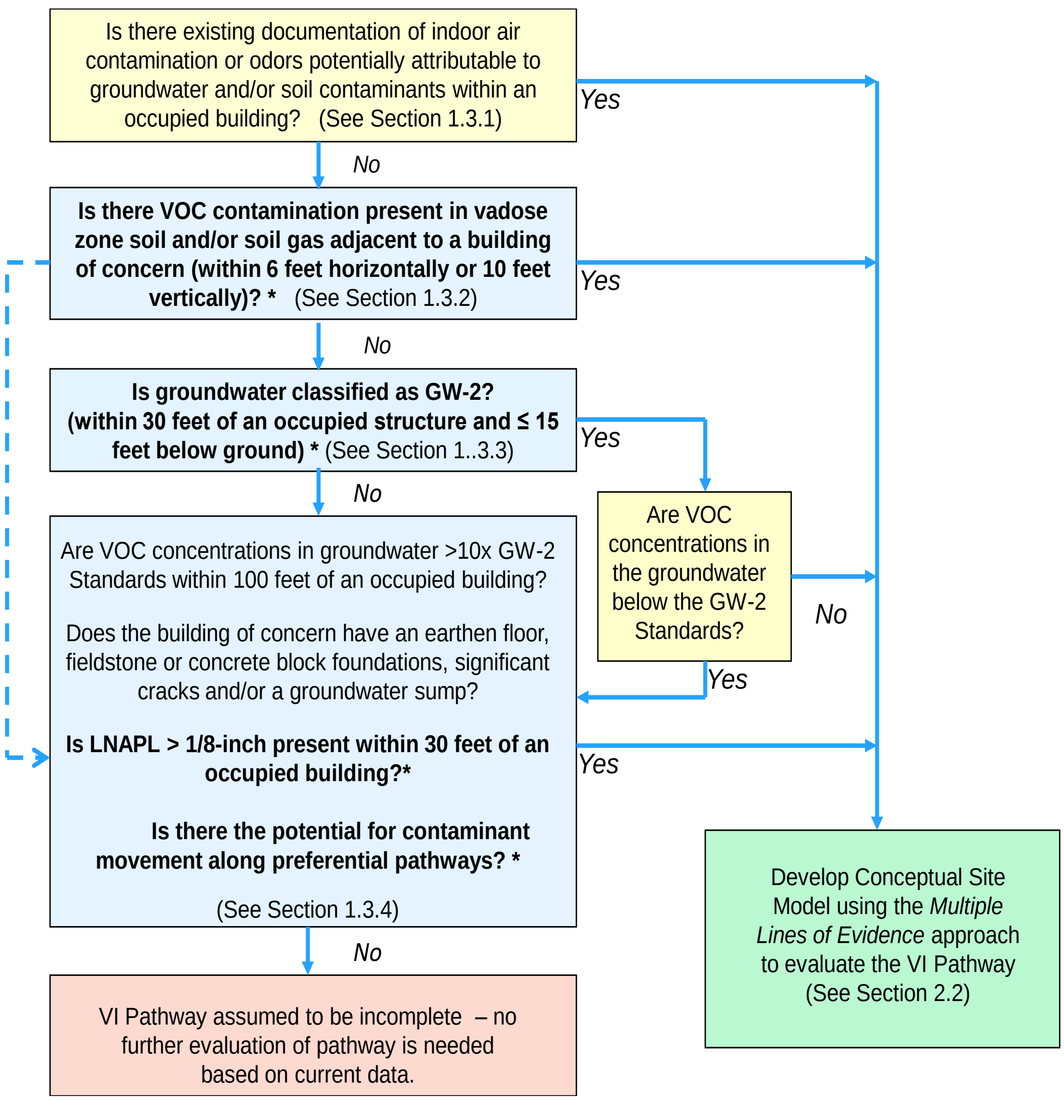
If the indoor air of an occupied building or structure is sampled and the analytical results indicate that VOCs are present, then there is a potential that vapor intrusion may be occurring. Sampling the indoor air for VOCs without prior collection of groundwater, soil or soil gas data indicating that there might be an issue is not common. Industrial hygienists investigating an odor complaint may collect indoor samples in an attempt to identify potential sources of an odor or reported health concerns.

1.3.2 VOCs in Soil

The MCP (310 CMR 40.0942(1)(d)) states that "If one or more Volatile Organic Compounds is present in the vadose zone soil adjacent to an occupied structure (within six feet, measured horizontally from the wall of the structure, and within ten feet, measured vertically from the basement floor or foundation slab) then the soil has the potential to result in significant indoor air concentrations of OHM and Method 1 alone cannot be used to characterize the risk at the disposal site."

Concentrations of VOCs in soil at which the potential for vapor intrusion is likely to occur have not been established as even low concentrations of VOCs in soil, below S-1 Soil Standards, have the potential to be a significant source of vapor intrusion. Consequently, Method 1 alone cannot be used to characterize the risk at the disposal site where there is soil contamination by VOCs near a building. The potential for vapor intrusion must be evaluated if VOCs are detected in soil or soil gas within the distances identified above, in accordance with 310 CMR 40.0925.

Figure 1-1: Evaluation of vapor Intrusion potential at sites where VOCs have been released to the environment



*** Bolded conditions** *above are related to Conditions of Substantial Release Migration (SRM) where the building of concern is a School, Daycare or Child Care Center or occupied Residential Dwelling (see 310 CMR 40.0313(4)(f)). Notification is required within 72-hour of obtaining knowledge of SRM conditions, triggering an Immediate Response Action. Refer to Section 4.1.2 of this guidance for more information.*

In some situations, a contaminant source under a building such as a dry well, leaking floor drain or piping, or a spill location can result in impacts to the soil in the vadose zone without significant contamination to the groundwater in the underlying aquifer. The investigator should carefully research historical and current chemical use and storage at the site to identify areas where releases to the soil were likely to have occurred. Soil contamination should be considered a possibility at sites with documented uses of VOCs (such as dry cleaners or industrial facilities using solvents). The presence of such sources or screening results or analytical data indicating that the soil in the vadose zone may be impacted with VOCs (e.g., direct measurements of soil or of soil gas) near or beneath the structure may be indicative of a potential vapor intrusion pathway.

The derivation of the Method 1 Soil Standards did not consider the vapor intrusion pathway. In some cases, VOCs in soil below the Method 1 Soil Standards could result in an impact to the indoor air of an adjacent building.

The regulatory distances identified in Figure 1-1 above represent the minimum requirements for the evaluation of the vapor intrusion pathway. The presence of contaminated soil or soil gas at distances beyond those identified above may indicate the need for additional characterization, depending on concentrations detected, the concentration gradients, and the possible presence of preferential migration pathways.

1.3.3 VOCs in Groundwater

The MCP Category GW-2 Standards presented in 310 CMR 40.0974(2) apply to groundwater that is considered a potential source of indoor air contamination. These Standards apply to groundwater that is both shallow (15 feet or less) and near (within 30 feet horizontally) an occupied building or a building where there are plans to occupy the building. The specific regulatory criteria used to determine the applicability of the GW-2 Standards are described at 310 CMR 40.0932(6).

These Standards are designed to be protective at most sites, and can generally be used as a screening tool to determine whether the vapor intrusion pathway should be further evaluated. The GW-2 Standards can only be used to eliminate the vapor intrusion pathway from further consideration when groundwater is the only source of contamination to indoor air. For example, potential impacts from soil, preferential pathways or Light Nonaqueous Phase Liquid (LNAPL) must be considered separately.

For the purposes of determining whether further evaluation of the vapor intrusion pathway is warranted, MassDEP recommends the following approach in order to achieve a meaningful evaluation. The concentration(s) of VOCs detected in each groundwater sample should be compared to the applicable GW-2 Standard. When contaminant concentrations within GW-2 areas exceed the GW-2 Standards, the vapor intrusion pathway should be further evaluated. The initial step in this investigation would be to delineate the extent of groundwater where the VOC concentrations exceed the GW-2 Standards, taking into account location of the source(s), groundwater transport (flow direction and velocity, preferential pathways, etc), contaminant fate, location of receptors, etc. The occupied buildings or structures within the area exceeding the GW-2 Standards should be evaluated for the potential vapor intrusion pathway.

In addition, the evaluation should address the potential for (a) increases in the concentrations of VOCs in the groundwater within 30 feet of existing buildings or structures that could result in contaminant concentrations that exceed the GW-2 Standards in the foreseeable future, and/or (b) increases in concentrations adjacent to the building that might result in higher indoor air exposure point concentrations in the foreseeable future.

In cases where a monitoring well has not been or cannot be installed within 30 feet of a building, the location and extent of groundwater where concentrations of VOCs exceed the GW-2 Standards can be extrapolated from an understanding of the source area, groundwater flow direction and groundwater quality using monitoring wells in the vicinity of the building and structures of concern. Through such extrapolation of the extent of GW-2 exceedances, the need for further evaluation of the vapor intrusion pathway can be determined.

In most, but not all, cases where contaminant levels in groundwater are below GW-2 Standards, the investigator can conclude that additional evaluation of vapor migration from groundwater to indoor air is *not* warranted.

Given that this is a screening evaluation to determine whether conditions exist that warrant further evaluation, averaging groundwater concentrations detected in the groundwater from different monitoring wells is not appropriate. Note that this *screening use of GW-2 Standards* is different from that used in an MCP risk characterization, where the nature and extent of OHM concentrations in groundwater and other site conditions must be well characterized in accordance with 310 CMR 40.0904.

VOC concentrations in groundwater at an average annual depth of15 feet or less within 30 feet of a building that is a School, Daycare or Child Care Center or occupied Residential Dwelling triggers a 72-hour notification as a Condition of Substantial Release Migration (310 CMR 40.0313(4)(f)2.).

1.3.4 Other Factors

Other conditions may be present that indicate the need for a vapor intrusion evaluation, even when groundwater concentrations at the site are below the Method 1 GW-2 Standards and/or the contamination is not within a GW-2 area.

As stated previously, 310 CMR 40.0942(1)(b) specifies that if OHM is likely to migrate at significant concentrations to indoor air, then Method 1, including the GW-2 Standards and distance criteria, is not applicable. The conditions below are the more common situations where further evaluation of the vapor intrusion pathway, beyond the screening evaluation based on the GW-2 Standards for groundwater near a building, is recommended:

- *Groundwater concentrations greater than ten times the GW-2 Standard within 100 feet of an occupied building or structure.*

  Groundwater is not classified as GW-2 in locations with an average annual depth to groundwater greater than 15 feet or where the contaminated groundwater is at a horizontal distance greater than 30 feet from an occupied building. However, data from existing sites indicates that high contaminant concentrations in groundwater beyond the GW-2 distances may act as a source for indoor air contamination. Many other regulators require or recommend an evaluation of groundwater at distances up to 100 feet from buildings (EPA 2013; ITRC 2005).

  In Massachusetts, the potential for vapor intrusion resulting from VOC-contaminated groundwater outside a GW-2 area cannot be dismissed simply because groundwater does not *categorically* meet the GW-2 definitions. If OHM has actually contaminated indoor air, or is likely to migrate at significant concentrations to indoor air, then Method 1, including the GW-2 distance criteria, is not applicable (310 CMR 40.0942(1)(b)). Groundwater assessments and vapor intrusion evaluations should consider this possibility, and document and affirm that this pathway has been ruled out whenever Method 1 GW-2 Standards are used. Such evaluations are particularly important where groundwater contaminant concentrations just outside GW-2 areas (in horizontal distance and/or depth to groundwater) are greater than ten times the GW-2 standard, or when contamination may have been spread along utility lines or other preferential pathways.

- *The structure of concern has an earthen floor, fieldstone or concrete block wall foundation, significant cracks, and/or a groundwater sump.*

  These conditions could allow an unusually direct connection between the interior of the structure and the soil gas and/or groundwater contamination beneath the structure and they are outside of/not consistent with the assumptions MassDEP used in the derivation of the Method 1 GW-2 Standards. In such cases, additional evaluation of the vapor intrusion pathway is necessary to determine whether the indoor air is impacted.

- *Volatile LNAPL is present or is likely to be present within 30 feet (horizontally) of the potentially impacted structure regardless of the depth to groundwater.*

  The presence of LNAPL is not consistent with the assumptions used in derivation of the Method 1 GW-2 Standards, and indicates the need for additional evaluation of the vapor intrusion pathway even if groundwater concentrations are less than the GW-2 Standards and the depth to the LNAPL is greater than 15 feet.

MassDEP considers volatile LNAPL to include gasoline, petroleum napthas, mineral spirits, kerosene, jet fuels and any petroleum mixture where more than 25 percent of component hydrocarbons (by mass) have a boiling point below 218ºC (424ºF), and any single component (or predominantly single-component) LNAPL with a boiling point below 218ºC. Diesel fuels, #2 fuel oils and heavier fuels oils (#3 - #6), waste oils, and lubrication oils are not considered volatile LNAPL.

This condition triggers a 72-hour notification as a Condition of Substantial Release Migration when volatile LNAPL greater than or equal to 1/8 inch is observed in a monitoring well, excavation or subsurface depression next to a building that is a School, Daycare or Child Care Center or occupied Residential Dwelling (310 CMR 40.0313(4)(f)3.).

- *VOC contamination is present in preferential pathways, such as utility lines or corridors, which connect to structures of concern.*

  Contamination may travel from source areas to receptors along preferential pathways such as utility corridors. Backfill material in utility corridors is often more porous and permeable than the adjacent native soil. Releases of VOCs in the vicinity of utilities may result in the contamination traveling preferentially along these pathways and entering buildings and structures of concern, regardless of the depth to groundwater. If site conditions indicate the possibility of this situation, the potential for a vapor intrusion pathway should be further evaluated.

  This condition also triggers a 72-hour notification as a Condition of Substantial Release Migration when there is evidence of vapor migration along a preferential pathway at a location that is likely to impact the indoor air at a building that is a School, Daycare or Child Care Center or occupied Residential Dwelling (310 CMR 40.0313(4)(f)4.).

The above list of conditions that indicate the need for additional evaluation of the vapor intrusion pathway is not all inclusive. The LSP should consider site history, site conditions, existing site monitoring data and the disposal site Conceptual Site Model in making a determination as to whether additional evaluation of the vapor intrusion pathway is warranted.

2. ASSESSMENT

This section describes considerations for the assessment of vapor intrusion once the potential for this pathway has been established as described in Section 1. Assessment activities are conducted for many different purposes, such as to: determine if a vapor intrusion pathway actually exists; provide information suitable for an IH evaluation, evaluate a CEP; complete a Phase II Comprehensive Site Assessment and risk characterization; and evaluate the need for and effectiveness of remedial measures. The assessment activities conducted for these different purposes will be different, and specific approaches should be determined based on the assessment objectives. The plan developed for the assessment, be it an IRA Plan, a Phase II Scope of Work, or Phase IV Remedy Implementation Plan, should discuss the objectives of the assessment activities and the rationale for the specific approach selected.
In many cases, sampling plans are used to support multiple objectives. If so, the sampling plan should identify and adequately address these different objectives as well as the performance-based standards for sample collection and analysis at 310 CMR 40.0017, including detection limits appropriate for the intended use.

Sampling plans should address the inherent variability associated with sampling environmental media related to the vapor intrusion pathway. This is generally accomplished by collecting an adequate number of samples to characterize that variability. Sampling plans used to evaluate the vapor intrusion pathway should include samples from each of the relevant media, such as groundwater, soil gas and indoor air to the extent necessary. When air sample data is used to evaluate the level of exposure to contamination and risk estimation, the Quality Assurance/Quality Control (QA/QC) for that data must be commensurate with this use. Such QA/QC generally includes laboratory level instrument and method calibration, and, precision, accuracy and sensitivity adequate to support the risk assessment.

The number of samples to be collected depends upon the specific purpose(s) of the sampling project. The most efficient and effective sampling strategy will depend upon whether the goal is to (a) evaluate the vapor intrusion pathway, (b) compare concentrations of Chemicals of Concern (COCs) to typical indoor or outdoor COC concentrations, or (c) estimate exposure point concentrations.

This section focuses primarily on assessment activities conducted to determine whether the vapor intrusion pathway at a disposal site is actually complete and potentially of concern (Section 2.2) and, provides recommendations on conducting the subsequent exposure assessment (Section 2.3) and risk characterization (Section 2.4). Section 2.2 can be used to determine whether additional evaluation is necessary, and also if a CEP is present. Sections 2.3 and 2.4 are focused on assessment activities suitable for risk characterization, such as would be completed as part of Phase II, or in support of Temporary or Permanent Solution Statement submittal. These sections also address considerations for IH evaluations.

Assessment of a vapor intrusion pathway should proceed iteratively as disposal site conditions warrant. This assessment typically includes sampling of groundwater, exterior[1] soil gas, sub-slab soil gas, soil, indoor air and outdoor air.

Direct sampling of indoor air without gathering other disposal site data can result in erroneous conclusions and unnecessary response actions to address conditions unrelated to those regulated by M.G.L. c. 21E and the MCP.

2.1 Conceptual Site Model

The Conceptual Site Model (CSM) provides a useful tool for characterizing and depicting the sources, migration pathways, exposure pathways, and receptors for a specific disposal site, including those relevant to vapor intrusion. It provides a framework for assessing risks from contaminants, controlling or eliminating sources, identifying data gaps and managing uncertainty, developing response action strategies, and determining whether those strategies have been effective in achieving desired endpoints. The MCP provides a CSM definition at 310 CMR 40.0006.

At the point in time at which a vapor intrusion evaluation is initially conducted, the CSM may or may not be fully developed. The CSM available at the time should be used to guide the vapor intrusion evaluation in terms of:

- Potential release sources, including locations and specific OHM used;
- Nature and extent of oil and hazardous materials (OHM) impacts;
- Known or suspected migration pathways;
- Potential sources of vapor intrusion;
- Concentrations and distribution of VOCs in soil and groundwater, to the extent known; and
- Potential indoor air receptors.

The CSM should be continually modified as necessary to incorporate new information from the vapor intrusion evaluation and to guide decision-making throughout the disposal site assessment, risk characterization, and remediation process. The complexity of the CSM is directly related to the complexity of disposal site conditions.

Figure 2-1 shows the examples of the vapor intrusion pathway. It is important for the CSM to describe or illustrate other disposal site conditions surrounding the building(s) of interest to provide the context for vapor intrusion, such as known or potential nearby sources, depth to groundwater, and groundwater flow direction and rate. As a vapor intrusion evaluation progresses, conditions specific to the vapor intrusion pathway should be added to the CSM, including:

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[1] In this document, “exterior soil gas” refers to soil gas collected in open areas, away from buildings. These areas could include locations under parking lots and undeveloped lots. Exterior soil gas should not be used as a substitute for sub-slab soil gas when assessing the groundwater to indoor air pathway.

- Known or potential nearby sources;
- Depth to groundwater and groundwater flow direction;
- Buildings potentially impacted by vapor intrusion;
- Building characteristics, including such aspects as the presence of a crawl space or basement, slab thickness, heating/air conditioning method and use, supplementary ventilation (bay doors, hoods, etc.), drainage control mechanisms (sumps, floor drain, interior or exterior French drains);
- Building use characteristics (e.g. receptors, use of different parts of the building), frequency, and duration of use; and
- Sub-slab soil conditions, including soil type and permeability.

These and other disposal site characteristics important to the assessment and remediation of conditions that result in vapor intrusion are described in Sections 2.2, 2.3, and 3.2.

CSM validation is integral to the disposal site assessment, mitigation and remediation process and should be conducted from the initial disposal site characterization through each data gathering event (both assessment and remedial activities) up to disposal site closure. It should include identification and evaluation of data gaps, further investigation to eliminate significant data gaps, and evaluation of other hypotheses that may be supported by the data.

Each MCP submittal should present the information collected in a manner that demonstrates that the investigative approach was logical and based upon the evolving CSM. CSM discussions should address relevant hypotheses that were explored and ruled out, technical justification for adopting one hypothesis over the other hypotheses, and a statement as to whether or not the objectives of the investigation were achieved.

Further discussion of important components of the CSM is provided in MassDEP guidance, *MCP Representativeness Evaluations and Data Usability Assessments* #WSC-07-350.

2.1.1 Identification of Sources

In order to adequately assess the vapor intrusion pathway, locations of where VOCs were released to the environment must be identified. As defined at 310 CMR 40.0006, a Source of OHM Contamination is a point of discharge of OHM into the environment, or waste deposits, sludges, or impacted soil, sediment or bedrock at or near a point of discharge/deposit of OHM into the environment that is contaminating surrounding environmental media.

These discharge locations are often the location of the highest concentration of contamination in the soil or groundwater. Source identification requires gathering and understanding, to the extent possible, release and relevant disposal site history information, including how the OHM is, or was, used at the source property.

Section 2.2.2.1 identifies a number of typical release locations. Soil, soil gas and groundwater should be sampled at these locations to determine if a release of OHM to the environment has occurred. Soil gas sampling, both from sub-slab and open areas, is a useful supplement to soil sampling efforts. While soil sampling targets discrete locations, exterior soil gas samples obtained from multiple soil gas points can be effective in characterizing contamination over a larger area.

Identification and delineation of sources contributing to the vapor intrusion pathway is critical to effective and long term mitigation of VOC impacts to indoor air. As specified at 310 CMR 40.1003(5)(b), achievement of a Permanent Solution requires that "all Sources of OHM are eliminated, or if they are not eliminated, they are eliminated to the extent feasible and they are controlled … " Locating and delineating Sources of OHM is a necessary first step for demonstrating compliance with the source elimination or control requirement (see also Sections 3.1 and 4.6).

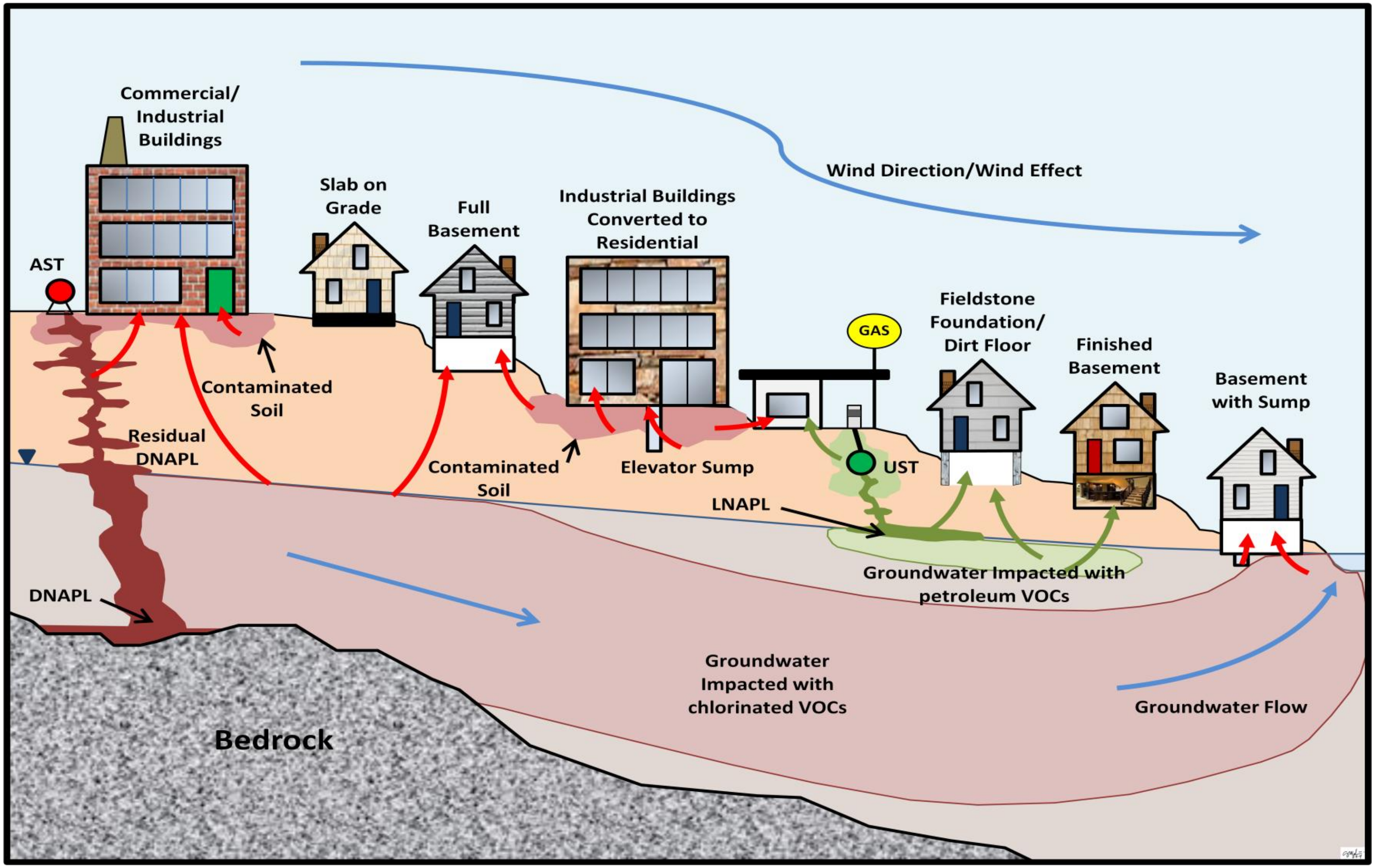
2.2 Vapor Intrusion Pathway Assessment

This section provides guidance on developing appropriate Lines of Evidence for assessing the vapor intrusion pathway for current site use, and how these Lines of Evidence can be used to determine if the pathway is complete and likely to be of concern. As previously discussed, Source of OHM as defined in the MCP includes the point of original discharge or deposit of OHM in the environment. These Sources may in turn contaminate surrounding environmental media via the processes of dissolution or volatilization, resulting in the migration of OHM. Where such migration results in VOCs attributable to the source entering into the indoor air of an occupied building, or a building where there are specific plans for occupation, the vapor intrusion pathway is considered complete.

MassDEP recommends a Lines of Evidence approach for determining if the vapor intrusion pathway is complete and likely to be of concern. In some cases, a complete pathway is sufficient to warrant further action, such as when a CEP is identified. In other cases, risk-based screening values can be used to determine whether the pathway is likely to be of sufficient concern to warrant further action.

The specific Lines of Evidence and the types and amount of data required to draw conclusions regarding a potential vapor intrusion pathway will vary depending upon site conditions and setting. Sampling plans should consider the CSM, including addressing data gaps relevant to evaluating the potential pathway.

Figure 2-1: Examples of the Vapor Intrusion Pathway



MassDEP recommends considering a number of distinct Lines of Evidence for determining whether or not a vapor intrusion pathway is complete and likely to be of concern at a disposal site, including those listed below.

These Lines of Evidence are developed through site observations as well as sampling activities. The Lines of Evidence that are relevant to evaluating a potential pathway and supporting a conclusion as to whether it is complete and of concern will depend on site-specific characteristics. Factors that might influence vapor intrusion, such as specific building characteristics and sub-slab soil type, may be relevant to vapor intrusion assessments, but are not considered distinct Lines of Evidence.

Lines of Evidence for the Vapor Intrusion Pathway

- Concentrations of VOCs in groundwater, soil, and sub-slab soil gas
- Concentrations of VOCs in indoor air that are Contaminants of Concern
- The presence of indoor sources
- The presence of outdoor sources
- The presence of LNAPL or DNAPL
- The presence of preferential pathways for vapors

Individual Lines of Evidence are discussed in more detail below, including where to sample media (location), the length of time to collect samples (collection time), and how often to collect samples (collection frequency) for use as Lines of Evidence. The discussion also includes how to apply such sampling data in a Lines of Evidence evaluation.

2.2.1 Groundwater

Groundwater depth and analytical data is often one of the early indicators of potential vapor intrusion, based on a comparison to MCP Method 1 GW-2 Standards established at 310 CMR 40.0974, as discussed in Section 1. As a result, it is an important Line of Evidence to be considered in a vapor intrusion evaluation. However, a vapor intrusion pathway should not be ruled out using groundwater data alone without the consideration of the factors identified in Section 1.3.

2.2.1.1 Groundwater Sampling Considerations

Groundwater sampling data used in a Lines of Evidence evaluation should be representative of stable site conditions and provide a conservative indication of contaminant concentrations near or under the building of interest, as these groundwater data are most suitable for determining whether the vapor intrusion pathway is likely to be complete.

Sampling locations should be selected based on knowledge of disposal site-specific conditions, identify the extent of groundwater contamination relative to occupied buildings, and consider depth, proximity to occupied buildings, and distance to the source area. For determining the extent of contamination, the horizontal distance of sampling locations from the source area is a key consideration. To better define contaminant concentrations, the density of sampling locations should be greater in potential source area(s), in hot spots, and in close proximity to buildings.

> Groundwater sampling should determine the horizontal and vertical extent of contamination and identify areas where groundwater concentrations exceed the Method 1 GW-2 Standards.

Groundwater samples used to evaluate the vapor intrusion pathway should be collected at or near the water table, as these provide more representative data for evaluation of vapor intrusion than deeper samples. Water table samples, however, can be diluted by heavy precipitation and should not be collected immediately after heavy rain, or snow melt.

Use of groundwater samples obtained at or near the water table to evaluate the vapor intrusion pathway does not mean that deeper groundwater contaminant levels should be ignored when evaluating the vapor intrusion pathway. Samples obtained from deeper groundwater intervals can provide valuable information regarding the extent of contamination and the ability to evaluate the potential for contaminants to migrate vertically and/or horizontally. Such migration can contribute to fluctuating VOC concentrations in the more surficial groundwater and/or a change in soil vapor levels under buildings. Therefore, contaminant levels that greatly exceed the applicable GW-2 Standard in deeper groundwater might indicate the need for sub-slab soil gas sampling even in cases where more surficial groundwater is not very contaminated.

Characterization of contamination in deeper groundwater is also important for the characterization of nature and extent of OHM required in a Phase II Comprehensive Site Assessment and as part of the information required to support a Permanent or Temporary Solution. Such information can be used in combination with groundwater flow patterns to identify areas where deeper contamination migrates to more surficial contamination. Full characterization of nature and extent of OHM will also allow for a more effective remedial approach.

> Uncertainty about groundwater contaminant concentrations can be reduced by sufficient sampling frequency over an extended period of time.

Uncertainty about groundwater concentration estimates can be reduced by sufficient sampling frequency and duration. The collection of multiple samples over time is more important if the data is to be used to estimate exposure point concentrations than if it will be used to estimate the extent of contamination. Temporal data are needed to detect increasing or decreasing trends and potential seasonal variations in the contaminant concentrations at various sampling locations within the contaminated area. In addition to evaluating a potential vapor intrusion pathway, temporal groundwater data is relevant to meeting the migration control requirement (310 CMR 40.1003(6)) for a Permanent Solution, i.e., demonstrating that plumes of dissolved OHM in groundwater and vapor-phase OHM in the vadose zone are stable or contracting (see also Section 4.6)***.***

Multi-year sampling programs may be necessary to distinguish seasonal concentration variation from long-term trends and to evaluate whether seasonal fluctuations in groundwater concentrations and elevations need to be considered when determining worst-case conditions for vapor intrusion. Composite sampling for the purposes of evaluating vapor intrusion is not recommended.

2.2.1.2 Groundwater Data Evaluation Considerations

MCP GW-2 Standards were developed using the mathematical screening model developed by Johnson and Ettinger (1991). MassDEP considers the use of this model appropriate for the development of GW-2 Standards because generic, conservative assumptions were used by MassDEP as inputs for the model to cover a wide variety of buildings. Therefore, barring certain disposal site-specific conditions, GW-2 Standards can be used to evaluate groundwater conditions in a Lines of Evidence evaluation, as identified in Table 2-2 and 2-3.

When interpreting groundwater data for petroleum-related compounds, it is important to consider biodegradation within the vadose zone. MassDEP has incorporated this consideration into the development of the GW-2 Standards for petroleum fractions and BTEX (benzene, toluene, ethylbenzene, and xylenes). MassDEP recognizes that there may be key differences in evaluating potential vapor intrusion for petroleum compounds and chlorinated solvents and these differences are addressed in more detail in Section 2.2.3.

2.2.2 Soil, Exterior Soil Gas and Sub-Slab Soil Gas

Soil, exterior soil gas or sub-slab soil gas data are also important Lines of Evidence to be considered in a vapor intrusion evaluation. Soil sub-slab soil gas immediately under the slab of a building is the media in direct contact with a building and may best reflect the potential for vapor intrusion.

2.2.2.1 Soil, Exterior Soil Gas and Sub-Slab Soil Gas Sampling Considerations

VOC contamination of soil can result in vapor intrusion even when groundwater is not significantly contaminated. However, adequately assessing the nature (including location and concentration) and extent of soil contamination under or near a building can be difficult. Difficulty arises from the heterogeneous nature of soil and the variability often observed in contaminant concentrations in soil, even in samples taken in close proximity, as well as the challenge of sampling soil under buildings. For example, if contaminant concentrations in soil samples are low or not detected, but elevated concentrations of a contaminant are found within indoor air, it is possible that localized soil contamination under the building was missed and that additional sampling is warranted. Grid sampling should be considered at locations with a history of volatile OHM use where there is an incomplete history of operations; spills can happen anywhere and grid sampling can increase certainty that source areas have been found.

Data from soil sampling is best used to confirm that contamination is present in the subsurface rather than rule out the vapor intrusion pathway. Unless the point of release of VOCs can be identified, accessed, and adequately sampled, soil data is often not a conclusive Line of Evidence for the vapor intrusion pathway.

As discussed above, a localized release to soil beneath a building foundation can be challenging to locate or verify. If the disposal site history indicates that the soil may be impacted, soil samples can be collected to identify possible impacts and extent, but sub-slab soil gas samples should be collected to assess the soil-to-indoor air pathway.

Soil sampling should incorporate historical information documenting the location of machinery, chemical storage areas, etc. Sampling locations to consider for investigation include, but are not limited to:

- current and former dry cleaning machine/degreaser locations,
- vent locations, including downspouts if the machines vent to the roof,
- floor drains,
- dry wells,
- sewer and septic tank/leachfield lines, laterals, cleanouts, and connections,
- any current or former solvent/OHM storage areas, including underground and above-ground storage tanks,
- service doors, loading docks or other solvent delivery locations,
- the location of any current or former solvent distillation or separator units, and
- current or former dumpster locations.

The number of soil samples obtained will be dependent upon the historical information related to potential release areas, such as those listed above.

Exterior soil gas samples can be useful in locating and defining areas of soil contamination that have not been identified by discrete soil sample data and to identify migration of contaminated soil gas along preferential pathways and soil gas migration through the vadose zone. It is important to note that exterior soil gas levels should not be used to assess soil gas concentrations for the purpose of evaluating potential vapor intrusion; sub-slab soil gas should be used for that evaluation.

Soil gas concentrations are often a better indicator of soil contamination than discrete soil sample data because soil gas samples reflect conditions over a larger area.

Sub-slab soil gas concentrations are often a better indicator of vapor intrusion potential than soil data because they provide measurements of COCs in the same phase (i.e., vapor) as that potentially present in indoor air when vapor intrusion is occurring. Nevertheless, a large spatial heterogeneity of contaminant concentrations in soil gas can be found under the slab, depending on the nature of the source, the building and contaminant migration. This variability should be taken into account when developing sampling plans for areas around suspected soil contamination and evaluating sub-slab soil gas results. The distribution of VOCs in soil gas associated with a contaminated soil tends to be more localized than the distribution of VOCs in soil gas from contaminated groundwater. Therefore, more sub-slab soil gas sampling locations may be needed to define a potential soil source area or migration pathway.

MassDEP recommends the use of evacuated canisters for the collection of sub-slab soil gas samples. The analytical method selected should be based on historical disposal site information and information on substances detected in other environmental media at the disposal site, but will generally be MassDEP APH and/or TO-15 CAM methods. Sub-slab soil gas analyte lists should not be limited because soil gas can sometimes detect VOCs missed by soil and groundwater sampling programs. The analyte list selected should be documented and justified based on this information. Details on soil gas sampling and analysis are presented in Appendix III.

It is not necessary to obtain time-weighted samples of sub-slab soil gas. However, care should be exercised to avoid sampling at too high a rate or via too high a vacuum, as that can create short-circuiting (Appendix III).

As stated previously, MassDEP recommends collecting sub-slab soil gas samples from the airspace immediately below a building's basement or slab. Soil gas directly beneath a slab or basement is most likely to be representative of what may be entering the building. If samples cannot be obtained directly beneath the slab due to access issues, soil gas samples obtained adjacent to the building and under pavement can be used to estimate conditions beneath the building. Sampling adjacent to the building should be performed at a depth below the slab and at an angle such the soil gas under the building footprint is obtained. It should be noted that collecting data from locations adjacent to the building of interest adds an additional degree of uncertainty to the vapor intrusion assessment at the site.

Sub-slab soil gas surveys should address the entire building footprint because soil gas concentrations beneath slabs can vary from point to point. At properties with past or current VOC use, sub-slab soil gas samples should be collected from potential source locations identified above. Two to four probes are recommended for a typical single family home; more may be needed in larger buildings or if soil or groundwater contamination is high or variable. At least one of the sub-slab soil gas samples should be obtained near the center of the building footprint to offset any type of "edge effect."

MassDEP recommends a minimum of one to two sub-slab soil gas sampling events. One sample might be sufficient to determine that the pathway is complete, but two or more samples would be needed to demonstrate that a vapor intrusion pathway is unlikely to be of concern. When conducting two rounds of sub-slab soil gas sampling, it is recommended that the sampling events be conducted over two different seasons and the potential influence of the heating season, changes in groundwater elevation and contaminant concentration fluctuations be considered when determining the most appropriate sampling times. More sampling events may be warranted if sub-slab soil gas concentrations are highly variable.

2.2.2.2 Soil, Exterior and Sub-Slab Soil Gas Data Evaluation Considerations

Sub-slab Soil Gas Screening Values provided in Appendix II are intended to be used in conjunction with soil gas data obtained within a few inches beneath the slab.

MassDEP has developed screening criteria for sub-slab soil gas results that can be used in a Lines of Evidence evaluation of vapor intrusion. These screening criteria are based on the indoor air Threshold Values discussed above and a generic sub-slab soil gas-to-indoor air dilution factor of 70. This generic dilution factor corresponds to the inverse of the 80th percentile of the sub-slab soil gas attenuation factors in the U.S. EPA (2008) database (Figure 11, "*U.S. EPA's Vapor Intrusion Database: Preliminary Evaluation of Attenuation Factors*", Draft, Office of Solid Waste, U.S. EPA, March 4, 2008). These soil gas screening values are provided in Appendix II.

In the absence of preferential migration pathways, representative sub-slab soil gas concentrations less than the soil gas screening values indicate that the vapor intrusion pathway would not be of concern under current disposal site conditions and use providing a good Conceptual Site Model has been developed with a sufficient amount of temporal sampling events.

Because total organic vapor instruments (PIDs and FIDs) are not sufficiently chemical-specific to assess vapor intrusion with an appropriate degree of confidence, these instruments should not be used to evaluate sub-slab soil gas concentrations. Sub-slab soil gas concentrations for petroleum compounds should be analyzed using MassDEP APH and/or TO-15 CAM methods and these concentrations should be compared to the soil gas screening concentrations in Appendix II (Appendix II values supersede the soil gas screening values in the MassDEP's Policy #WSC-02-411, *Implementation of the MADEP VPH/EPH Approach* (2002)). Although these instruments should not be used to assess the sub-slab soil gas concentrations, they may be useful as a screening tool to potentially locate preferential pathways and delineate source areas.

2.2.3 Special Considerations for the Assessment of Petroleum Vapor Intrusion from Discrete, Well-defined and Stable Petroleum Sources

MassDEP is seeking feedback: A summary of USEPA's Inclusion Distance Approach for screening out vapor intrusion concerns related to petroleum disposal sites has been included in this section of the public comment draft for the purpose of soliciting review and comment on its appropriate application to Massachusetts sites. MassDEP is interested in hearing from LSPs and other environmental professionals who have experience applying the Inclusion Distance Approach or other petroleum vapor intrusion screening approaches to better our understanding of their strengths and weaknesses and how they may be used in a vapor intrusion pathway assessment.

This section provides an overview of petroleum vapor intrusion screening approaches; readers should refer to the references in this section for a more

Typical soil conditions in Massachusetts are sufficient to support a viable microbiological community. Under normal aerobic vadose zone conditions petroleum hydrocarbons (PHCs) in soil gas are readily degraded to carbon dioxide and water by native microbiota. For disposal sites with discrete, well-defined petroleum sources, the Inclusion Distance Approach or IDA (USEPA 2013) has been presented as a tool to delineate between disposal sites that require additional data collection and those where vapor intrusion is very unlikely to occur and no further investigation of vapor intrusion may be required.

USEPA's Inclusion Distance Approach includes:

1. Vertical Distance Analysis - an analysis of the vertical thickness of biologically active clean soil required for benzene concentrations to attenuate to < 100 µg/m^3.
2. Lateral Distance Analysis - an analysis of the lateral thickness of biologically active clean soil required for benzene concentrations to attenuate to < 100 µg/m^3.

** 6 feet for dissolved PHC sources to attenuate; 15 feet for LNAPL PHC sources to attenuate.*

The basis of the IDA is the understanding that PHCs are readily degraded in the vadose zone under normal aerobic conditions. The IDA is an expansion of the theory and data analysis put forth in the Clean Soil method (Davis 2009). Davis found that if 5 feet of clean soil overlie dissolved sources where benzene in groundwater is less than 1,000 µg/L and total petroleum hydrocarbon (TPH) is less than 10,000 µg/L, a vapor-intrusion investigation is not necessary. Davis also found that most of the greater than 200 sampling events conducted at 53 locations analyzed as part of his study exhibited vapor attenuation factors greater than a 10,000-fold contaminant reduction. Abreu et al.

conclude that there is an approximate three orders-of-magnitude reduction in the attenuation factor for a source-foundation separation distance of 5 feet (Abreu 2009). The most common cause of a complete petroleum vapor intrusion (PVI) pathway is when high concentrations of dissolved contaminants and/or LNAPL are in direct contact with building structures such as sumps, basements or elevator pits (McHugh 2010).

Inclusion Distance Approach

The IDA is based on the observed empirical attenuation of PHCs over a distance beyond which there is limited potential for a complete PVI pathway (USEPA 2013). The IDA consists of an analysis of the thickness of biologically active clean soil required for the soil vapor benzene concentration to attenuate to below a defined threshold. USEPA's analysis of the IDA was based on a soil gas concentration of 100 µg/m^3 benzene.

Benzene is considered the primary contaminant of concern for PHCs because of its volatility, toxicity, mass fraction in common fuels (gasoline and diesel), and fate and transport in the unsaturated zone (Lahvis 2013). The vertical screening distances derived from benzene data were greater than for other petroleum hydrocarbons and thus are assumed to be conservative for establishing screening distances for dissolved-phase and LNAPL sources which contain mixtures of hydrocarbons. This position is supported by USEPA who conclude that benzene is the risk driver for the disposal sites evaluated for PVI (USEPA 2013).

In an effort to assess the suitability of this approach, USEPA compiled an empirical database from 74 petroleum-contaminated sites across the U.S., Canada and Australia. The majority of these disposal sites were underground storage tank (UST) sites. USEPA compiled analytical data for soil gas, soil and groundwater as well as supporting data to draw conclusions about the behavior of petroleum vapors in the environment. For the IDA, the 95th percentile vertical clean soil thickness for benzene vapor attenuation to less than 100 µg/m^3 is approximately 5.4 feet for dissolved-phase PHCs (USEPA 2013). Because of the difficulty in accurately measuring precise distances to contamination under field conditions, USEPA rounded the 5.4 foot value to 6 feet of clean soil. For petroleum sites with LNAPL, approximately 95 percent of the benzene soil vapor concentrations decreased to less than 100 µg/m^3, and 93 percent of the concentrations decreased to less than 50 µg/m^3 at a contamination source-to-building separation distance of 13.5 feet. USEPA rounded this value to 15 feet.

The IDA only applies to stable, discrete petroleum sources with an oxygenated vadose zone that are properly characterized. The full extent and location of contamination must be established so that lateral and vertical separation distances can be accurately determined. The IDA is not meant to be used as a single decision point to conclude no further action is necessary, rather it is meant to be used in the multiple lines of evidence approach.

Petroleum Vapor Biodegradation

With aerobic biodegradation in unsaturated soils, PHCs are degraded, oxygen is consumed, and carbon dioxide is produced (**Figure 2-2**). Under some conditions, aerobic biodegradation of petroleum compounds can have half-lives as short as hours or days (DeVaull 2007). However, if PHC concentrations are high enough, available oxygen may be depleted, which in turn limits aerobic biodegradation.

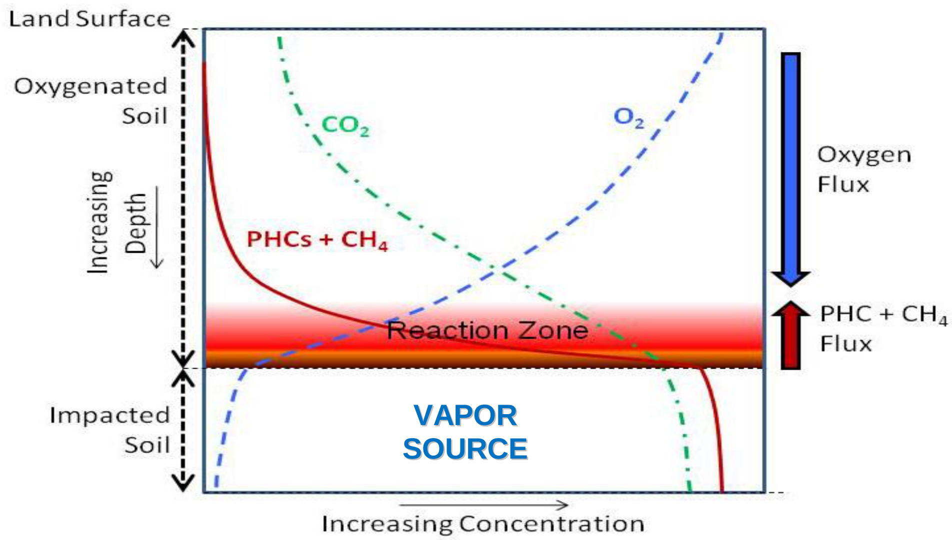


Figure 2-2: Typical vertical concentration profile in the unsaturated zone for PHCs, carbon dioxide, and oxygen (modified from USEPA 2013).

Aerobic biodegradation of PHCs leads to a characteristic vertical concentration profile (Figure 2-2) in the unsaturated zone. The vertical profile shows oxygen concentrations decreasing with depth from the surface due to microbial growth and metabolism. Conversely PHCs, methane (from anaerobic biodegradation) and carbon dioxide concentrations increase with depth (USEPA 2012) as you approach the source of vapor contamination. Vertical soil gas profiles can be acquired by collecting soil gas data at different depths. This data is useful for defining the biologically active zone, demonstrating biodegradation and the decrease in petroleum soil gas concentrations. In some cases, soil gas profiles above petroleum-impacted soils and groundwater show significant attenuation across distances of less than one meter (Lundegard 2008).

Biodegradation rates in the vadose zone are stoichiometrically related to the flux of oxygen, carbon dioxide, and methane. Oxygen concentrations greater than 1percent by volume are required for aerobic biodegradation to occur (Abreu 2006). By measuring soil gas vapor profiles, one can determine if and where subsurface oxygen levels may be too low to support aerobic biodegradation. In general, hydrocarbon vapor attenuation is predicted to increase exponentially with increasing distance from the source (DeVaull 2007). Because the soil gas profile provides important information about the biodegradation/attenuation of petroleum fractions, adequate vertical soil gas profile data is necessary to assess biodegradation/attenuation potential.

Conditions that may preclude the use of IDA include:

- large scale petroleum operations (e.g., fuel terminals)
- presence of > 10% gasoline additives (e.g., ethanol) which can result in methane production and reduce oxygen availability
- presence of chlorinated compounds
- presence of lead scavengers (e.g., ethylene dibromide) presence of preferential pathways
- high organic soil content (e.g., peat) which can reduce oxygen availability
- exceptionally dry soils (≤ 2% soil moisture) which can limit biological activity
- extensive impervious surfaces resulting in low soil moisture (while conditions vary from site to site, there can be reduced oxygen availability below hard surfaces (USEPA 2013))
- reduced oxygen flux in certain geologic conditions (e.g., wet surface clays)
- contaminant migration through fractured rock (there is limited PVI data for these site conditions thereby increasing the uncertainty of the suitability of the IDA)
- coarse sand and gravel with a low content of silt, clay, or organic matter
- consolidated rock with solution channels (i.e., karst).

Steps that would be required to develop the IDA include, but are not limited to:

1. A comprehensive disposal site investigation to identify the nature and extent of contamination.
2. A review of disposal site conditions to ensure no exclusionary conditions exist.
3. Sufficient data collection to support conclusion that source is discrete, stable and is comprised of PHCs only.
4. Development of the Conceptual Site Model.
5. Adequate vertical soil gas profile data to characterize the biodegradation reaction zone, including evidence of an oxygenated vadose zone.

2.2.4 Indoor Air Sampling Considerations

Indoor air measurements as a Line of Evidence should be given substantial weight when evaluating the vapor intrusion pathway, since they provide a direct measure of contaminant concentrations in indoor air under current conditions. If disposal site-related contaminants (present in groundwater, soil, exterior soil gas and/or sub-slab soil gas) are not detected in indoor air over multiple rounds of testing, there is not likely to be a complete vapor intrusion pathway. If contaminants detected in the sub-surface are detected in indoor air, it may be reasonable to conclude that the vapor intrusion pathway is complete.

2.2.4.1 Indoor Air Data Evaluation Considerations

Indoor air analytical data relevant to evaluating whether the vapor intrusion pathway is complete and likely to be of concern should be representative of site conditions. In addition, it should generally be biased towards those locations most likely to be impacted by VOCs attributable to the disposal site, such as basements, crawlspaces, or areas closest to potential source(s) and migration pathways, and collected when conditions are most conducive to vapor intrusion based on the CSM. It may be difficult to rule out the pathway without such data, especially if other Lines of Evidence suggest the potential for vapor intrusion.

> Items suspected of containing chemicals of concern should be removed prior to the sampling of indoor air. Failure to take such precautionary measures could result in unnecessary, additional sampling efforts.

The consideration of other sources not attributable to the disposal site (a.k.a. confounding sources) that may be contributing VOCs to indoor air is critical to the evaluation of this Line of Evidence. When sampling indoor air, efforts should be made to eliminate confounding sources of contamination within or near the building. These efforts include:

- Not conducting indoor air sampling while contaminant-generating activities are occurring, especially if the same contaminants will be generated by those activities as the disposal site-related contaminants. For example, collect indoor air samples on days when a nearby dry cleaner is not using the dry cleaning machines or when adjacent gas stations are not being re-fueled. Smoking and use of sprays, solvents, paints, etc. should be noted and, if practicable, suspended 48 hours prior to sampling.
- Removing items that might contain disposal site-related compounds. Examples of these sources include recently dry-cleaned clothing, solvents or other similar products. Products that contain VOCs should also be removed prior to sampling, preferably at least 48 hours.
- If outdoor air is a suspected source of contamination, collecting outdoor air samples, if possible, on a day that outdoor sources are not emitting contaminants. For example, when investigating vapor intrusion by tetrachloroethylene (PCE), air samples should be collected during a time period when nearby dry cleaner(s) are closed.

The above recommendations are specific to a vapor intrusion evaluation using Lines of Evidence. Indoor air sampling to establish exposure point concentrations should be focused on characterizing representative, current exposure conditions (see Section 2.3.3.

Evacuated canisters are recommended for the collection of indoor air samples for the analysis of petroleum-based and chlorinated organic contaminants encountered at most disposal sites. The analytical method selected should be based on a thorough disposal site history relative to the use of OHM and information on contaminants detected in other site media. Generally MassDEP's Air-Phase Petroleum Hydrocarbons (APH) (WSC-CAM-IX A) and/or Volatile Organic Compounds in Air Samples (TO-15) (WSC-CAM-IX B) air methods should be used.

While analyzing the indoor air for the full method target analyte list has the benefit of providing building occupants with information regarding their general exposure to chemicals in the indoor air, the indoor air analyte list can be limited to the group of chemicals known to be or likely to be disposal site-related based on the site history and the documented presence (or absence) of these contaminants as confirmed through robust sampling and analysis of other site media (groundwater, soil, and soil gas). For example, if PCE is the primary contaminant of concern, you may limit your analyte list to the chlorinated solvents. Since many other chlorinated solvents are often associated with PCE as either breakdown products or present as part of the manufacturing process, PCE should not be selected as the only analyte. The justification for the selected analyte list should be documented in the applicable sampling plan. Additional guidance on conducting indoor air sampling and analysis are presented in Appendix III.

The collection of indoor air samples should occur while people are using the building for its intended purpose and the duration of the sampling should be based on collecting samples that are representative of the building residents'/occupants' exposure. For residential buildings, MassDEP recommends a 24-hour sampling time period. A 24-hour sample captures the fluctuations in indoor air concentrations due to changing conditions throughout the day and night. Longer sampling periods generally provide more representative exposure data, but are sometimes not practical. For commercial buildings, MassDEP recommends an 8-hour sampling period during regular business hours, except where regular business activities would potentially contribute VOCs to the indoor air from confounding sources.

If both sub-slab and indoor air sampling is planned at a building, the sub-slab samples should be obtained immediately following the collection of indoor air samples. Sampling sub-slab soil gas immediately after indoor air will avoid potential cross-contamination from opening the sub-slab sampling probes prior to indoor air sampling and, provide indoor air and sub-slab soil gas samples that are comparable because they were obtained within a similar timeframe and under similar site conditions.

MassDEP recommends multiple rounds of indoor air sampling across several seasons in order to address the considerable temporal variability associated with vapor intrusion. At least one sampling round conducted during winter is recommended, representative of presumed worst case conditions for vapor intrusion (MassDEP recommends that worse-case conditions be identified when developing the CSM such that the greatest number of samples is collected during these conditions). During winter, windows are usually closed and heating systems are more active, resulting in conditions conducive for vapor intrusion. MassDEP also recommends sampling when the groundwater elevation is high and during a low pressure event. **Table 2-1** presents site conditions that are most likely to represent worse case scenarios.

Table 2-1: Conditions for Sampling Indoor Air

Parameter	Most Conservative (Worst Case) Conditions	Least Conservative Conditions
Season	Late Winter/Early Spring	Summer
Temperature	Indoor Temp. 10^{o} F > Outdoor Temp.	Indoor Temp. < Outdoor Temp.
Wind	Steady > ~ 5 mph	Calm
Soil	Saturated with Rain or Frozen	Dry
Groundwater	High Water Table	Low Water Table
Barometric Pressure	Decreasing	Increasing (3 days before)
Doors/Windows	Closed	Open
Heating System	Operating	Off

MassDEP recommends greater sampling frequency for more sensitive receptors. For daycares, schools, residences, or other locations where sensitive receptors may be present, MassDEP recommends that at least two to four indoor air sampling rounds be conducted, depending on the degree of subsurface contamination, before determining that the vapor intrusion pathway does not exist.

For commercial and industrial buildings where sensitive receptors are not present, two indoor air sampling rounds are recommended to provide sufficient information to make decisions regarding the presence of the vapor intrusion pathway. In order to obtain an estimate of long-term conditions (chronic exposure), the sampling rounds should be obtained over at least two different seasons, one of which is winter.

MassDEP recommends that both the occupied (or living) areas as well as basement areas be sampled to assess concentrations and the level of risk in different exposure locations. In multi-unit buildings, representative units can be selected for sampling based on location of the source(s) to indoor air and any preferential migration pathways. When sampling for a Lines of Evidence evaluation or an exposure assessment, samplers should be situated in the breathing zone, approximately 3 to 5 feet off the ground (and lower if the receptors of concern are children, as for a residence, school or daycare/childcare center[2]). Samples should be taken in a location where there is good air circulation, such as in the center of the room. Manipulation of airflow should not be

[2] Sampling canisters should be placed lower as long as they can be kept out of reach of children.

done prior to sampling. Samplers should not be placed adjacent to windows or exterior walls where drafts may be present.

2.2.4.2 Indoor Air Evaluation Considerations

The evaluation of indoor air data can be complex due to the many factors that can affect vapor intrusion and indoor air quality. The detection of disposal site-related OHM in indoor air is an indicator that a complete vapor intrusion pathway may exist. In addition, the presence of breakdown products of OHM known to be disposal site-related in indoor air may also be indicative of a complete vapor intrusion pathway. However, the absence of breakdown products should not be used to rule out the pathway. In theory, dilution factors for breakdown products should be the same as those for the parent compound. In practice, however, the spatial variation in sub-slab parent/daughter concentrations makes the evaluation of breakdown products as a Line of Evidence difficult.

> The absence of breakdown products and/or disposal site-related VOC concentration gradients in building air should not be used alone to rule out the vapor intrusion pathway.

Comparisons of concentrations of disposal site-related contaminants between a basement and the first floor can be misleading. Higher concentrations of a disposal site-related chemical in a basement compared to the first floor suggest that vapor intrusion may be occurring. However, the absence of such a concentration gradient should not be used to rule out the pathway before considering possible preferential pathways, and other factors that can influence air movement within a building (such as the heating venting and air conditioning (HVAC) system, ventilation fans, etc.), and result in higher COC concentrations on upper levels of a building. This illustrates why developing empirical Lines of Evidence and using the CSM is particularly important in assessing the vapor intrusion pathway.

To simplify the process of evaluating whether the vapor intrusion pathway is complete and likely to be of concern, MassDEP has developed Residential and Commercial/Industrial Threshold Values (TVs). The derivation of the TVs is outlined in Appendix I. TVs can be used as one of the Lines of Evidence to evaluate the vapor intrusion pathway.

Residential Threshold Values (TV_r), based on indoor air data from residences unaffected by vapor intrusion provided in MassDEP's technical update titled *Residential Typical Indoor Air Concentrations* (2008), and MCP risk management criteria, are intended to expedite the evaluation of indoor air data collected as part of MCP response actions in residential settings. It can generally be concluded that representative residential indoor air samples with contaminant concentrations less than their TV_r indicate that the vapor intrusion pathway is unlikely to be of concern under current site conditions and use.

The Commercial/Industrial Threshold Values ($TV_{c/i}$) are largely risk-based using typical exposure scenarios for commercial/industrial settings. Similar to residential threshold values, it can generally be concluded that representative indoor air samples with contaminant concentrations in commercial/industrial settings less than their $TV_{c/I}$ indicate that that the vapor intrusion pathway is unlikely to be of concern under current site conditions and use.

If VOC concentrations in the indoor air exceed the applicable TVs, then this Line of Evidence suggests that the pathway may be complete and of concern. Any investigation which concludes that indoor air VOC concentrations greater than the TVs are not from vapor intrusion should be technically justified using additional Lines of Evidence that demonstrate that indoor air contamination is not disposal site-related. Such Lines of Evidence may include a comparison of indoor air concentrations to outdoor (ambient) air concentrations to determine whether indoor air concentrations may be resulting from exchange with outdoor air rather than vapor intrusion. The identification of indoor sources of the specific contaminants of concern (such as household products) may also be a relevant Line of Evidence and should be appropriately evaluated.

2.2.4.3 Household Products and Building Materials

Household products used and/or stored in a residence that contain VOCs are relatively common sources of indoor air contaminants. Many of these same products are also used in office and commercial and industrial buildings. A list of household products and activities that potentially release volatile chemicals to the indoor air can be found at http://householdproducts.nlm.nih.gov/. Additionally, materials used in building construction can be a source of indoor air contamination. If a building material is suspected of being a source of VOCs in indoor air, the chemical constituents should be confirmed using documentation such as Safety Data Sheets. Non-disposal site related VOCs in indoor air from household products or building materials can complicate an evaluation of whether a vapor intrusion pathway is present and therefore are often referred to as “confounding sources.”

Surveying and documenting items that could contain VOCs, is an essential part of an indoor air sampling program. To the extent possible, items that contain the same VOCs that are contaminants of concern at the disposal site should be removed several days before sampling the indoor air.

In some cases, indoor air may be affected by a site-specific indoor air source with a contaminant that is not referenced in the Typical Indoor Air Concentrations. Such a source should be documented and quantified to the extent possible to support conclusions that the contaminant(s) in indoor air are not disposal site-related.

2.2.5 Outdoor Air

Outdoor air can influence the concentrations of contaminants in indoor air. The consideration of ambient air concentrations as a Line of Evidence is recommended when indoor air VOC concentrations are being evaluated to determine whether the pathway is complete and likely to be of concern.

2.2.5.1 Outdoor Air Sampling Considerations

Outdoor sources of pollution can affect indoor air quality due to the exchange of outdoor and indoor air in buildings through natural ventilation, mechanical ventilation or infiltration. Ambient air sampling for the purposes of a Lines of Evidence evaluation is useful, particularly if an outdoor source of disposal site-related chemicals is known or suspected. While sampling near any such outdoor sources may provide useful information, concentrations in close proximity to the building under investigation are most relevant to a Lines of Evidence evaluation.

> MassDEP recommends at least one outdoor air sample be obtained at the time and for the same duration as each indoor air sampling event to determine if outdoor sources of VOCs exist until it can be technically justified that outdoor air samples are not necessary.

Outdoor air samples should be collected and analyzed by the same method as the indoor air samples. Details on outdoor air sampling and analysis are presented in Appendix III. If sufficient outdoor air sampling results indicate that there is not an outdoor source of COCs, further outdoor sampling is not necessary.

Assessing spatial variability in outdoor air is difficult. Considerations for outdoor air sampling should include potential sources of VOCs that may affect outdoor air quality (e.g., automobiles, lawn mowers, oil storage tanks, gasoline stations, industrial facilities). If possible, outdoor activities that may contribute to VOCs in the outdoor air (lawn mowing, painting, asphalting, etc.) should be suspended during sampling.

2.2.5.2 Outdoor Air Data Evaluation Considerations

If indoor air concentrations of disposal site-related contaminants are clearly consistent with outdoor air concentrations of the same contaminants, then it is possible that the indoor air contamination is not disposal site-related. Consideration should be given to whether or not the activities that contribute to the confounding outdoor air sources were on-going or in operation during the sampling event. If the outdoor air source activities were suspended during sampling, then the indoor air contamination may be disposal site-related. Potential outdoor air source conditions should be documented such that the appropriate conclusions may be drawn.

> If ambient air has been impacted by releases related to the disposal site, resulting in impacts to indoor air from the ambient air, these impacts warrant response actions under the MCP.

There may be disposal site-related VOC contamination that is affecting the indoor air via the ambient air. Examples include recent VOC releases to soil or pavement, and VOC-contaminated soil piles. Such contamination warrants response actions to address the impact to indoor air and can confound the evaluation of potential vapor intrusion from the subsurface environment. Therefore, to the extent possible, measures to mitigate disposal site conditions that are contaminating or could potentially contaminate ambient air should be taken prior to conducting a vapor intrusion pathway evaluation.

2.2.6 Non-Aqueous Phase Liquids

The presence of volatile Light Non-Aqueous Phase Liquids (LNAPL) could represent a significant source of vapors to indoor air, which may not be reflected in dissolved phase OHM in groundwater and/or OHM in soil data. The interpretation of Lines of Evidence should separately consider the presence of LNAPL, even when the concentrations of VOCs in groundwater and/or soil data suggest that vapor intrusion is unlikely to be a pathway of concern.

Volatile LNAPL includes gasoline, petroleum napthas, mineral spirits, kerosene, jet fuels, any petroleum mixture where more than 25 percent of component hydrocarbons (by mass) have a boiling point below 218ºC (424ºF), and any single component (or predominantly single-component) LNAPL with a boiling point below 218ºC. Diesel fuels, #2 fuel oils, heavier fuels oils (#3 - #6), waste oils, and lubrication oils are not considered volatile LNAPL.

Where other sources have been ruled out, the presence of Dense Non-Aqueous Phase Liquids (DNAPL) is generally indicated by persistently high dissolved VOC concentrations in groundwater over time. The presence of DNAPL can result unpredictable fluctuations in groundwater contaminant concentrations and in greater uncertainty when characterizing groundwater plumes and concentration trends. This unpredictability should be reflected in sampling plans and accounted for in the CSM.

Pursuant to 310 CMR 40.1003(7), a Permanent or Temporary Solution shall not be achieved at a disposal site where NAPL is or was visibly present at levels requiring notification under the provisions of 310 CMR 40.0300 unless and until response actions are taken to adequately assess the nature, extent, and mobility of the NAPL, and, where necessary, remedial actions are taken to adequately contain or remove such NAPL. This requirement applies regardless of the potential for NAPL to result in vapor intrusion.

2.2.7 Preferential Pathways

The presence of preferential pathways such as elevator shafts, sumps, extensive cracks that extend through the foundation or slab, and annular spaces around the entrance point(s) of utility lines that connect the subsurface environment and/or sub-slab air space directly to indoor air should be considered in a Lines of Evidence evaluation. Such direct routes can result in significant impacts to indoor air.

Preferential pathways can result in significant impacts to indoor air and should be evaluated as a distinct Line of Evidence.

Soil gas screening values and GW-2 Standards do not account for such a direct connection between soil gas and indoor air.

2.2.8 Lines of Evidence Interpretation for the Presence of a Vapor Intrusion Pathway

Conclusions regarding whether or not the vapor intrusion pathway is complete and likely to be of concern under current site uses should be supported by appropriate Lines of Evidence. To aid in the interpretation of Lines of Evidence, MassDEP has developed matrices applicable to: residences, schools, and daycares; and industrial/commercial settings. These matrices, presented in Tables 2-2 and 2-3 respectively, consider contaminant concentrations in groundwater, sub-slab soil gas, and the indoor air to develop conclusions regarding whether the pathway is complete and likely to be of concern. The matrices apply to scenarios under which the potential for vapor intrusion has already been identified, as described in Section 1.

Data used in a Lines of Evidence evaluation should be representative of current conditions and not averaged over sampling locations.

Data used for a Lines of Evidence evaluation of whether a vapor intrusion pathway is complete, as shown in Tables 2-2 and 2-3, should be representative of site conditions and account for seasonal and other time-related variability. Data used in a Lines of Evidence evaluation should not be averaged over sampling locations. Averaging the results of samples from the same location over time is appropriate only when concentrations are consistent and an adequate number of samples are used. Justification should be provided for eliminating sampling results from the evaluation.

Tables 2-2 and 2-3 focus on groundwater, sub-slab soil gas, and indoor air sample results and identify some, but not all, circumstances when consideration of other Lines of Evidence may be important. Recommendations provided in Tables 2-2 and 2-3 are based on the assumption that the site characterization, including a survey of potential preferential pathways, is appropriate and adequate. Decisions to consider or exclude other Lines of Evidence should be based on the CSM, and technically justified and documented.

In applying the Lines of Evidence matrices, if it is concluded that the vapor intrusion pathway is not likely to be a concern under current conditions and use, then generally no additional evaluation is necessary. However, in situations where indoor air has not been sampled and groundwater and sub-slab soil gas concentrations are low (≤ GW-2

Standard and ≤ SG screening criterion, respectively), the possibility of a preferential migration pathway should be considered before concluding that the vapor intrusion pathway is not likely to be of concern. If in applying the Lines of Evidence matrix, if the current pathway is determined to be complete and likely to be a concern, additional response actions are necessary to address any CEP in a residential, school or daycare setting, or potential exposure in commercial/industrial settings.

The matrix presented in **Table 2-3** should be used with caution when conducting a vapor intrusion assessment at commercial or industrial locations that use disposal site-related chemicals as part of ongoing, permitted operations (e.g., dry cleaners, gasoline filling stations, etc.). Indoor air measurements and TVs have limited utility at these locations because it is difficult to determine what portion of indoor air contamination, if any, is the result of vapor intrusion. For these locations, greater weight should be given to other Lines of Evidence such as contaminant concentrations in the subsurface and outdoor air. For example, if contaminant concentrations in sub-slab soil gas are below screening criteria, then it is unlikely that the pathway is a complete pathway of concern, even if indoor air concentrations exceed TVs.

2.3 Indoor Air Exposure Assessment

> An exposure assessment must be conducted to provide *"… a conservative estimate of the exposure to oil and/or hazardous material which a receptor may receive within the contaminated area over a period of time"* (310 CMR 40.0920).

Where it has been determined that the vapor intrusion pathway is likely to be complete, an exposure assessment must be conducted to characterize Imminent Hazards, Substantial Hazards (310 CMR 40.0950), and conditions of No Significant Risk (NSR) to human health (310 CMR 40.0993(7)). These assessments must address exposures under current uses and, where appropriate, reasonably foreseeable uses if such uses could result in exposures greater than the current exposures.

The following sections provide guidance on exposure assessment for the vapor intrusion pathway, including recommendations on the Contaminants of Concern (Section 2.3.1), Site Activities and Uses (Section 2.3.2), Exposure Point Concentrations (Section 2.3.3), and Exposure Assumptions (Section 2.3.4).

It is important to note that the following assessment steps are intended for sites where indoor air data has been collected. If groundwater and/or soil gas data are used to conclude that the vapor intrusion pathway is not likely to be of concern, an indoor air exposure assessment is not relevant or necessary. Such a conclusion should be documented in the risk characterization for the disposal site.

Table 2-2: Interpreting Lines of Evidence for Presence of Current Exposure Pathways at Residences, Schools and Daycares

Lines of Evidence					
Groundwater Contaminant Levels	≤ GW-2 AND			> GW-2 OR	
Sub-Slab Soil Gas Contaminant Levels [a]	≤ Screening Criteria AND			> Screening Criteria AND	
Indoor Air Contaminant Levels	Not Tested	≤ TV_r	> TV_r	≤ TV_r	> TV_r
Likely Current Pathway of Concern?	No	No	See Footnote [b]	No	Yes

Table 2-3: Interpreting Lines of Evidence for Presence of Current Exposure Pathways at Commercial/Industrial Locations

Lines of Evidence					
Groundwater Contaminant Levels	≤ GW-2 AND			> GW-2 OR	
Sub-Slab Soil Gas Contaminant Levels [a]	≤ Screening Criteria AND			> Screening Criteria AND	
Indoor Air Contaminant Levels	Not Tested	≤ $TV_{c/i}$	> $TV_{c/i}$	≤ $TV_{c/i}$	> $TV_{c/i}$
Likely Current Pathway of Concern?	No	No	See Footnote [b]	No	Yes

Notes for Tables 2-2 and Table 2-3:

TV_r - Refers to Residential Indoor Air Threshold Values contained in Appendix I.
$TV_{c/i}$ - Refers to Commercial/Industrial Indoor Air Threshold Values contained in Appendix I.

a - Sub-Slab Soil Gas Screening Values provided in Appendix II.
b - Evaluate potential indoor air sources and/or preferential migration pathways. Indoor air results are not consistent with low subsurface contamination, which raises the possibility of indoor air source(s), preferential pathway(s), or unidentified subsurface sources. Consult with MassDEP on ambiguous results.

2.3.1 Contaminants of Concern

The first step in the indoor air exposure assessment is to determine which contaminants should be considered in the risk characterization. The general process for selecting Contaminants of Concern (COCs) is described in MassDEP's *Guidance for Disposal Site Risk Characterization* #WSC/ORS-95-141 (1995). For vapor intrusion, if subsurface contamination has been adequately characterized in accordance with the MCP (310 CMR 40.0904), only those chemicals and their breakdown products detected in the subsurface (soil, groundwater, and soil gas) should be considered as COCs in indoor air. For example, at a disposal site where the subsurface is found to contain chlorinated VOCs in all media, but not petroleum VOCs, petroleum compounds detected in indoor air would not be considered COCs for an MCP risk characterization. For more guidance on selecting COCs, see the *Guidance for Disposal Site Risk Characterization*.

> There may be a concern about the health risk associated with non-disposal site related contaminant exposure, but such risks are not regulated by M.G.L. c. 21E or the MCP.

For IH Evaluations, if a small subset of oil and/or hazardous material are likely to dominate the risk estimates based upon their concentration and toxicity, then the Imminent Hazard Evaluation may be limited to those chemicals (310 CMR 40.0953(5)).

2.3.2 Site Receptors, Activities, and Uses

The MCP (310 CMR 40.0923) specifies that the risk characterization must consider current and reasonably foreseeable (i.e., future) site activities and uses, as well as receptors consistent with each activity and use.

Activities and Uses - Current

If the vapor intrusion pathway is complete and likely to be of concern (Section 2.2), activities and uses associated with onsite buildings, as well as any planned changes, would be considered in the risk characterization for current activities and uses. Current site activities and uses typically fall into one of three categories: residential; schools and daycares; and commercial/industrial. The term residential in this context includes locations where people reside for an extended period of time, such as a residence (single or multi-unit), dormitory, or assisted living facility, consistent with the MCP definition of Residential Dwelling (310 CMR 40.0006). Exposure assumptions for these activities and uses are discussed in Section 2.3.4.

Activities and Uses - Future

To this point, the focus of this guidance document has been on vapor intrusion evaluations for current site conditions and use. However, establishing a condition of

NSR using a Method 2 or Method 3 risk characterization (Section 2.4) to support a Permanent Solution must consider reasonably foreseeable site activities and uses. Pursuant to 310 CMR 40.0923(3), reasonably foreseeable site activities and uses include any possible activity or use that could result in exposures to COCs that are greater than the exposures associated with current site activities and uses.

For the vapor intrusion pathway, future exposures greater than those associated with current use could result from changing building use or building conditions. Changes in use may be eliminated from consideration in the risk characterization through the implementation of an Activity and Use Limitation (AUL), as allowed by 310 CMR 40.0923(3)(b).

In the special case where there is currently no occupied building (or planned building) within the boundaries of the disposal site, the MCP does not require a quantitative evaluation of vapor intrusion for future buildings. However, pursuant to 310 CMR 40.1041(2)(c)(2), where groundwater contaminant levels exceed GW-2 standards and groundwater is at an average annual depth of 15 feet or less, any Permanent Solution achieved for the disposal site would be a "Permanent Solution with Conditions." While an AUL *is not required* as part of this type of Permanent Solution with Conditions, an AUL *may* be used in such cases to specify measures to be followed in the event of future construction to ensure that the potential for vapor intrusion is addressed. For more discussion of the requirements related to Permanent Solutions, future buildings, and AULs, see Section 4.0.

Table 2-4 identifies current and future site activities and uses to be evaluated in an assessment of exposure to indoor air contamination from vapor intrusion.

2.3.3 Exposure Point Concentrations

The MCP specifies requirements for identification of Exposure Points and Exposure Point Concentrations at 310 CMR 40.0924 and 310 CMR 40.0926, respectively.

Exposure Point Concentrations (EPCs) must be developed for each Exposure Point and provide a conservative estimate of the exposure to the COCs identified for the site. Exposure Points in the context of vapor intrusion are the locations in the building where exposure occurs or could occur. Exposure in various locations can be different as a result of the concentrations present or the nature and duration of exposure. MassDEP recommends that areas of the building where exposure is likely to be different be identified as distinct exposure points.

For a residence, a separate EPC should be developed for the basement (if present) and the first floor.

Table 2-4: Site Activities and Uses to Evaluate in an Indoor Air Exposure Assessment

Current Use and Activity	Future Use and Activity
Residential	Residential (see Section 2.3.3.2 for discussion of potential future structural changes)
Commercial or Industrial	Residential
	Commercial or Industrial * (see Section 2.3.3.2 for discussion of potential future structural changes)
Undeveloped property	Evaluation not required (Permanent Solution with Conditions flags concern/requirements for future construction)

* In cases where the site use is currently commercial or industrial, assessment of the risk posed by future residential exposure is not necessary if an Activity and Use Limitation is used to preclude residential use at a commercial/industrial site.

2.3.3.1 Exposure Point Concentrations – Current Use

EPCs for current exposure must be developed using the analytical results of indoor air samples, except where interior sources from ongoing commercial or industrial operations or contaminated building material confound the assessment of indoor air analytical results (i.e., it is not possible to distinguish site-related VOCs from interior sources (310 CMR 40.0926(6) and (7)).

Determining indoor air EPCs is contingent upon the goal of the risk characterization. For IH evaluations, a shorter-term exposure (e.g., 5 years) should be the basis for EPC development. When determining whether or not NSR or No Substantial Hazard (NSH) exists, EPCs should be developed to represent a longer-term exposure (e.g., greater than 5 years).

EPCs for Imminent Hazard Evaluations (Current Use)

It is important to quickly identify if site conditions constitute an IH. As a result, IH evaluations often occur during the initial investigation into vapor intrusion and initially may be based upon a limited data set. If an IH is suspected, the EPC can initially be developed from one round of indoor air testing. In cases where the data set is limited, the maximum detected concentration should be used for the EPC.

Pursuant to 310 CMR 40.0411(7), consideration of potential Imminent Hazards is an ongoing obligation. Until the disposal site is fully assessed and a Permanent Solution is achieved, persons conducting response actions must act on new information that indicates the potential for an Imminent Hazard.

EPCs for No Significant Risk and No Substantial Hazard Evaluations (Current Use)

EPCs that represent a long-term exposure should be based upon multiple rounds of indoor air sampling. Consistent with 310 CMR 40.0926 and MassDEP's *Guidance for Disposal Site Risk Characterization*, indoor air sample results from a given exposure point may be averaged (over time and location within the exposure point) provided there is sufficient data such that the average value is a "conservative estimate of the average concentration contacted by a receptor over the period of exposure." Multiple rounds of consistent and representative data are necessary to support the use of averaging for EPCs. When data is variable or limited, a maximum or 95^{th} upper confidence limit on the mean should be used to develop an EPC as specified in 310 CMR 40.0926(3)(c).

EPCs calculations should be based on the total concentration of a COC measured in indoor air.

EPCs for Ongoing Permitted Commercial or Industrial Operations (Current Use)

In buildings where VOCs are released to indoor air from ongoing commercial or industrial operations, it is often difficult to evaluate vapor intrusion and develop EPCs for current receptors. Examples of such situations include active dry cleaners and active petroleum dispensing operations. In such cases, interpretation of indoor air, and in some cases sub-slab soil gas[3] data, can be confounded by VOC use within the building.

Mass DEP recognizes that it may not be practical to implement a remedial measure (e.g., installation of a sub-slab depressurization system) if ongoing and legally permissible occupational exposure to a chemical is higher than exposure that resulting from vapor intrusion. Sub-slab soil gas data may be used (e.g., the Sub-Slab Soil Gas Screening Values) to screen out the vapor intrusion pathway where the issue of confounding sources does not affect the sub-slab soil gas data (310 CMR 40.0926(7)(a)1.). In cases where it is not possible to screen out the vapor intrusion pathway and permitted discharges from ongoing commercial or industrial operations are confounding the evaluation of indoor air EPCs for current exposure, the vapor intrusion pathway need NOT be evaluated under current use within the building where the ongoing commercial or industrial operation are operating if permitted discharges from the operations result in the same chemicals being present in indoor air at concentrations higher than the estimated contribution from the vapor intrusion pathway. In such cases, a Permanent Solution cannot be supported because the presence of confounding conditions prevents completion of a risk characterization for both current and foreseeable conditions.

The above approach applies only to ongoing business, commercial, and/or industrial operations that are actively using chemicals in a licensed and permitted manner that have also been identified as site COCs. EPCs must still be developed for any vapor

[3] In commercial buildings that use OHM, sub-slab soil gas can be contaminated through communication with indoor air.

intrusion into neighboring buildings or spaces that are NOT licensed and permitted to operate such processes and do not use such chemicals (e.g., neighboring/common-wall businesses in a strip mall containing a dry cleaner).

2.3.3.2 Exposure Point Concentrations – Future Use

Current indoor air data has limited use for predicting future EPCs because buildings change over time. As buildings age or are repaired or renovated, preferential pathways can be created. Examples include:

- The development of cracks in the foundation;
- Annular spaces surrounding newly installed utilities;
- The installation of sub-slab lines that connect an above-ground heating oil storage tank to an oil furnace; and
- The installation of an open sump.

In addition, building renovations can alter factors that change the movement of vapors between the shallow sub-slab space and indoor air, such as:

- HVAC adjustments;
- Change in building use that alters the frequency of doors being opened and closed; and
- Construction of an addition that is located over an area of higher contamination.

Thus, an existing building not currently showing evidence for vapor intrusion might develop a vapor intrusion pathway of concern in the future if soil vapor levels are sufficiently high.

EPCs for Existing Buildings (Future Use)

MassDEP seeking feedback on the effectiveness of the following options for addressing potential future structural changes which could increase exposure in an existing building.

The example of concern is a “tight” building where the measured indoor air levels pose NSR for a future residential exposure scenario (regardless of current use), but the measured sub-slab soil gas concentrations exceed residential screening levels. It is assumed here that the site is appropriately characterizes and Sources of OHM been eliminated or controlled and thus it is unlikely that groundwater concentrations will increase over time.

MassDEP recognizes that the likely biodegradation of petroleum compounds should result in lower long-term concerns for vapor intrusion and thus it may be appropriate to address petroleum and chlorinated VOC sites differently when considering future conditions (e.g., petroleum sites could fall under Option 3 while chlorinated sites would be subject to Option 1 or 2).

Option 1 – Close with a Permanent Solution with Conditions with either (a) an Activity and Use Limitation or (b) a New Permanent Solution with Conditions (No AUL) Category.[4]

In this option, significant changes to the building structure would be limited (or controlled) through the implementation of an Activity and Use Limitation. A variation on this option would be to create a new closure category to allow these conditions to achieve a Permanent Solution with Conditions but No AUL by adding a new clause to 310 CMR 40.1013.

This option gives greater weight to the current building condition and measured EPCs while recognizing that future changes, whether they are intentional renovations or inevitable building deterioration, must be monitored and addressed when necessary to maintain a condition of NSR.

Option 2 – Identify (Higher) Soil Gas Screening Levels (or Model Future Indoor Air Concentrations) to Trigger Option 1 Only at the "Worst" Sites

In this option MassDEP would identify a new set of soil gas screening criteria (or modeling conditions) that could be used to determine which sites with elevated soil gas levels could close with a Permanent Solution with No Conditions (Option 3) and which sites would require a Permanent Solution with Conditions (Option 1).

For example, with respect to modeling the future EPCs, the MCP provides for the use of empirically-based fate and transport modeling from sub-slab soil gas data. Use of a generic sub-slab soil gas-to-indoor air dilution factor of 70 provides a conservative estimate of the EPC for the purposes of 310 40.0926(3) and is consistent with 310 CMR 40.0926(7)(a)2, which allows for the use of sub-slab soil gas data to rule out an indoor air exposure pathway.

This option gives greater and greater weight to sub slab soil gas results as those levels increase.

- If the soil gas levels are only somewhat greater than the residential screening levels, then the combination of these soil gas and the currently low indoor air concentrations indicate that no additional conditions are required.
- If the soil gas levels are substantially higher than the residential screening levels, then the combination of these high soil gas and the currently low indoor air concentrations would indicate a potential issue needing further monitoring through a Permanent Solution with Conditions.

[4] The MCP currently does not include this concern among the "Limitation, Assumptions and Conditions on Site Activities and Uses That Do Not Require an AUL" pursuant to 310 CMR 40.1013. Adding soil-gas that is not currently posing a risk, but has the potential for vapor intrusion would require an MCP amendment.

Option 3 – Assume Current EPCs and No Significant Future Changes

In this option, the future EPC would be the same as the current EPC and the building conditions are assumed to remain stable into the future. The applicable closure category would be a Permanent Solution with No Conditions.

This option ONLY gives weight to the current building condition and measured EPCs and does not account for elevated soil gas concentrations and the effect they may have with any possible future changes - whether they are the result of intentional renovations or inevitable building deterioration. It may be appropriate to assume that biodegradation of petroleum VOCs would reduce the potential for future vapor intrusion to a degree that higher future EPCs can be considered unlikely and ruled out as a concern.

EPCs for Ongoing Permitted Commercial or Industrial Operations (Future Use)

The vapor intrusion pathway should be considered a relevant foreseeable exposure pathway in buildings with ongoing commercial or industrial operations where VOCs are present in indoor air. For the purpose of evaluating a site for NSR, empirically-based fate and transport modeling from sub-slab soil gas data can be used as described above. In cases where sub-slab soil gas is contaminated by OHM originating from indoor air, future EPCs based on modeling from the sub-slab space may be overly conservative. Sampling during times when the business in not in operation may help in these circumstances.

EPCs for Future Buildings

The use of site-specific models to estimate EPCs in indoor air in buildings that have yet to be constructed is not allowed pursuant to 310 CMR 40.0926(7)(b). Where concentrations exceed the GW-2 standards at a location that is currently without an existing occupied building or structure, any Permanent Solution achieved must be identified as a Permanent Solution with Conditions that includes documentation of the obligation to ensure any future construction at the disposal site does not result in OHM impacts to indoor air. For more discussion of Permanent Solution with Conditions related to the potential for vapor intrusion in future buildings, see Section 4.0.

2.3.4 Exposure Assumptions

Exposure assumptions vary depending on the receptor being evaluated and the purpose of the risk assessment.

Exposure Assumptions – Current Use

Exposure assumptions for current use are generally based on current site use and activity as described in Section 2.3.2.

Imminent Hazard Evaluations (Current Use)

For IH evaluations, the focus should be on current site conditions (310 CMR 40.0953). Therefore, the exposure assumptions will be based on a thorough understanding of the building as it is currently used by the receptors. The exposure period should be five years unless the COC indicates a shorter period (e.g., the OHM more toxic acutely, sub-chronically, or chronically). Exposure durations, frequencies and averaging periods used in an IH evaluation should also reflect current site conditions.

Substantial Hazard Evaluations (Current Use)

For Substantial Hazard evaluations, exposure assumptions should be the same for assessing NSR, with the exception that the exposure period must be equal to or greater than the time from notification to the date that the Substantial Hazard evaluation is conducted, plus five years (310 CMR 40.0956).

No Significant Risk (Current Use)

In order to demonstrate that NSR exists or has been achieved for current residential use, the exposure assumptions used in calculating an average daily exposure should be based on continuous exposure (24 hours per day, 365 days per year, for 30 years). These assumptions address the homebound adult and unrestricted use of the residence. Where different EPCs are developed for the basement and upper floors of a residential building, MassDEP recommends using an exposure duration of 12 hours in the basement or the bottom-most floor and 12 hours on upper floors, which corresponds to having a bedroom located in the basement. The averaging period for estimating cancer risks should be 70 years and for non-cancer risks 30 years.

For the evaluation of current exposures at a school, the assessment should address both the students (based on the actual school schedule, such as 8 hrs/day, 180 days/year, and 6 years) and teachers (based on the actual school schedule, for 27 years). In order to demonstrate NSR for commercial or industrial use, MassDEP recommends assuming 8 hours per day, 250 days per year, for 27 years. For estimating cancer risks, the averaging period for school, business, or industrial receptors should be 70 years. For estimating non-cancer risks, averaging periods should be 27 years for teachers and 6 years for students, while that for students.

If more than one EPC is developed for a building, such as an EPC for the basement and an EPC for the first floor, the exposure durations can be subdivided accordingly in order to develop a time-weighted average EPC provided there is sufficient data to develop location-specific EPCs.

Exposure Assumptions – Future Use

For future use evaluations, exposure assumptions for residential use should be used for buildings that are currently non-residential. If NSR at a site can be demonstrated for a site using the unrestricted, residential use exposure assumptions that include estimated future EPCs (2.3.3), exposure assumptions for other uses do not need to be evaluated. If NSR is inconsistent with some future exposure assumptions, then AULs can be used to eliminate such exposures from further consideration in accordance with 310 CMR 923(3)(b).

2.4 Risk Characterization

2.4.1 General Risk Characterization Requirements

Achieving a Permanent Solution at a site requires, in part, that NSR be demonstrated (310 CMR 40.1003). There are three methods of risk characterization described in the MCP. Methods 1 and 2 are designed to address risks associated predominantly with contamination of soil and groundwater. Method 3, a site-specific risk characterization, is an option at any site, but is required when significant exposure to OHM occurs through a medium other than soil or groundwater, such as indoor air.

A more detailed description for each method of risk characterization is presented in MassDEP's *Guidance for Disposal Site Risk Characterization*. However, assessing risks associated with the vapor intrusion pathway presents a number of unique challenges not covered in this previous guidance document. Vapor intrusion-specific guidance for each method is provided below.

2.4.2 Method 1 Risk Characterizations

The use of a Method 1 Risk Characterization under the MCP is restricted to disposal sites where current and reasonably foreseeable exposure would occur predominantly through contact with soil and groundwater. Method 1 is therefore not applicable if the vapor intrusion pathway has been determined to be complete and likely to be of concern in existing buildings, either currently or in the future, as described in Sections 2.2 and 2.3. Method 1 can be used, barring potential exposures to other media (surface water and sediment), if it has been concluded that a vapor intrusion evaluation is not warranted, as described in Section 1.3, or if has been determined to be incomplete or unlikely to be of concern, as described in Section 2.2 and 2.3

Method 1 may also be used to streamline the risk characterization process in a Phase II Risk Characterization where GW-2 Standards are exceeded at a site, by quickly concluding that NSR does *not* exist and the assessment can proceed to evaluation of potential remedies.

2.4.3 Method 2 Risk Characterizations

The limitations to Method 1 regarding contaminated media also apply to Method 2. Pursuant to 310 CMR 40.0983, Method 2 can be used to develop a Method 1 Standard for a chemical that does not have a promulgated Method 1 standard as specified at 310 CMR 40.0983(3).

Method 2 also allows the use of limited site-specific information to supplement the use of Method 1 Standards (310 CMR 40.0942(2)). Site-specific Method 2 GW-2 Standards can be developed as described at 310 CMR 40.0986. The MCP at 310 CMR 40.0986(2) requires that a Method 2 GW-2 Standard "be protective of migration of oil and/or hazardous material into indoor air."

The MCP requires that Method 2 GW-2 Standards be developed using site-specific soil gas, indoor air, building conditions and other site data to demonstrate that groundwater concentrations do not result in indoor air concentrations which pose a significant risk of harm to health, public welfare or the environment. The MCP Method 2 GW-2 Standard may be greater or less than the corresponding MCP Method 1 GW-2 Standard, or it may be determined that the Method 1 Standard is not applicable.

A Method 2 Risk Assessment used to determine the Method 1 Standard is not applicable must document that the vapor intrusion pathway is unlikely to be a pathway of concern, as described in Section 2.2.7. Documenting this conclusion is considered demonstration that the contamination "*will not infiltrate to indoor air and result in significant risk of harm to health, public welfare or the environment*" pursuant to 310 CMR 40.0986(2), and thus would pose NSR under a Method 2 Risk Characterization.

Method 2 modifications to the Method 1 Standards that are based upon measurements made under current building-specific conditions do not necessarily reflect potential future building. Therefore, changes to any such building conditions would need to be "locked-in" with an appropriate AUL where there is the potential that future changes to building conditions would change the conclusion of NSR or no SH (40.0956(1)) evaluation. Method 2 modifications to the GW-2 Standards *may not* be based on site-specific fate and transport modeling. MassDEP has determined that the use of models incorporating site-specific information (such as Johnson and Ettinger (1991)) for calculating Method 2 Standards is not supported by empirical evidence.

2.4.4 Method 3 Risk Characterizations

A Method 3 Risk Characterization is required when vapor intrusion into a building is demonstrated to be a complete pathway and likely to be of concern, as described in Section 2.2. A Method 3 Risk Characterization would also be required if sub-slab vapors could result in a future EPC that exceeds NSR for residential use (Section 2.3). The Method 3 Risk Characterization is performed with the objective of producing quantitative estimates of risk for threshold and non-threshold effects. The risk assessment process consists of five general steps as it pertains to the evaluation of risks to public health.

These include Hazard Identification, Dose-Response Assessment, Exposure Assessment, Risk Characterization and Uncertainty Analysis.

Guidance for each of these steps is presented above in Section 2.3. The information collected in Section 2.3, including current and future EPCs, is combined with chemical-specific toxicity to estimate cancer risks and non-cancer health effects.

- Imminent Hazard risk limits are presented in 310 CMR 40.0955(2)(b) and 40.0955(2)(c);
- Substantial Hazard risk limits are presented in 310 CMR 40.0956(1)(a); and
- No Significant Risk limits are presented in 310 CMR 40.0993(5) and 310 CMR 40.0993(6).

3. MITIGATION

This section presents guidance on considerations for remediating disposal site conditions that result in vapor intrusion, and describes a range of approaches for mitigating the vapor intrusion pathway.

Removal or treatment of contaminated soil and/or groundwater contributing to indoor air concentrations is the most effective long term approach for eliminating or mitigating the vapor intrusion pathway. However, the implementation of measures designed to prevent the migration of vapors into buildings is often necessary to prevent exposure for some period of time while more comprehensive measures are undertaken.

A variety of techniques to eliminate or mitigate the vapor intrusion pathway may be implemented together or at various times during response actions. The selection of the appropriate approaches to eliminate or mitigate vapor intrusion should be based on consideration of site conditions (building construction, depth to groundwater, etc.), the remedial objectives, and circumstances at the time the indoor air impact is discovered.

3.1 Addressing VOC Sources and Controlling Migration

While many approaches may be used to eliminate or mitigate the vapor intrusion pathway, the most effective and reliable long-term approach to eliminate the impact to indoor air is to eliminate or control sub-surface sources of contamination that are contributing to VOC concentrations in the soil gas and indoor air.

Permanent and Temporary Solutions require that all Sources of OHM be adequately identified and addressed pursuant to the Source Elimination or Control requirement at 310 CMR 40.1003(5). For a Permanent Solution, all Sources of OHM must be eliminated or if they are not eliminated, they must be eliminated to the extent feasible and controlled. Temporary Solutions require that all sources of OHM be eliminated or controlled to the extent feasible.

Source Elimination or Control is also a requirement of Remedy Operation Status (ROS). 310 CMR 40.0893(2)(d) of the ROS provisions requires that each Source of OHM be eliminated or controlled as specified at 310 CMR 40.1003(5), which means, at a minimum, eliminated or controlled consistent with a Temporary Solution.

Even after Sources of OHM have been successfully mitigated, the Migration Control provisions at 310 CMR 40.1003(6) require that plumes of dissolved OHM in groundwater and in vapor phase be stable or contracting. Further, MGL chapter 21E § 3A(g) requires that Permanent Solutions, where feasible, include measures to “reduce to the extent possible the level of oil or hazardous materials in the environment to the level that would exist in the absence of the disposal site of concern.”

Persons conducting response actions at vapor intrusion sites should work diligently to remediate sources of VOCs in a comprehensive and timely manner to ensure that the extent of VOC migration is minimized and the indoor air pathway is effectively mitigated for the long term. A variety of soil and groundwater remedial approaches may be appropriate to address VOC sources to achieve indoor air remedial goals including: soil vapor extraction, air sparging, in-situ chemical oxidation, bioremediation, multi-phase extraction, groundwater recovery and treatment, removal and disposal of contaminated soil, soil washing; in-situ thermal treatment; permeable reactive barriers; soil solidification/stabilization, and phytoremediation. These remedial approaches can be initiated as an IRA, a Release Abatement Measure (RAM), or as a Comprehensive Response Actions identified as the selected remedial alternative in the Phase III Remedial Action Plan.

3.1.1 Application of Remedial Additives

Remedies that use Remedial Additives to treat VOC warrant measures to ensure that the application of additives does not exacerbate site conditions. With respect to vapor intrusion sites, care should be taken to ensure that the application of Remedial Additives to treat VOCs in groundwater or soil does not result in vapor intrusion to nearby buildings. The requirements for Remedial Additives are specified at 310 CMR 40.0046

Specific site conditions should be considered when developing a plan for the use of Remedial Additives near occupied buildings. These conditions include, at a minimum, the depth to groundwater, groundwater flow direction, soil type and hydraulic conductivity, presence of aquitards, presence of preferential pathways and subsurface structures, presence of NAPL, volume of Remedial Additives to be applied, radius of influence of injections, and distance to receptors, particularly sensitive receptors.

Remedial Additives can be used as part of an IRA, RAM or CRA. Prior approval of a plan to use Remedial Additives is required when the proposed application is within 100 feet of a School, Daycare or Child Care Center or occupied Residential Dwelling (310 CMR 40.0046(3)(a)5). MassDEP will approve, conditionally approve or deny the plan within 30 days of receipt; approval of the plan may be presumed if MassDEP does not issue a written approval or denial of the plan. MassDEP may give oral approval of a plan to apply additives in cases where such application is proposed in an oral IRA Plan and written approval would delay the timely implementation of an IRA.

3.2 Indoor Air Pathway Mitigation

Where response actions are ongoing to fully assess and remediate sources of soil and/or groundwater contamination contributing to VOCs in indoor air, more immediate measures to prevent or reduce current human exposure to VOCs from the disposal site are often warranted. These measures are directed preventing or reducing the migration of soil gas into indoor air and/or ventilating or treating the indoor air.

Mitigating the vapor intrusion pathway can be accomplished by a variety of methods. Selection of the best approach will depend on the magnitude of the indoor air impact and consideration of a number of building construction and site characteristics. Several different measures may be implemented in stages to allow for more immediate mitigation while longer term approaches are developed. For example, ventilation by opening windows and/or removal of VOCs by indoor air treatment may be used initially to mitigate vapor intrusion while a sub-slab depressurization system (SSD) system is designed and installed. Once the SSD system is operational and the vapor intrusion pathway is eliminated, response actions to treat groundwater and/or eliminate or control the source of VOCs to indoor air can be implemented.

> The use of an active SSD system is the method preferred by MassDEP to mitigate vapor intrusion and should be considered as the first choice to eliminate or reduce contaminants in indoor air emanating from soil gas.

Aside from the eliminating and controlling VOCs sources at the disposal site, MassDEP considers active SSD systems to be the most effective means of mitigating vapor intrusion. This view is based on MassDEP's experience overseeing numerous vapor intrusion sites, including many state-funded projects, and its review of more than 20 years of data from radon mitigation.[5] In circumstances where VOC concentrations of contaminants in the soil, groundwater and/or soil gas are low, and/or site conditions preclude installation of an SSD system, a variety of other mitigation measures should be considered and may provide adequate mitigation.

Regardless of the vapor intrusion pathway mitigation measure selected, the MCP requires demonstration and documentation that the performance standards for the mitigation measure are met both at the time of installation and over the course of its operation. The specifics of the performance standards depend on the objectives of the mitigation measure and must be defined in the remedial plan (i.e., IRA Plan, RAM Plan or Phase IV Remedy Implementation Plan) that describes the implementation of the mitigation measure. Consideration of this requirement is important in developing an adequate monitoring program. Monitoring requirements will vary depending on the mitigation method. More monitoring of indoor air quality is typically needed to demonstrate the effectiveness of passive measures than active systems, as passive measures are less predictable and less efficient at preventing vapor intrusion than active systems. Tables 3-1 and 3-2 contain MassDEP's recommendations for monitoring vapor intrusion mitigation system effectiveness.

When planning the mitigation approach, several factors should be taken into consideration relative to the building structure and conditions in the subsurface near the building. These factors are discussed in more detail below.

3.2.1 Building Survey Considerations

Prior to selecting the method to mitigate the vapor intrusion pathway, an inspection of the building foundation and slab should be conducted to identify all potential entry routes for

[5] Refer to http://www.epa.gov/radon/pubs/ for more information about the mitigation of radon contaminated soil gas.

VOCs in soil gas and building features that may affect the implementation of mitigation measures. Building plans, if available, can aid in this survey, but a thorough inspection of the interior and exterior of the building is necessary to determine the current condition and configuration of the structure.

Potential soil gas entry routes include dirt floors, cracks in concrete walls or slabs, gaps in fieldstone foundation or concrete block walls, construction joints between walls and slabs, annular space around utility pipes, open sumps, etc. These potential entry points can be surveyed with a portable Total Organic Vapor instrument such as a photo-ionization detector (PID) or a flame ionization detector (FID), ideally that measures in the parts per billion (ppb) range. Use of a PID or FID meter for screening inflowing sub-slab soil gas also has the benefit of providing continuous, real-time concentration data to evaluate trends and/or detect possible short-circuiting situations. It should be noted that PID and FID meters are survey instruments and because of their low sensitivity and the variable nature of vapor intrusion, should not be used to conclude that vapor intrusion is not occurring.

An effort should be made to identify perimeter drains or French drains, as these can be significant migration pathways and entry points for soil vapor. These drainage systems can also be an asset in vapor intrusion mitigation, as they can be connected to sub-slab depressurization systems and used to depressurize the subsurface around the foundation perimeter. Conversely, if not accounted for prior to system installation, these drains may short-circuit active depressurization systems.

The location of footings or other sub-slab structures should also be identified, as this may impact the effectiveness of a sub-slab depressurization system by altering sub-slab vapor flow and inhibiting uniform depressurization.

Collecting differential pressure measurements throughout the building may be useful in determining whether there are impediments to sub-slab vapor flow. In addition, this information can also be used to quantify the effects of other forces such as wind, temperature, household appliances, heating or ventilation systems and occupant activities that the mitigation system will have to overcome. This information may be especially important for passive sub-slab venting systems because the sub-slab differential pressures produced by passive systems are low compared to differential pressures produced by active systems. Methods for determining differential pressures are available in the EPA (1991) Handbook, "*Sub-Slab Depressurization for Low-Permeability Fill Material, Design and Installation of a Home Radon Reduction System*."

3.2.2 Sub-Slab Materials

Understanding fill/soil conditions beneath the floor of the foundation or slab is necessary to select and design an effective mitigation system. Permeable fill/soil materials beneath the slab will usually allow rapid soil gas movement, and only a slight vacuum will create sufficient flow rates, and fewer extraction points may be necessary. Less permeable

Table 3-1: Recommendations for Active Vapor Intrusion Mitigation Monitoring

	ACTIVE SYSTEMS	COMMENTS
RECOMMENDED USE	Active sub-slab depressurization (SSD)[1] systems are the recommended method to address the vapor intrusion pathway in all cases and particularly if an Imminent Hazard exists	
NUMBER OF DAYS TO ALLOW SYSTEM TO EQUILIBRATE	Sample indoor air approximately 7 days after system start-up. Sampling can be sooner in the case of a known or suspected Imminent Hazard.	
SAMPLING TO DEMONSTRATE EFFECTIVENESS	Once a pressure differential across the slab is established, using vapor points installed during the communication test, conduct at least one round of indoor air sampling during the heating season. If it is determined that the system is effectively reducing indoor air contaminant concentrations, the differential pressure confirmed to be adequate during this initial sampling can then be used to monitor system effectiveness. A negative pressure field should be maintained beneath the slab during al weather conditions, appliance use, etc. for effective mitigation.	**If any sampling to demonstrate effectiveness indicates that the system installed or measures taken are not effective, either augment and/or modify the system or select another approach to achieve the goals of the response actions. These measures should be implemented immediately and re-sampled following these guidelines.** **If the sampling to demonstrate effectiveness indicates that the system is effective, the system should be monitored following the guidelines outlined in the maintenance and monitoring section.**
MAINTENANCE and MONITORING (Including Permanent Solution with Conditions and AUL and Temporary Solution Operation Maintenance and Monitoring, if applicable)	Differential pressures across the slab can be used to demonstrate system effectiveness. If the sub-slab pressure differential is adequate to prevent vapor intrusion (i.e., equal to or greater than it was when the indoor air sampling indicated that the concentration of contaminants in the indoor air were at or below the appropriate TVs), it can be assumed that the system is working properly. Indoor air sampling to verify system performance is recommended when differential pressures measured during system monitoring are less than those observed during the initial evaluation described above. Annual checks for pressure drops and fan operation should be conducted until the system is no longer necessary.	**If monitoring indicates that the system installed or measures taken are not effective, either augment and/or modify the system or select another approach to achieve the goals of the response actions. These measures should be implemented immediately and the indoor air re-sampled following these guidelines.** **If, during the maintenance inspections it is noted that modifications have been made to the building that might change the vapor intrusion assumptions, an evaluation should be conducted to determine whether the modifications are likely to have an impact on vapor intrusion.**
MONITORING TO SUPPORT CLOSURE WITH PERMANENT SOLUTION [2]	To demonstrate that continued mitigation is no longer necessary, conduct at least 3 indoor air sampling events spread over a period of two years with at least one round during the heating season, and at least one round during any other time that might represent worst-case conditions (e.g., seasonally high water table where there is shallow groundwater); and with SSD system off to determine indoor air concentrations without SSD system operating (refer to Section 2.2.2 for sampling procedures). Active systems upgraded from a passive system with a passive design should conduct sampling with the vent piping capped/valve closed to determine indoor air concentrations without a functioning passive measure[3].	

Notes:
1. Sections 3.3.1.1, 3.5 and Appendix IV of this document contain additional information regarding the design, installation and monitoring of sub-slab depressurization systems.
2. Refer to Section 4.6 of the text for additional information regarding disposal site closure.
3. If passive venting is found to be occurring and necessary for achieving NSR, an AUL is necessary to ensure the passive system is maintained/remains in place.

Table 3-2: Recommendations for Passive Vapor Intrusion Mitigation Monitoring

	PASSIVE MEASURES		COMMENTS
RECOMMENDED USE	Passive measures (such as passive venting systems, sealing cracks in concrete walls and floors, sealing the annular spaces around utilities, and sealing sumps) may be an alternative to active SSD systems when the subsurface contaminant concentrations are low. Passive measures are not recommended to address Imminent Hazards.		
NUMBER OF DAYS TO ALLOW SYSTEM TO EQUILIBRATE	Sample indoor air approximately 7 days after system installation.		
SAMPLING TO DEMONSTRATE EFFECTIVENESS	**Sampling regimen should be based on concentration of contaminants in the groundwater, sub-slab soil gas and/or indoor air determined PRIOR to system installation:** **If GW Conc. > GW-2 and ≤ 2X GW-2** **AND** **Sub-Slab Soil Gas Conc. ≤ 2X Soil Gas Screening Values[1, 2]** **AND** **Indoor Air Conc. ≤ 2X TVs[2]:** Conduct at least two rounds of sampling in the first year after the measures are implemented, with one round conducted during heating season.	**If GW Conc. >2X GW-2** **AND/OR** **Soil Gas Conc. > 2X Soil Gas Screening Values[1,2]** **AND/OR** **Indoor Air Conc. > 2X TVs[2]:** Quarterly indoor air sampling in the first year after the measures are implemented with two rounds conducted during the heating season.	**If any sampling to demonstrate effectiveness indicates that the system installed or measures taken are not effective, either augment and/or modify the system or select another approach to achieve the goals of the response actions. These measures should be implemented immediately and re-sampled following these guidelines.** **If the sampling to demonstrate effectiveness indicates that the system is effective, the system should be monitored following the guidelines outlined in the maintenance monitoring section.**
MAINTENANCE and MONITORING (Including Permanent Solution with Conditions and AUL and Post-Temporary Solution Operation, Maintenance and Monitoring if applicable)	Indoor air sampling to evaluate the passive measures should be performed at a frequency commensurate with the contaminant concentrations and temporal variability sufficient to ensure their effective performance and integrity.		**If the maintenance monitoring indicates that the system installed or measures taken are not effective, either augment and/or modify the system or select another approach to achieve the goals of the response actions. These measures should be implemented immediately and the indoor air re-sampled following these guidelines.** **If, during the maintenance inspections it is noted that modifications have been made to the building that might change the vapor intrusion assumptions, an evaluation should be conducted to determine whether the modifications are likely to have an impact on vapor intrusion.**
MONITORING TO SUPPORT CLOSURE WITH PERMANENT SOLUTION [4]	To demonstrate that continued mitigation is no longer necessary conduct (3) indoor air sampling events over a period of two years with one round during the heating season. The passive venting system should be sampled with the vent piping capped/valve closed to determine indoor air concentrations without a functioning passive measure.[5]		

Notes:

1. If sub-slab soil gas samples cannot be collected due to site conditions (shallow groundwater), the decisions should be based on groundwater concentrations (inferred or directly measured) and indoor air concentrations.
2. The applicable Threshold Values (TVs) and Sub-Slab Soil Gas Screening Values should be used for the expected exposure scenarios, whether residential or commercial/industrial (refer to Section 2.3.2 of the text and Appendices I and II).
3. Section 3.4.2 contains additional information regarding passive techniques and Section 3.4.2.4 contains additional information regarding passive venting systems.
4. Refer to Section 4.6 of the text for additional information regarding disposal site closure.
5. If passive venting is found to be necessary for achieving NSR, an AUL is necessary to ensure the passive system is maintained/remains in place.

materials beneath the slab may require higher head fan units and more extraction points to draw the appropriate amount of vacuum necessary to mitigate the vapor intrusion pathway when employing active sub-slab depressurization methods.

Small diameter test holes can be drilled through the slab at various representative locations to collect sub-slab material for visual inspection to assess its relative permeability (these samples can be collected when installing sub-slab soil gas probes). The test holes should be executed to collect information about the material immediately below the slab.

3.2.3 Depth to Groundwater

The depth to groundwater is a consideration in selecting the most appropriate mitigation method. Depth to groundwater data can be determined from monitoring wells in the vicinity of the building as well as from test holes drilled through the slab for the installation of sub-slab soil gas probes. If the seasonal high groundwater table is very shallow and close to the bottom of the foundation floor or slab, active depressurization systems may not be the most appropriate method. However, an evaluation of the cause of the high level of water beneath the slab should be conducted before eliminating an SSD system as a mitigation option.

Often, water in or around a basement is the result of improper stormwater drainage. Relatively simple and inexpensive modifications to the stormwater drainage around the building (i.e., installing gutters, directing rain and stormwater away from the house, etc.) can reduce the water in the basement and high water level in the vicinity of the foundation. Dewatering the area beneath the slab, as with a sump, may be another method of reducing the water elevation beneath the slab. Groundwater with high concentrations of VOCs should not be discharged directly to the exterior ground surface because this could potentially spread contamination on the ground surface, and impact surficial soil and nearby receptors. Sumps used to dewater highly contaminated groundwater would be required to treat the water (i.e., using granular activated carbon (GAC)) prior to discharge and require the GAC vessels to be appropriately maintained. Installing an aerated floor above an existing slab may be an effective at some sites where modifying the stormwater drainage and/or dewatering is not possible or has not been effective.

> Installation of SSD systems where water is present in close proximity to the slab may require modifications to stormwater drainage in and around the structure or dewatering beneath the slab. An evaluation of the cause of elevated sub-slab water will be necessary to determine a potential remedy.

3.3 Active Mitigation Systems

Brief summaries of various active mitigation techniques are presented below. Appendix IV contains a detailed description of standard procedures for the installation of an active SSD system.

3.3.1 Depressurization Systems

Depressurization systems create a negative pressure (i.e., vacuum) beneath and/or around the foundation and slab of the building to prevent the migration of contaminants from sub-slab soil gas into the indoor air.

3.3.1.1 Active Sub-Slab Depressurization (SSD) Systems

Active SSD systems mitigate the vapor intrusion pathway by creating a negative pressure field beneath the slab of a structure of concern, thereby inducing the flow of VOC vapors to one or more collection points and subsequently discharging the vapors up a stack and into the ambient air.

Active SSD systems are based on traditional radon-mitigation technology, and consist of a fan or blower that draws air from the soil beneath a building and discharges it above the roofline of the building to the atmosphere. Where an existing building is retrofitted with an SSD system, one or more extraction points installed through the building slab are used to create a negative pressure field. In most cases these points are installed vertically through the slab. In some cases, however, the system may require horizontal extraction point(s). The system includes a fan or blower that should be installed outside of the building or in an unoccupied attic and exhausted above the top of the roof at a location that ensures that the exhaust will not be drawn back into the building.

In new construction, the sub-slab components of the SSD system can be put in place before the slab is poured, which facilitates effective system design and installation. In addition, the vertical vent pipe can be installed within the interior of the building walls.

Effective mitigation requires sub-slab depressurization that is strong enough to overcome competing forces within the house or building caused by furnaces, bathroom fans, stove vents, occupant activities (i.e., opening windows and doors) or weather effects (e.g., changes in temperature, wind and barometric pressure).

The sub-slab differential pressure necessary for effective mitigation by SSD systems may vary. In buildings with very permeable sub-slab material, large volumes of air can be moved with little pressure drop. For buildings with less permeable material beneath the slab, an SSD system designed to maintain a differential pressure of 0.015 inches water (approximately 4 Pascals) measured across the slab in mild weather with exhaust appliances off may be adequate to maintain effective sub-slab flow even under worst case stack effect conditions during winter heating (EPA, 1993, Section 2.3.1, p. 34). Increased vacuum may be necessary to overcome the operation of heating equipment, ventilation fans, etc. Excessive sub-slab depressurization can result in the back draft of combustion exhaust. Appendix IV contains more detailed information regarding the design, installation of sub-slab depressurization systems and back draft evaluations.

The presence of a sump or major utility penetration in a basement can result in significant "short circuiting" of the SSD system and significantly interfere with establishment of a sub-slab negative pressure (i.e., vacuum) field. Sumps and utility penetrations should be sealed not only to prevent the migration of VOCs into the indoor air, but also to ensure that the SSD system operates effectively. Where finished basements preclude a thorough inspection of basement walls and floors, it may be advisable to install an upgraded SSD system with an enlarged suction pit and a more powerful fan or blower to avoid or overcome potential short-circuiting. In some locations condensate or groundwater (at disposal sites with high groundwater) can enter the SSD piping. In such cases, consideration should be given to adding a knock-out drum before the blower.

<u>Off-Gas Treatment</u> Off-gas treatment is not required for an SSD system that is used to prevent the migration of contaminated soil gas from entering the living/working spaces of a building, provided that the system will not emit more than 100 pounds of VOCs per year (310 CMR 40.0049(3)(a)). However, MassDEP may require off-gas controls on these systems if emissions exceed, or potentially exceed significant risk level concentrations or create adverse health, safety, or odor conditions downwind of the discharge. Additional guidance on off-gas treatment is provided in MassDEP Policy #WSC-94-150: *Off-Gas Treatment of Point Source Remedial Air Emissions*.

All SSD systems should be designed in conformance with standard engineering principles and practices. The installation of an SSD system should be conducted under the direct supervision of a competent professional with demonstrated experience in building soil vapor mitigation, disposal site remediation, or environmental engineering. As the work will likely be conducted in close proximity to building inhabitants, safety concerns are a priority. Attempts should be made to minimize noise, dust, and other inconveniences to occupants. Alterations in the appearance of the building should also be minimized and system components should be discreetly located as practicable.

3.3.1.2 Active Drain Tile Depressurization (DTD)

Many buildings have systems in place referred to as drain tiles or French drains that are designed to drain water away from the basement. Existing drain tile systems can be used to mitigate vapor intrusion by applying a vacuum to the system. This mitigation method is referred to Active Drain Tile Depressurization (DTD).

Since DTD takes advantage of existing drain tile networks located around the perimeter of the building foundation, it can be a very expeditious vapor intrusion mitigation approach to implement. These networks may be depressurized by connecting them to suction piping and a blower. Drain tiles are typically located either above or beside foundation footings, and typically consist of porous clay pipe, perforated rigid plastic pipe (i.e., PVC), or perforated flexible plastic pipe (i.e., polyethylene or polypropylene). Interior drain tiles are located on the inside of the footings toward the structure while exterior drain tiles are located toward the exterior, on the outside of the foundation.

Interior drain tiles will likely provide more suction beneath the slab than exterior drain tiles. Interior drain tiles offer the advantage of being next to or below the expansion joint located near the footing and floor slab interface, which is a common soil gas entry point. It is important to determine the extent of the drain tile network, which may extend around the entire perimeter of the structure or only along a portion of the structure. DTD is most effective with a drain tile network that extends around the entire perimeter. However, effective depressurization may be possible with a drain tile network installed on one or two sides of a structure underlain by permeable soil/fill that provides good communication beneath the slab.

Sump Hole Suction Drain tiles often drain toward a basement sump. The sump should be fitted with an air tight cover with a gasket to ensure an air-tight seal to the slab while readily allowing easy access to the pump. SSD system piping may be inserted through the sump cover to depressurize the drain tiles and beneath the slab. Appropriate fittings should be used to ensure an air tight seal around piping and wiring installed through the sump cover. If flooding of the basement floor is an issue, the sump cover should be level with the basement floor or slightly concave allowing water to flow onto it and be fitted with a one-way drain (i.e., Dranjer-type drain) equipped with a check valve that allows water to drain into the sump but prevents soil gas from flowing into the building or conditioned air from being drawn into the sump. A check valve should also be installed in the sump drain ejection piping that pumps sump water to the outside to prevent outside air from being drawn into the sump which could short-circuit the SSD system.

To prevent short-circuiting of the system in buildings equipped with existing drain tiles that discharge to a dry well or topographic low point, a check valve should be installed in the discharge piping to prevent outdoor air from entering the system. A DTD system may not be the most appropriate option for addressing the vapor mitigation pathway when the basement is finished and piping needs to be inserted into the perimeter drains or when communication beneath the slab is poor. In addition, as drain tiles are often used in buildings with high water in and around the basement, there may be challenges related to handling groundwater containing VOCs.

3.3.1.3 Active Block-Wall Depressurization (BWD)

Active block-wall depressurization (BWD) is a method of mitigating vapor intrusion that is occurring from soil gas migrating through void spaces in a block wall foundation. Block walls have been observed to create a stack effect, drawing soil gas through void spaces into the living space of the building. SSD or DTD systems installed in buildings with block wall foundations are designed to depressurize the zone beneath the slab and around the foundation and footings underlying the foundation to prevent soil gas migration through porous foundation walls. In cases where the SSD or DTD system alone is insufficient, a BWD system can be installed as a modification to enhance an SSD or DTD system.

BWD uses a vacuum to depressurize the void spaces within the foundation walls. There are generally two available BWD methods. The first method consists of inserting one or two suction pipes horizontally within the void space of a foundation wall and connecting the pipes to fans to create a vacuum and depressurize the wall. The second, less common method involves drilling holes in the wall just above the slab, enclosing the holes with a perimeter baseboard, and connecting piping from the baseboard to a fan to depressurize the baseboard and wall.

It is often difficult to effectively seal the cracks and gaps in foundation walls, especially block walls, and therefore it may be difficult to depressurize the entire foundation wall. In some cases, it may be possible to use a plastic membrane to limit the amount of indoor air (or outdoor air from above the ground surface) drawn into the BWD system. Excessive indoor air drawn into a BWD system (and/or SSD or DTD system) may cause back drafting of combustion equipment. Please refer to Appendix IV for information about back drafting.

3.3.1.4 Active Sub-Membrane Depressurization (SMD)

Sub-membrane depressurization (SMD) systems are typically used in buildings with dirt floor basements or crawlspaces. SMD systems are similar to SSD or DTD systems with the exception that an impermeable membrane is used instead of a concrete slab. The best approach for using an SMD system is to place various lengths of perforated piping horizontally over the dirt floor and cover the piping with an impermeable membrane such as a vapor barrier. Individual suction points may be used where concrete footings divide the subsurface area beneath the dirt floor. To prevent the impermeable membrane from blocking the perforations in the piping when a vacuum is drawn, highly permeable material (gravel or pea stone) can be packed between and on top of the piping.

Membranes used in SMD systems are recommended to be a 40 to 60 millimeters thick (EPA, 2008). Membranes should cover the entire floor area and be sealed to walls, piers, extraction piping, etc. using an adhesive (see Section 3.4.2.3 for additional information about membrane systems). Proper sealing of the membrane to perimeter walls and piers and of membrane seams is critical for SMD systems to function effectively. Tightening the membrane too much during installation can strain seals and seams when the system is turned on and the membrane is pulled to the floor. Care should be taken to ensure that the membrane will not be pulled away from walls and piers when the SMD system is activated. A wearing surface is recommended above the membrane for protection. This is particularly important in areas that receive foot traffic. Sufficient vacuum beneath the membrane will ensure that the flow of gas/air through any minor tears will be toward the depressurization system.

3.3.2 Air Purification Units

Air purification units (APUs) refers to treatment equipment used to remove contaminants that are already present in indoor air through the use of activated carbon adsorption. Contaminant removal methods that employ adsorption materials, such as activated carbon, require that the spent material either be regenerated or properly disposed as waste. APUs that use high surface area sorption filters generally have better removal efficiencies due to the high sorbent to air contact. APUs may be a good temporary mitigation measure during the initial stage of responding to vapor intrusion and prior to the implementation of a more reliable longer term mitigation measure; APUs should not be used as a long term measure. Use of APUs requires calculating the appropriate air exchange rate based on the size of the space being treated and contaminant concentrations.

> APUs are considered a *temporary* mitigation method because they are limited to removing contaminants present in indoor air and do not mitigate the vapor intrusion pathway and prevent contaminants from entering the building. APUs should be restricted to mitigation during the planning or implementation of a more reliable and robust mitigation method, i.e., sub-slab depressurization. APUs should not be relied upon for long term mitigation.

3.4 Alternative Mitigation Approaches

This section presents mitigation alternatives to depressurization systems including active pressurization systems and passive techniques that may be appropriate in some circumstances.

3.4.1 Pressurization Techniques

Pressurization techniques create a positive pressure in or beneath the building to prevent the migration of contaminants in the sub-slab soil gas into the indoor air.

3.4.1.1 Building Pressurization & HVAC Modification

In certain situations, it is possible to modify or supplement the existing heating, ventilation and air conditioning system to create positive pressure within at least the lower level of the structure to temporarily mitigate vapor intrusion. Positive pressure within the building must be consistently maintained so that advective transport of soil gas into the structure does not occur. This approach is likely to be most effective in tight, newer construction; it may be less reliable and more costly in older buildings that leak air around windows, doors, and other gaps. Heating and air conditioning systems may need to be modified from running on an as-needed basis to running continuously. Although this approach may be capable of reducing advective forces, diffusive flow may continue. Therefore, building pressurization may not be appropriate when the concentrations of contaminants in the soil gas are high. In some buildings, manipulation of the HVAC system may be too complicated to effectively mitigate the vapor intrusion pathway.

While HVAC modifications may be effective in controlling vapor intrusion for some interim time period, such modifications are not suitable as a long term mitigation measure and cannot be used to achieve a Permanent Solution. It is unreasonable to expect that running an HVAC system outside the usual range of operations will be maintained over time. Occupant activities and minor unscheduled adjustments to the HVAC system are likely to confound efforts to create positive pressure.

At buildings where establishment of a negative pressure field is difficult, steps can be taken to improve the effectiveness of the SSD system by reducing the degree of under-pressurization occurring within the basement. These include: ducting make-up air from outside the building for combustion and drafting; and/or over-pressurizing the basement by using fans to direct air from the rest of the building into the basement, or an air/air heat exchanger to direct outside air into the basement.

3.4.1.2 Sub-slab Pressurization

Sub-slab pressurization mitigates soil vapor intrusion by using a fan to create a positive pressure below the slab. The positive pressure below the slab in turn creates a barrier, preventing soil gas from entering the structure. Sub-slab pressurization may be appropriate when the sub-slab material is too permeable to allow depressurization or if flows produced by the fan are too low to effectively vent beneath the slab.

3.4.1.3 Block Wall Pressurization (BWP)

Block wall pressurization (BWP) can be used to augment sub-slab pressurization in situations where the permeability of the sub-slab material is too high to effectively depressurize. It can also be used as an alternative to block wall depressurization when depressurization has resulted in back drafting of combustion appliances. BWP may be particularly helpful when a block wall is identified as a soil gas entry route/preferential pathway. In this configuration, piping is typically inserted into the base of the block wall at one or more locations so that air blows into the wall and sub-slab environment creating a flow away from the block wall and slab.

3.4.2 Passive Techniques

Passive techniques employ the installation of a barrier or barriers to prevent the migration of contaminated vapors to the indoor air, or a passive venting system to create a preferential pathway to divert the vapors from the subsurface to the ambient air above the building.

Since passive systems are not generally as effective as active SSD systems, they should not be used to mitigate Imminent Hazards, and require sufficient monitoring to determine their effectiveness. However, if it can be demonstrated through indoor-air sampling that passive measures have mitigated the vapor intrusion pathway, and monitoring is conducted to ensure that these passive measures remain intact, these techniques may be appropriate to mitigate the vapor intrusion pathway. Periodic evaluation of passive measures used for long term mitigation is necessary to confirm the passive measures remain intact and are performing as intended (see **Table 3-2**).

3.4.2.1 Sealing of Cracks, Sumps and Utility Conduit Penetrations

Regardless of the type of measures used to mitigate soil vapor intrusion, all vapor entry routes should be sealed to prevent infiltration of soil gas. Sealing foundation penetrations will enhance the effectiveness of every type of mitigation measure, and will enable SSD systems to maintain adequate negative pressure beneath the slab. Foundation penetrations include cracks and gaps (particularly cracks and gaps in fieldstone and block foundations), sumps, floor drains, and utility conduit penetrations. Realistically, the evaluation of cracks and gaps in foundation floor slabs and walls is not always possible in finished basements where wood or carpet on floors and walls prohibit inspection. Therefore, MassDEP does not typically consider the sealing of cracks used as the sole mitigation measure in an affected building to be a measure that can be that can be adequately maintained and evaluated over time.

Sealing materials containing significant amounts of VOCs should be avoided. Smaller cracks and gaps up to 1/8 inch in diameter may be sealed with an elastomeric sealant (e.g., caulking) or insulating foam in accordance with the manufacturer's instructions. Sealant products should be specifically designed to seal concrete. Cracks and gaps larger than 1/8 inch may require a foam backer rod or other comparable filler material, or filled with non-shrinking or expanding cement material (i.e. hydraulic cement).

A sump in a basement can be a significant conduit for vapor intrusion and result in a direct connection between groundwater and indoor air. In addition, sumps can significantly short-circuit negative pressures created by the installation of an SSD system.

Sumps should be sealed with an air tight cover with a gasket to ensure an air-tight seal to the slab while facilitating easy access to the pump. Appropriate fittings should be used to ensure an air tight seal around piping and wiring. Covering and sealing the sump should be done with the knowledge that basement flooding may occur in the event that water on top of the slab drains toward the sealed sump. If flooding of the basement floor is an issue, the sump cover should be level or slightly concave allowing water to flow onto it and be fitted with a one-way drain (i.e., Dranjer-type drain) equipped with a check valve that allows water to drain into the sump but prevents soil gas from flowing into the building or conditioned air to be drawn into the sump. In addition, a check valve should also be installed in the sump drain ejection piping that pumps sump water to the outside to prevent outside air from being drawn into the sump which could short-circuit an SSD system.

Floor drains should be sealed with concrete or grout and may be subject to Underground Injection Control (UIC) closure requirements administered by MassDEP's Bureau of Resource Protection (BRP) and/or the local Building Department. Floor drains in commercial/industrial or school buildings can be particularly problematic because the water seal within the plumbing trap of these drains is often ineffective as the result of the water leaking out or evaporating from the trap. This provides a vehicle for soil gas to discharge into these areas, especially in lavatories with fans or vents that create a negative pressure in the rooms where the drains are located. Water should be added to traps periodically to maintain the water seal or a Dranjer-type seal should be installed.

Utility conduits penetrating the slab or foundation should be sealed to prevent soil gas from entering the building with closed-cell polyurethane foam or other inert gas-impermeable material. Utility bedding may be more permeable than the surrounding soil and may serve as a preferential pathway for vapor migration into a structure. Mitigation in these instances can include venting or depressurization of the utility bedding itself if sealing the utility penetration(s) is not feasible or is ineffective.

3.4.2.2 Ventilation

Ventilation as a vapor intrusion mitigation measure means opening windows, doors, vents or installing fans within a structure to increase the amount of outdoor air mixing with indoor air and reduces indoor air contaminant concentrations by dilution (provided there isn't an outside source of contaminants of concern). Ventilation solely of the upper story, however, may exacerbate the stack effect and actually draw more soil gas into the structure. Balancing ventilation between the lowest level and upper stories of a structure (i.e., opening a window on the ground floor when a window on a higher floor is opened) may lessen an increased stack effect.

Ventilation should only be considered as a measure to reduce concentrations of contaminants in indoor air while additional mitigation activities are occurring (e.g., immediately after a residential fuel oil release).

3.4.2.3 Membrane Systems

Membrane systems installed for the purpose of preventing VOC-contaminated soil gas from entering a building should not be confused with membranes used in conventional building construction to prevent the intrusion of water vapor.

Membrane systems intended to address VOCs should be installed above a gas-permeable layer to prevent soil gas migration upwards and to direct soil gas to the perimeter of the building or up and out through passive or active vent piping. Membrane systems may be composed of high density polyethylene (HDPE), low density polyethylene (LDPE), very-low density polyethylene (VDPE) sheet materials or spray-applied materials composed of a rubberized asphalt emulsion or epoxy (EPA, 2008).

While there are currently no standards for the thickness, composition, or physical properties of a membrane system that will ensure its effectiveness, it is recommended that membranes be at least 40 to 60 millimeters thick (EPA 2008), be composed of materials that are compatible with chemicals known or likely to be present at the disposal site, and be demonstrated to not significantly absorb VOCs. Using a membrane with a thickness of 60 to 100 millimeters may help reduce the potential for punctures during construction activities (e.g., cutting or grinding of rebar just above the barrier, installation of stakes for concrete forms, dropping tools, foot traffic, etc.) or from the installation of the slab after the membrane is in place (ITRC, 2007). Ultimately, the membrane should have a thickness and composition adequate to prevent vapor intrusion and withstand damage during construction. Although it is possible to install a membrane barrier as a retrofit to an existing building, these systems are generally better suited to new construction, where the appropriate amount and type of sub-slab bedding material can be specified and verified, and the proper installation of membrane barriers can be assured.

Membrane systems should undergo a comprehensive quality assurance/quality control (QA/QC) process as part of the installation procedure to ensure soil gas entry routes have been eliminated. Manufacturers of membrane systems typically have stringent QA/QC standards and testing requirements. These requirements include ensuring manufacturer recommended overlap at seams, complete welds connecting sheet materials, and effective sealing of utility penetrations through the membrane. Smoke testing is one method of testing membrane integrity and consists of pumping smoke beneath the membrane, checking for smoke penetrating the membrane, and patching areas of observed smoke penetration.

Membrane installation should be performed by a trained, experienced, and certified installer. Some manufacturers provide installer certification, or offer third party inspection services and warranties. Multiple rounds of QA/QC testing are recommended, with at least one round conducted immediately after membrane installation and at least one round after the floor system has been constructed. Repair of the membrane before the floor is installed is likely to be more straightforward and less expensive than afterward. Because a visual inspection cannot be conducted after the floor is installed, periodic indoor air monitoring for VOCs is needed to confirm that the membrane system remains effective in preventing vapor intrusion (see Tables 3-1 and 3-2).

3.4.2.4 Passive Venting

Passive venting mitigates the vapor intrusion pathway by intercepting sub-slab soil gas with a series of perforated pipes (typically 4-in. diameter), installed below the slab within in permeable bedding material, such as sand or gravel. The perforated piping is typically connected to solid piping and vented to the atmosphere above the roof line. Where possible, a membrane barrier such as that described in Section 3.4.2.3 above should be used in conjunction with a passive venting system.

A passive venting system relies instead on temperature and pressure differences, and wind speed to induce soil gas removal. As a result, it is critical that the system includes sufficient interception piping and highly permeable bedding, and that the barrier system is properly installed. Passive venting systems should be designed so that a fan can be easily added, transforming the system to an active sub-slab depressurization system if a greater reduction in the concentrations of VOCs is necessary to achieve mitigation goals; active sub-slab depressurization systems are considered more effective and reliable than passive venting systems at mitigating vapor intrusion.

Pre-fabricated floor systems that create a continuous aerated space beneath the slab or raised aerated floor above an existing slab are a form of passive venting system that eliminates the need for passive vent piping and permeable bedding material. These aerated floor systems may also, when fitted with a fan or blower, converted to an active sub-slab depressurization system.

As with the membrane barrier, passive venting systems are generally better suited to new construction, where the appropriate amount and type of sub-slab bedding material can be specified and verified, and the proper installation can be assured. A passive venting system relies instead on temperature differences, pressure differences, wind speed and barometric pressure to induce soil gas removal. As a result, it is critical that the system includes sufficient interception piping and highly permeable bedding, and that the barrier system is properly installed.

Some passive ventilation systems incorporate the use a wind-driven turbine on the top of the vent pipe to enhance flow within the passive system. If the wind-driven turbine is determined to be necessary to maintain NSR, then the system would be considered an active mitigation system and this would have implications for MCP closure as discussed in Section 4.6. Wind-driven turbines should be used with caution. Turbines will not induce the flow of sub-slab soil gas if the wind is not blowing, and may actually inhibit the flow of soil gas to the atmosphere when ice or snow accumulates on or within the turbine.

Passive venting may be effective in mitigating vapor intrusion in some situations, especially when soil gas concentrations are relatively low. However, EPA, ITRC and other sources suggest that passive systems may not reliably mitigate soil vapor intrusion during a variety of weather conditions, occupant activities, and/or appliance usage. For example:

- EPA state; "*Passive soil depressurization techniques will always be less effective than active soil depressurization. The effectiveness of passive soil depressurization techniques in existing houses is unpredictable, highly variable, and often modest, at best. Passive systems will likely find their greatest application in new construction, where features can be incorporated into the house during construction to help improve passive performance*" (EPA 1993, Section 1.4, p.3).
- ITRC lists disadvantages of passive venting systems as "*not as effective as active venting [sub-slab depressurization]; ambient temperatures and winds can adversely impact success; not suitable for existing structures unless very modest concentration reductions are required; upgrade to active venting [sub-slab depressurization] likely to be necessary for new structures when large reductions in concentrations (e.g., greater than ~90%) are required*."(ITRC, 2007, Table 4-3 Passive Venting Pros and Cons, p 47).

Where passive venting is employed to mitigate vapor intrusion at a site, post-installation indoor air monitoring is necessary to demonstrate the effectiveness of the passive system to ensure the system is reducing indoor air concentrations to the extent necessary (see **Table 3-2**).

3.5 Mitigation Demonstration of Effectiveness, Maintenance and Monitoring

As with any mitigation or remedial action conducted under the MCP, post-installation verification of system performance *and* demonstration of continued effectiveness are required. Regardless of the mitigation approach selected, indoor air sampling should be conducted after implementation to demonstrate that the approach was effective. The appropriate method, frequency and timing for demonstrating continued effectiveness will depend on the mitigation approach.

Recommended sampling and monitoring regimens for both active and passive mitigation measures are outlined in Tables 3-1 and 3-2 and discussed in this section.

3.5.1 Performance Standards

The remedial objectives and specific performance objectives for remedial measures should be specified in the relevant plan (e.g. IRA Plan, Remedy Implementation Plan (RIP)). The specific approach to demonstrating that performance standards have been and continue to be met should also be specified in the plan, and will vary depending on the type of mitigation measure employed. MassDEP's recommendations for such demonstrations are described below.

3.5.2 Demonstration of Effectiveness for Active Mitigation Systems

As discussed in Section 3.3, there are a variety of different active mitigation systems that can be implemented. This section focuses on active SSD systems, as they provide an effective, reliable and consistent means of addressing vapor intrusion.

The effectiveness of an SSD system can be demonstrated by sampling indoor air in conjunction with confirmation of a negative pressure field beneath the slab as described in Sections 3.5.2.1 and 3.5.2.2. Once the effectiveness has been demonstrated, future monitoring may be limited to measuring the negative pressure field beneath the slab and where warranted, additional indoor air sampling, as described in Section 3.5.2.3.

3.5.2.1 Indoor Air Quality Monitoring of Active Mitigation Systems

The creation of an effective sub-slab negative pressure field should result in the reduction of VOC concentrations in the indoor air within the building. After SSD system startup, indoor air quality samples should be collected to confirm that concentrations of VOCs in indoor air are reduced to the extent specified in the relevant plan. This confirmatory monitoring should be done approximately 7 days after system startup. In the case of an Imminent Hazard, sampling can be conducted as soon as 24 hours after startup.

If sampling indicates that the system as installed is not meeting specified remedial objectives, the system should be augmented, modified, or another approach selected that will achieve the goals of the response actions. These additional measures should be implemented as soon as possible, and re-sampling to determine effectiveness should be conducted as outlined in **Table 3-1**. Once the system is operating as specified, monitoring should be conducted according to the recommendations provided in Table 3-1.

Subsequent to this initial evaluation, consideration should be given to conducting one additional indoor air sampling event during the winter heating season (unless the initial evaluation is conducted during winter months) if non-winter SSD negative pressure conditions or initial indoor air sampling results were marginal.

If, despite system modifications, indoor air quality data continues to indicate elevated concentrations of VOCs, further evaluation of indoor air data and other Lines of Evidence should be conducted. Building conditions, SSD system parameters, sub-slab pressure readings, and soil gas data should be reviewed to determine whether (1) the indoor air sampling is detecting contaminants from indoor/non-site sources, or (2) the SSD system requires additional modification or expansion in the form of additional soil vapor extraction points. "Short-circuiting" problems are of particular concern, where cracks, holes, sumps, or annulus spaces in the building foundation/slab disrupt a negative pressure field.

3.5.2.2 Confirmation of Pressure Field of Active Mitigation Systems

The ongoing effectiveness of the SSD system can be demonstrated by confirming that a negative pressure field extends under the slab where VOCs are present. Pressure testing at representative "worst case" soil vapor monitoring locations after system startup should provide sufficient information to demonstrate the presence of a negative pressure field. Measurement of differential pressure is the most direct indicator of vapor extraction and should be checked periodically. After the pressure field is confirmed following system start-up, and the system is shown to be consistently effective, monitoring of the in-line manometer or other pressure gauge is generally an adequate indicator of satisfactory system operation.

As stated in Section 3.3.1.1, in buildings with very pervious sub-slab material, large volumes of air can be moved with little pressure drop. For other buildings with less pervious material beneath the slab, an SSD system designed to maintain 0.015 inches water gauge (approximately 4 Pascals) measured across the slab in mild weather with exhaust appliances off should be adequate to avoid being overwhelmed by the stack effect during winter (EPA, 1993, Section 2.3.1, p. 34). Additional sub-slab depressurization may be necessary to overcome ambient fluctuations in building pressures caused by HVAC systems, vents, fans and appliances. It is possible for taller buildings to exhibit greater stack effects due to wind effects on higher floors. Therefore, some structures may require additional sub-slab negative pressure to overcome building specific effects.

3.5.2.2 Indoor Air Quality Monitoring of Active Mitigation Systems

The creation of an effective sub-slab negative pressure field should result in the reduction of VOC concentrations in the indoor air within the building. After SSD system startup, indoor air quality samples should be collected to confirm that concentrations of VOCs in indoor air are reduced to the extent specified in the relevant plan. This confirmatory monitoring should be done approximately 7 days after system startup. In the case of an Imminent Hazard, sampling can be conducted as soon as 24 hours after startup.

If sampling indicates that the system as installed is not meeting specified remedial objectives, the system should be augmented, modified, or another approach selected that will achieve the goals of the response actions. These additional measures should be implemented as soon as possible, and re-sampling to determine effectiveness should be conducted as outlined in **Table 3-1**. Once the system is operating as specified, monitoring should be conducted according to the recommendations provided in Table 3-1.

Subsequent to this initial evaluation, consideration should be given to conducting one additional indoor air sampling event during the winter heating season (unless the initial evaluation is conducted during winter months) if non-winter SSD negative pressure conditions or initial indoor air sampling results were marginal.

If, despite system modifications, indoor air quality data continues to indicate elevated concentrations of VOCs, further evaluation of indoor air data and other Lines of Evidence should be evaluated. Building conditions, SSD system parameters, sub-slab pressure readings, and soil gas data should be reviewed to determine whether (1) the indoor air sampling is detecting contaminants from indoor/non-site sources, or (2) the SSD system requires additional modification or expansion in the form of additional soil vapor extraction points. "Short-circuiting" problems are of particular concern, where cracks, holes, sumps, or annulus spaces in the building foundation/slab disrupt a negative pressure field.

Once SSD system effectiveness has been demonstrated through concurrent indoor air sampling and collection of sub-slab differential pressure measurements, indoor air quality should continue to be acceptable as long as the differential pressures identified as being adequate during the initial sampling are maintained at the soil vapor monitoring locations across the slab. Such pressure field measurements can be used to monitor the system following the initial evaluation.

If differential pressure measurements across the slab observed during monitoring are less than those observed during the initial evaluation, the reason for the weaker measurements should be investigated and the system modified, if necessary. The indoor air should be re-sampled to determine if a change in the differential pressure is adequate to prevent vapor intrusion or to evaluate whether modifications were effective.

Although reading the magnahelic gauge from the extraction point(s) may be considered an indicator of sub-slab differential pressure, vacuum applied from the extraction point(s) may not translate into adequate differential pressure beneath the slab if, for example, short circuiting occurs. Therefore, direct measurement of the differential pressure across the slab is recommended.

3.5.2.3 Maintenance and Monitoring of Active Mitigation Systems

The primary performance criteria for active SSD systems during maintenance and monitoring is to ensure the differential pressure observed across the slab during system start up is being maintained. Monitoring the differential pressure may be accomplished by reading the manometer value at the primary extraction point(s), and ideally collecting differential pressure measurements at soil vapor monitoring points across the slab, using a magnehelic gauge or digital micromanometer with a range suitable for the vacuum encountered. The differential pressure should be checked to verify that the value is adequate to prevent vapor intrusion (i.e., equal to or greater than the differential pressure value observed at the time it was demonstrated that the indoor air concentrations were acceptable). If the differential pressure is not adequate to prevent vapor intrusion based on the original testing, the indoor air should be sampled to determine whether the observed differential pressure is effectively reducing indoor air concentrations. Annual checks for pressure drops and fan operation should be conducted while the system is in operation. Appendix IV of this document contains additional information regarding the confirmation of the pressure field of an active mitigation system.

Maintenance should be performed as necessary. Monitoring should include a visual inspection of mitigation system piping to identify cracks and gaps at joints. Condensate bypass and interior drain lines should be inspected with valves in the open position. Mitigation system monitors and alarms, including telemetry and carbon monoxide alarms, should be tested during each site visit if they are present. An inspection of the fan should include observation as to whether there is excessive noise; a visual inspection to identify vibration, moisture, or corrosion; and determination as to whether the fan cut off switch is operable. A mitigation system Completion Report with an as-built drawing of the system can be helpful during routine inspections to identify changes to the system. An example of a Sub-Slab Depressurization System Completion Report used by MassDEP is provided in Appendix IV.

The condition of basement walls and floors should be evaluated during each inspection to identify cracks and gaps or associated with utility penetrations. The location and size of cracks should be documented. Sumps should be inspected to ensure the seal for the sump is not compromised and there are no openings through which soil vapor may enter. Floor drains should be equipped with a seal that has no cracks or gaps that would allow soil vapor to enter. Any modifications to the building should be noted and an evaluation conducted to determine whether the modifications have had an impact on vapor intrusion.

If any observations are made during the inspections that indicate that the system installed or measures taken are not effective (e.g., new openings in the foundation/slab, broken or blocked piping, etc.), the necessary repairs should be made immediately and the indoor air should be sampled to demonstrate the effectiveness of repairs.

3.5.3 Demonstration of Effectiveness of Passive Mitigation Measures

Passive measures (such as passive venting systems, sealing cracks and concrete walls and floors, sealing the annular spaces around utilities, and sealing sumps) may be an alternative to active SSD systems. When passive measures are used, additional monitoring of indoor air quality is typically needed to demonstrate effectiveness, since these systems are less predictable and efficient at preventing vapor intrusion than active systems. Passive measures should not be used for mitigating Imminent Hazards.

3.5.3.1 Indoor Air Quality Monitoring of Passive Mitigation Measures

After implementation of passive measures, indoor air quality samples should be collected to confirm that concentrations of VOCs in indoor air are reduced to the extent specified in the relevant plan. Generally, this confirmatory monitoring should be done approximately seven days after the measures are completed.

The recommended sampling approach to demonstrate effectiveness of passive measures depends on the relative groundwater and sub-slab soil gas concentrations, as well as the indoor air concentrations prior to the completion of the passive mitigation measures. More extensive testing is recommended when subsurface and indoor air concentrations are higher. Recommendations for sampling to demonstrate the effectiveness of passive measures are provided in **Table 3-2** and discussed below:

- If the concentrations of VOCs in the vicinity of the building prior to implementing the passive measures are relatively low (groundwater concentrations are equal to or less than 2 times the GW-2 Standards and the sub-slab soil gas concentrations in are equal to or less than 2 times the appropriate Sub-Slab Soil Gas Screening Values in Appendix 2); and the indoor air concentrations are equal to or less than two times the appropriate Threshold Values), then indoor air sampling at least twice in the first year is recommended, with one round conducted during the heating season.

- If the concentrations of VOCs in the vicinity of the building prior to implementing the passive measures are relatively high (groundwater concentration is greater than 2 times the GW-2 Standards, and/or the sub-slab soil gas concentrations are greater than 2 times the appropriate Sub-Slab Soil Gas Screening Values in Appendix 2; and/or the indoor air concentrations are greater than two-times the appropriate Threshold Values), then quarterly indoor air sampling within the first year is recommended, with two rounds conducted during the heating season.

If sampling indicates that the measures as installed are not effective, the approach or system should be augmented, modified or another approach selected that will achieve the goals of the response actions. In cases where a passive venting system is not effective, the system should be made active by the installation of a fan or blower. These additional measures should be implemented as soon as possible, and re-sampling to determine effectiveness should be conducted following the guidelines for active systems outlined in Table 3-1 and Section 3.5.2 above.

3.5.3.2 Maintenance and Monitoring of Passive Mitigation Measures

If the passive measures are determined to be effective based on the initial sampling, on-going monitoring should consist of additional indoor air sampling conducted at a frequency commensurate with the contaminant concentrations and temporal variability that is sufficient to ensure the measures effective performance and integrity. Monitoring recommendations are provided in Table 3-2. The monitoring program should be specified in the relevant plan for the response action.

Routine inspections should be conducted as appropriate to ensure continued effectiveness and/or as required by the MCP. Their nature will depend on the specific measures implemented. For example, for a passive venting system, inspections should include a visual check of mitigation measure piping to identify cracks and gaps at joints. The as-built drawing for the system should be examined to ensure the system configuration has not been modified.

The condition of basement walls, floors and utility penetrations should be evaluated during each inspection to identify cracks and gaps. The location and size of cracks should be documented. Sumps should be inspected to ensure the seal for the sump is not compromised and there are no openings through which soil vapor may enter. Floor drains should be equipped with a seal that has no cracks or gaps that would allow soil vapor to enter. Any modifications to the building should be noted and an evaluation should be conducted to determine whether the modifications are likely to have an impact on vapor intrusion.

If any observations are made during the inspections that indicate that the measures implemented may no longer be effective (e.g., identification of new penetrations in the foundation/slab, broken or blocked piping, etc.), the necessary repairs should be made immediately and the indoor air should be sampled to confirm the effectiveness of the repairs. If it is determined that the passive measures are no longer effective, either through sampling or observation, the measures should be augmented or modified, or another approach selected that will achieve the response action goal. In cases where a passive venting system was installed, the system should be made active by the installation of a fan or blower when sampling indicates the system is not effective.

3.5.4 Monitoring Reports

Information collected during the inspections of the active systems or passive measures, including, but not limited to: pressure test data and flow rate readings, laboratory and screening results of indoor air and/or discharged vapor samples (if conducted), and any problems/changes made to the mitigation system should be included in the appropriate Status Report or Remedial Monitoring Report, as required by the MCP. MassDEP recommends keeping this information in a logbook located onsite.

3.5.5 Telemetry on Active Mitigation Systems

The MCP requires the use of telemetry or remote monitoring as part of SSD systems implemented as Active Exposure Pathway Mitigation Measures to: maintain a Permanent Solution with Conditions (310 CMR 40.1025(3)(d)); or as a component of a Temporary Solution or Remedy Operation Status (310 CMR 40.1026(3)(d)). Telemetry is required to alert the property owner, mitigation system operator, and MassDEP immediately upon failure of the system, as the result of a loss of power, mechanical failure or other significant disruption of the effectiveness of the system.

To implement telemetry on an SSD system as a requirement of maintaining a Permanent Solution with Conditions or as a component of a Temporary Solution or Remedy Operation Status, the system must be registered with MassDEP. Registration instructions titled "Remote Telemetry Information for Active Exposure Pathway Mitigation Measures" may be found on MassDEP's website at http://www.mass.gov/eea/agencies/massdep/cleanup/regulations/remote-telemetry-information.html. Telemetry systems must be set up to send information by email, text message or telephone; the website indicates the required information and format for communications from telemetry systems.

3.6 Closure Sampling to Demonstrate that Mitigation System in No Longer Required

To demonstrate that an active or passive system is no longer required to mitigate the vapor intrusion pathway, MassDEP recommends a minimum of three rounds of indoor air sampling collected over two years, with at least one round collected during the heating season (generally presumed worst-case condition), and one during any other time that might represent worst-case conditions (e.g., seasonally high water table where groundwater is shallow). Recommendations for closure sampling are summarized in Tables 3-1 and 3-2.

In the case of an active system that has been in operation, the system should be shut off prior to and during these sampling events and the vent pipe should be capped or the valve in the vent piping closed. *MassDEP recommends the system be turned off* for at least seven days prior to sampling to allow for equilibration. Once the indoor air samples have been collected, *the system should be turned back on* until the next sampling event. If it can be demonstrated that remedial objectives have been achieved without the system operating during each of the three sampling events, the system can be shut down.

In the case of a sampling to demonstrative that a passive venting system is no longer required, the passive venting system vent pipe should be capped or the valve in the vent piping closed during each of the indoor air sampling events to effectively prevent the venting.

If the closure sampling demonstrates that concentrations in indoor air are at NSR and have achieved or approached Background to the extent feasible, then the ongoing presence and maintenance of the mitigation system is not necessary to support a Permanent Solution. If, however, a barrier is a component of the system, the need to maintain the barrier would have to be assessed separately.

Refer to Section 4.6 of this document for additional information about regulatory requirements related to closure at vapor intrusion sites.

4. REGULATORY FRAMEWORK

There are a number of MCP regulatory requirements that are specific to or have special implications for the vapor intrusion pathway. This section outlines requirements related to vapor intrusion site identification and response actions, including reporting obligations, IRAs, CEPs, Tier Classification, Comprehensive Response Actions and MCP closure and AULs.

4.1 Common Reporting Obligations Related to the Vapor Intrusion Pathway

There are no Reportable Concentrations (RCs) for OHM concentrations in indoor air or soil gas; RCs only exist for groundwater and soil. However, OHM concentrations in indoor air or soil gas may constitute a separately reportable 2-hour or 72-hour reporting condition under the MCP, as discussed below.

4.1.1 Two-Hour Notifications for Imminent Hazards

Pursuant to 310 CMR 40.0311(7), a release of OHM that poses or could pose an IH, as described in 310 CMR 40.0321 and 40.0950, must be reported to MassDEP within 2 hours of knowledge of the condition. The following conditions that pose or could pose an IH are potentially relevant to the vapor intrusion pathway and require reporting to MassDEP within 2 hours:

- A release resulting in OHM in structures at a concentration equal to or greater than 10% of the Lower Explosive Limit (310 CMR 40.0321(1)(a));
- A release which poses a significant risk to human health when present for even a short period of time as specified in 310 CMR 40.0953 (310 CMR 40.0321(1)(d));
- A release to the environment which produces readily apparent effects to human health including respiratory distress or dermal irritation (310 CMR 40.0321(1)(f)); and
- A release to the environment for which estimated long-term risk levels associated with current exposures are greater than ten times the Cumulative Receptor Risk Limits in 310 CMR 40.0993(6) (310 CMR 40.0321(2)(c)).

To evaluate whether a condition related to OHM in indoor air is an IH based on risk levels, an IH Evaluation of human health risk must be conducted in accordance with 310 CMR 40.0950. This evaluation is focused on actual or likely exposures to humans under *current* site conditions (310 CMR 40.0953). In the case of vapor intrusion, this means consideration of the current occupants and their likely exposures given how the structure is used. Additional discussion of exposure assessment and risk characterization is found in Sections 2.3 and 2.4. Additional guidance on conducting risk characterizations is provided in MassDEP's *Guidance for Disposal Site Risk Characterization*.

A unique IH concern may occur at vapor intrusion sites where trichloroethylene (TCE) is an indoor air COC. TCE is considered to pose a short term exposure risk of heart malformations in developing fetuses in the early stages of pregnancy (first 8 weeks).

MassDEP may set short IRA deadlines for taking actions to investigate the potential for and reduce TCE exposures in indoor air, particularly where women who are or may become pregnant are receptors. MassDEP has published information regarding IH concentration triggers and timeframes for IRAs at TCE sites at http://www.mass.gov/eea/docs/dep/cleanup/laws/tcevalsm.pdf as well as fact sheets about TCE in workplace and residential indoor air, and an example of a TCE Imminent Hazard Notice (available under the Technical Support Documents section at http://www.mass.gov/eea/agencies/massdep/cleanup/regulations/site-cleanup-policies-guidance.html).

4.1.1.1 IH Evaluation with On-going Commercial or Industrial Operation

When a vapor intrusion evaluation is being conducted for a building with an on-going commercial or industrial operation, the vapor intrusion pathway need not be considered in an IH evaluation if permitted discharges from the operations result in the same chemicals being present in indoor air at concentrations higher than the estimated contribution from the vapor intrusion pathway (see Section 2.3). This is consistent with the focus of the IH evaluations in 310 CMR 40.0953 on current site uses and site conditions.

It is important to stress that this consideration applies only to ongoing business, commercial and/or industrial operations that are actively using the same chemicals subject to vapor intrusion in a licensed and permitted manner. Vapor intrusion into neighboring buildings or spaces that are NOT covered under such license or permit should be considered in an IH evaluation (e.g., neighboring/common-wall businesses in a strip mall containing a dry cleaner should be evaluated for Imminent Hazards via this pathway). Moreover, this consideration would no longer be applicable if and when the site or building use changes (e.g. when an active dry cleaning operation is terminated).

4.1.2 72-Hour Notifications Potentially Relevant to the Vapor Intrusion Pathway

A Condition of Substantial Release Migration (SRM), where such condition is associated with a release for which notification otherwise is or has at any time in the past been required, must be reported to MassDEP within 72 hours of knowledge of the condition.

Specific Conditions of SRM related to vapor intrusion are listed in 310 CMR 40.0313(4). They include:

- 310 CMR 40.0313(4)(a) - releases that have resulted in the discharge of separate-phase oil and/or separate-phase hazardous material to surface waters, buildings, or underground utilities or conduits; and

- 310 CMR 40.0313(4)(f) - releases to the groundwater or to the vadose zone that have resulted or have the potential to result in the discharge of vapors into a School, Daycare or Child Care Center or occupied Residential Dwelling.[6] Conditions that indicate a potential discharge of vapors into a School, Daycare or Child Care Center or occupied Residential Dwelling include, but are not limited to:

1. soil or soil gas impacted with one or more volatile organic compounds within six feet, measured horizontally from the wall of the structure, and within ten feet measured vertically from the basement floor or foundation at concentrations that are likely to discharge vapors into the structure;

2. one or more volatile organic compound in the groundwater exceed the applicable Groundwater Category GW-2 Standard within 30 feet of the structure, and the average annual depth to groundwater in that area is 15 feet or less;

3. volatile light non-aqueous phase liquid (LNAPL) is present in a groundwater monitoring well, excavation, or subsurface depression within 30 feet of the structure at a measured thickness equal to or greater than 1/8 inch (0.01 feet); or

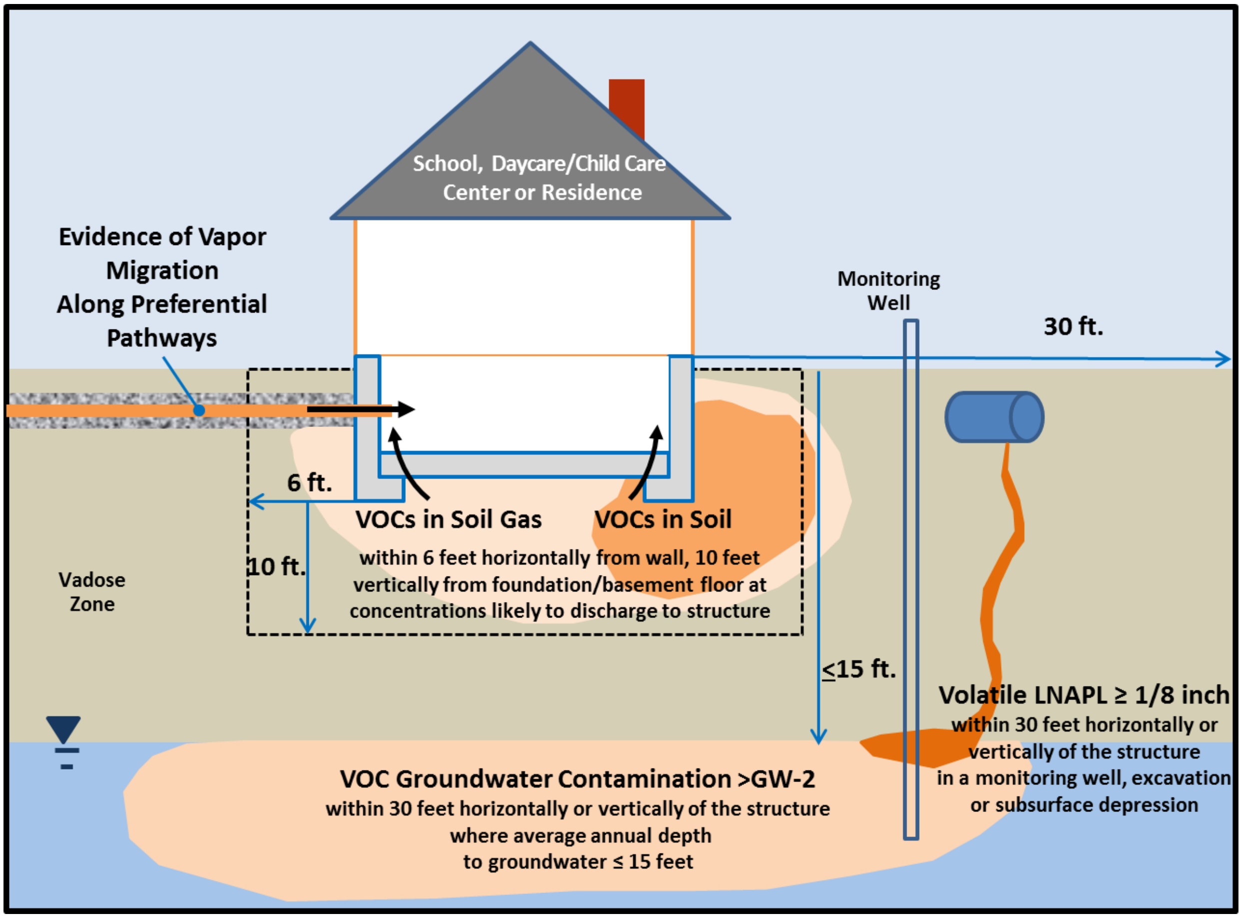
4. evidence of vapor migration along preferential pathways at a location that is likely to result in the discharge of vapors into the structure.

The SRM notification triggers at 310 CMR 40.0303(4)(f) related to potential vapor intrusion at Schools, Daycare or Child Care Centers, or Occupied Residences are depicted in **Figure 4-1** below.

With respect to evaluating the SRM conditions at 310 CMR 40.0313(4)(f)1., MassDEP recommends comparing contaminant concentrations in sub-slab soil gas to the applicable Sub-Slab Soil Gas Screening Values (SSGSV) in Appendix II of this guidance. Soil gas contaminant concentrations exceeding the applicable SSGSV would be considered “likely to discharge vapors into the structure.” If the building under investigation has a history of OHM use, and sub-slab soil gas contaminant concentrations are below SSGSV, further investigation may still be necessary to fully determine the nature and extent of contamination before ruling out the pathway. Limited sampling that detects relatively low contaminant levels may indicate that there are areas of contamination not yet identified or adequately characterized. Timely sampling is important if there is any indication of the potential for source-level contamination near a building. The relationship between VOCs in soils and the potential for vapor intrusion is complex and highly variable. As such, MassDEP currently does not provide soil screening values to screen for potential vapor intrusion concerns. Potential vapor intrusion impacts from soil were not addressed in the development of the Method 1 Soil Clean-up Standards; likewise MassDEP has not developed *de minimis* soil levels below which vapor intrusion is unlikely to occur. LSPs, therefore, should exercise professional judgment in evaluating whether VOC contamination in soils is likely to result in vapor intrusion into a structure.

[6] See 310 CMR 40.0006(12) for definitions of “School,” “Daycare or Child Care Center,” and “Residential Dwelling.”

Figure 4-1: 72 Hour SRM Notification Triggers – Schools, Daycare or Child Care Centers, Occupied Residences (310 CMR 40.0313(4)(f))



When evaluating soil contamination near structures, consideration should be given to the type of contaminant, concentrations and variability, the distance from the structure, soil type, and whether the soil contamination is indicative of a source at/near the structure. When VOC soil contamination is detected near structures, follow-up sub-slab soil gas sampling is recommended to determine whether vapor intrusion is likely. Sub-slab soil gas data generally provides a clearer indication of the potential for vapor intrusion than soil data.

The requirement to report a Condition of SRM applies only when there is evidence associating the condition with a release "for which notification otherwise is or has at any time in the past been required in accordance with 310 CMR 40.0300" (310 CMR 40.0313(4)). This means that if groundwater or soil concentrations at the source of a release do not and have never exceeded the applicable Reportable Concentrations, and the release does not trigger other notification criteria, then a Condition of SRM would not require reporting. Note, where the contamination found is below Reportable Concentrations, it may be that higher levels of contamination are present but have not yet been identified. In such cases additional investigation is warranted to confirm that the low levels of contamination are representative of the area under investigation.

4.1.3 Notification and Releases to the Interior of Buildings

If a release of OHM is completely contained within a building (i.e., the OHM never reaches the environment), the release is exempt from the notification under the MCP (310 CMR 40.317(19)(b)). A common example of this is a release from a leaking or overfilled free-standing fuel oil storage tank in a basement. MassDEP considers this notification exemption appropriate when a preponderance of the evidence indicates that less than the Reportable Quantity (e.g., 10 gallons for fuel oil) has reached environmental media from within the building (e.g., after flowing through cracks in a concrete basement floor or into an unlined sump) over a 24-hour period. Releases to earthen floors in buildings are releases to soil (the environment), and therefore require notification based on the MCP's notification requirements.

> Releases that are "completely contained within the building" may result in impacts to indoor air; however, any such impacts would not be addressed under the MCP where the OHM does not otherwise impact the environment above a reportable level.

A 120-day reporting obligation pursuant to 310 CMR 40.0315 may still exist if environmental releases of oil and/or waste oil less than the Reportable Quantity contaminate more than 2 contiguous cubic yards of soil at levels exceeding an applicable soil Reportable Concentration or if environmental releases of hazardous materials in amounts less than the Reportable Quantity contaminate groundwater at levels exceeding a Reportable Concentration applicable at the site.

4.1.4 Downgradient Property Status

Buildings affected by a vapor intrusion pathway are often located on properties downgradient of the property where the OHM contaminant plume originates (i.e., the upgradient source property). Such downgradient affected buildings are considered part of the disposal site.

Owners of such downgradient affected buildings may qualify for Downgradient Property Status (DPS) pursuant to the provisions at 31 CMR 40.0180. To qualify, the downgradient property owner filing DPS may not be affiliated with the upgradient source property.

The DPS submittal must provide an evaluation of groundwater flow direction, document that the contamination affecting their building and property is coming from an upgradient location, and indicate on a plan the locations of any known or suspected sources of the OHM that is affecting their property. The DPS submittal must also include an evaluation of the need to conduct Immediate Response Actions. With respect to vapor intrusion concerns, this would include whether IRAs are warranted to further assess or mitigate the vapor intrusion pathway.

DPS has the effect of relieving the downgradient property owner from conducting Tier Classification and Comprehensive Response Action to achieve a Permanent Solution for the larger disposal site and paying Tier I or Tier II annual compliance fees.

To maintain DPS (310 CMR 40.0185), current owners of the downgradient property must provide reasonable access to the property by persons conducting response actions (e.g., the upgradient source property owner or operator) as well as MassDEP staff and its contractors. Persons with DPS must also take reasonable steps to prevent exposure of human and environmental receptors to OHM. This includes not making exposures worse through alterations of the building or property. Maintenance of DPS also requires performing Immediate Response Actions, if necessary. This may include implementing vapor intrusion mitigation measures where the source property owner has not been identified or is unable or unwilling to take necessary mitigation steps.

4.2 Immediate Response Actions

IRAs must be conducted at sites that require notification to the MassDEP under the 2- or 72-hour reporting provisions of 310 CMR 40.0313 or 40.0312, including those with an IH (310 CMR 40.0412). The MCP requires (310 CMR 40.0411(1)(a)) that an IRA abate, prevent, or eliminate IH conditions. In addition, pursuant to 310 CMR 40.0414(3), IRAs are presumed to require the elimination and/or mitigation of CEPs, as discussed further in Section 4.3.

A variety of approaches for the mitigation of vapor intrusion, as described in Section 3, may be part of an IRA. An IRA conducted under the MCP requires submittal to MassDEP of an IRA Plan, IRA Status Reports and, where Active Operation and Maintenance of a remedial action is occurring (this would include use of an AEPMM), Remedial Monitoring Reports (RMRs).

4.2.1 Immediate Response Action Submittals

The standard submittal schedule for IRA Plans, and Status Reports is the following:

1. Submittal of an IRA Plan within 60 days of providing oral notification of a 2-hour or 72-hour release or threat of release, knowledge of a Condition of Substantial Release Migration, or from the date that the Department issues a Notice of Responsibility for a disposal site at which an IRA is required (310 CMR 40.0420(7));
2. Submittal of a written IRA Status Report within 120 days after the date on which the intent to conduct the IRA was first communicated to the Department (310 CMR 40.0425(1)), and every six months thereafter, until an IRA Completion Report is submitted (310 CMR 40.0425(2)).

The frequency at which RMRs are required to be submitted in addition to Status Reports depends on the conditions being addressed by the remedial action. Initially, RMRs are required monthly if the system is addressing an Imminent Hazard or Condition of Substantial Release Migration; otherwise the RMR is required every six months (which corresponds with the frequency of the Status Report submittal). As described below, the frequency of submitting both Status Reports and RMRs may also be reduced where certain requirements are met.

4.2.1.1 Reduced IRA and Status Report Frequency

There are specific provisions that provide for reducing the frequency of IRA Status Reports and RMRs when the ongoing Active Operation and Maintenance of remedial action conducted as an IRA is limited to operation of an AEPMM. Pursuant to 310 CMR 40.0425(5), **for disposal sites where IRAs are being taken solely to eliminate, mitigate or prevent a CEP that does not pose an IH** with the use of an AEPMM, the frequency of IRA Status Reports may be reduced **from every six months to annually**, once the following information is submitted:

1. Results of sampling demonstrating the AEPMM is effectively maintaining, at a minimum, NSR for the Receptors of Concern;
2. A listing of the specific system conditions, operating parameters, and/or maintenance necessary for ensuring the ongoing effectiveness of the AEPMM in maintaining NSR for the Receptors of Concern;
3. A description of a monitoring program designed to ensure the ongoing effectiveness of the AEPMM in maintaining NSR for the Receptors of Concern; and
4. An LSP Opinion supporting a reduced reporting schedule pursuant to 310 CMR 40.0425(5)(b) as being adequate to document the ongoing IRAs.

Where the schedule for Status Reports is reduced pursuant to 310 CMR 40.0425(5), the frequency of RMR submittals is also reduced to an annual submittal; RMRs in such cases are to be submitted with the Status Report (310 CMR 40.0425(7)(c)).

For disposal sites where the AEPMM is operating to address an IH, the Department may consider and approve alternate schedules or Interim Deadlines for submitting RMRs pursuant to 310 CMR 40.0425(7)(d). In such cases, a reduced RMR schedule may be appropriate where sufficient measures have been put in place to ensure the effective monitoring of the AEPMM, such as use of remote monitoring on the AEPMM and/or a schedule for indoor air testing to confirm the mitigation system's effectiveness.

For disposal sites where active remedial systems and/or continuing response actions are being taken as IRAs to address an IH, 310 CMR 40.0426(6) includes specific requirements for IRA termination. These IRAs must not be terminated until the response objectives and/or approval conditions have been met and approval for termination has been obtained from the Department. Requests to terminate these systems must be supported by data, documentation and technical information sufficient to justify the cessation of the IRA. Approval can be presumed if the Department does not issue a written approval or denial within 21 days of the receipt of the termination request.

4.3 Critical Exposure Pathways

> Critical Exposure Pathways mean those routes by which oil and/or hazardous material(s) released at a disposal site are transported, or are likely to be transported, to human receptors via:
> (a) vapor-phase emissions of measurable concentrations of oil and/or hazardous materials into the living or working space of a pre-school, daycare, school or occupied residential dwelling; or
> (b) ingestion, dermal absorption or inhalation of measurable concentrations of oil and/or hazardous materials from drinking water supply wells located at and servicing a pre-school, daycare, school or occupied residential dwelling.

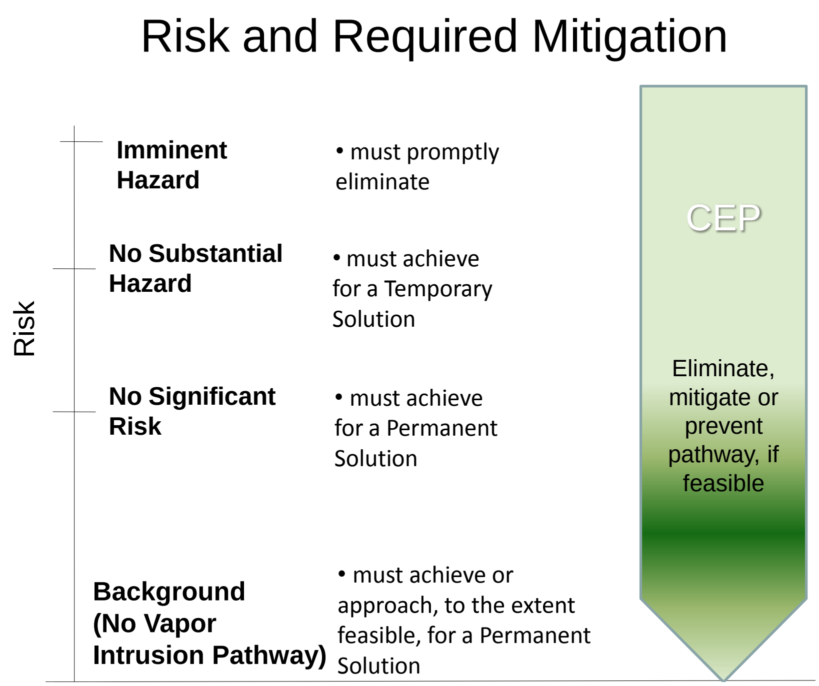
The CEP requirements in the MCP ensure that timely action is taken, where feasible, to protect sensitive human receptors from exposures to disposal site-related contaminants in indoor air or in drinking water, while a disposal site is under investigation and remediation. When conducting an IRA, the presence of a CEP triggers consideration of expedited action to eliminate and/or mitigate the CEP. This requirement reflects the concern that given the toxicological and site characterization uncertainties and the range of relatively low-cost, effective mitigation measures available to address these exposure pathways in many if not most cases, there is benefit in taking prompt response actions to reduce the OHM exposure to sensitive populations, such as infants, children, pregnant women, and those who are ill or have compromised immune systems in school buildings, daycares and occupied residential dwellings.

As depicted in Figure 4-2 below, the requirement to eliminate, mitigate or prevent a CEP, where feasible, as part of an IRA applies regardless of the quantitative level of risk.

This guidance addresses only CEPs related to vapor-phase emissions (i.e. vapor intrusion). CEP applies to current building uses. However, evaluating whether a CEP exists at a site is not a one-time-only event. For example, a CEP could exist once a previously vacant building with measured OHM in indoor air is occupied for residential use.

The locations where CEP conditions apply are outlined in the MCP definition specifically as “the living or working space of a pre-school, daycare, school or occupied residential dwelling.” The MCP also defines the terms “School,” “Daycare of Child Care Center,” “Residential Dwelling,” and “Living and Working Space” at 310 CMR 40.0006(12). The definition of Daycare or Child Care Center excludes occasional, short-term, and informal child care arrangements. The definition of Living or Working Space includes space with the potential for use for more than an hour at a time; basements used only for storage or periodic laundry are not included.

Figure 4-2: Risk and Required Remediation



4.3.1 CEP Feasibility Evaluations

The MCP presumes that an IRA will eliminate and/or mitigate an existing CEP (310 CMR 40.0414(3)). However, the presumption that response actions are required as part of an IRA to eliminate, mitigate or prevent a CEP may be rebutted based on consideration of feasibility, pursuant to 310 CMR 40.0414(3) and (4), *as long as the CEP does not also present an Imminent Hazard*.

No CEP feasibility evaluation is required if an IRA is implemented that eliminates the CEP; the elimination of the CEP would be documented in the IRA Completion Statement.

The conceptual and regulatory tenets of feasibility and feasibility evaluations are contained in the feasibility criteria found in Section 3A(h) of M.G.L. c. 21E and incorporated into the MCP at 310 CMR 40.0860. These criteria include whether or not a technology exists, expertise is available, a disposal location (if needed for the remedy) is available, and whether the costs of the remedial action outweigh the benefits (cost-benefit analysis). Additional guidance on these criteria is provided in MassDEP Policy #WSC-04-160, *Conducting Feasibility Evaluations under the MCP*. As stated at 310 CMR 40.0860(7)(a), in such a cost-benefit analysis the benefits shall justify the costs unless “the incremental cost of conducting the remedial action alternative is substantial and disproportionate to the incremental benefit of risk reduction, environmental restoration, and monetary and non-pecuniary values."

Sections 4.3.2 and 4.3.3 identify response actions that MassDEP considers to be generally feasible and generally infeasible, respectively, when conducting response actions to address CEPs related to vapor intrusion. Section 4.3.4 lists factors to be considered when rebutting the presumption for CEP elimination/mitigation as an IRA. Figure 4-3 illustrates how considerations of feasibility are incorporated into the decision-making process at sites where a CEP has been identified.

4.3.2 Generally Feasible Response Actions to Address CEP

The installation of an active SSD system is generally considered a technologically feasible and cost effective approach to eliminate a CEP. The feasibility of this approach may be rebutted as part of a CEP Feasibility Evaluation based on site-specific considerations such as environmental and/or building characteristics. The rebuttal of the presumption for CEP elimination or mitigation via an active SSD system must include a CEP Feasibility Evaluation to determine which, if any, response actions are feasible to eliminate CEP. If no response actions are determined to be feasible to eliminate CEP, the feasibility study must also include an evaluation of the feasibility of response actions to mitigate CEP by reducing the level of OHM exposure to the extent feasible (see Section 4.3.3).

4.3.3 Generally Infeasible Response Actions to Address CEP

At owner-occupied residences with a CEP that does not pose a Significant Risk, MassDEP considers response actions to eliminate or mitigate CEP conditions to be infeasible if the owner-occupant will not agree to allow actions to address the CEP conditions. Documentation of the PRP/LSP's efforts to conduct measures to address CEP conditions at the residence should be provided in the CEP Feasibility Evaluation.

4.3.4 Rebutting the MCP Presumption for CEP Elimination/Mitigation

Where there is no IH condition, the PRP may rebut the presumption of the need for response actions as part of an IRA to address a CEP (310 CMR 40.0414) based upon a showing by a preponderance of evidence that such response actions are not feasible, using the feasibility criteria outlined in 310 CMR 40.0860. The feasibility evaluation includes a cost/benefit analysis to determine whether the costs of eliminating or mitigating the CEP would be substantial and disproportionate to the benefits. Note that this CEP Feasibility Evaluation only addresses actions to be taken as part of an IRA

The feasibility of *eliminating* the CEP and the feasibility of *mitigating* the CEP must be evaluated separately and sequentially pursuant to 310 CMR 40.0414(3), which codifies a preference for elimination of exposure to sensitive populations rather than merely reducing such exposures. The feasibility of eliminating CEP is considered first, and the feasibility of CEP mitigation is evaluated only if elimination of the CEP is determined not to be feasible. The feasibility of CEP mitigation should be evaluated and documented in a manner similar to feasibility of CEP elimination (see Figure 4-3).

CEP Feasibility Evaluations should consider the following when evaluating the risk-reduction benefits of eliminating or mitigating a CEP: the health benefits of quick reductions in exposure, especially when the site-related OHM have high toxicity and/or persistence; the uncertainty of the current risk estimates considering the quality/quantity of available data; and the likelihood that vapor intrusion elimination or mitigation will be needed to achieve NSR and a Permanent Solution.

Site-specific costs that may affect the feasibility of eliminating or mitigating a CEP would likely be an issue at buildings with the need for: reconstruction of basement walls or pouring of new slabs; installation of raised floors for SSD system installation due to the presence of a high groundwater table; or an excessive number of extraction points and fans due to poor sub-slab communication with the area of known contamination. Increased costs alone would not necessarily support a conclusion that CEP elimination or mitigation activities are not feasible, as these costs must be weighed against the benefits provided by the risk reduction.

The Feasibility Evaluations for a CEP elimination/mitigation systems should anticipate operation and maintenance costs for a period of 3 to 5 years (the time typically taken to complete a Phase II Comprehensive Site Assessment and attain a Permanent or Temporary Solution), as well as the benefits from risk reduction accrued over the same period of time. If the subsequent Phase II Assessment concludes that Comprehensive Remedial Actions are required to achieve a Permanent or Temporary Solution (conditions pose a Significant Risk), a comprehensive Phase III evaluation of remedial alternatives must also be performed. Where remedial actions are necessary to achieve a Permanent Solution, the Phase III evaluation of remedies must consider reducing OHM in the environment to the extent feasible.

4.3.5 Documentation of a CEP Feasibility Evaluation

Appropriate documentation of the feasibility evaluation should be provided in the relevant Response Action submittal(s). Documentation for a CEP Feasibility Evaluation should include:

1. a description of the CEP as it relates to the disposal site Conceptual Site Model;
2. a list of measures evaluated to prevent, eliminate or mitigate the CEP;
3. estimated costs of the measures and an explanation of how the costs were determined;
4. an evaluation of the relative effectiveness of each measure or combination of measures considered;
5. a description of the basis for determining whether the measures are feasible or infeasible; and

6. a statement identifying the measure or combination of measures chosen to address the CEP, if any.

The documentation should distinguish between the feasibility evaluation for eliminating CEP and that for mitigating CEP. The recommendation documented in a CEP Feasibility Evaluation may result in Response Actions to eliminate and/or mitigate the CEP, or it may result it no action being taken as part of an IRA (in cases where it is not feasible to eliminate or mitigate the CEP). An IRA Completion Report would be submitted in cases where addressing CEP is determined to be infeasible and no response actions are otherwise being performed as an IRA.

CEP Feasibility Evaluations usually address affected buildings individually. It is important to distinguish between CEP Feasibility Evaluations and Phase III Feasibility Evaluations, which are performed following Phase II Assessments concluding that response actions are needed to address Significant Risk at a site. Phase III Feasibility Evaluations consider the feasibility of implementing various remedial alternatives and look at the entire site comprehensively, especially in terms of addressing the source of the contamination.

4.3.6 CEP Closure - Immediate Response Action Completion (IRAC) Criteria and Possible Outcomes

The requirements for closure of IRAs are specified at 310 CMR 40.0427. An IRA is considered complete when the condition which gave rise to the need for the IRA has been assessed and, where necessary, remediated in a manner and to a degree that will ensure: (a) that the site is stabilized; (b) IHs are addressed without the continued operation and maintenance of Active Remedial Systems or AEPMMs or by the incorporation of ongoing response actions to eliminate or control the IH into the Phase IV Remedy Implementation Plan for the disposal Site, and (c) time-critical measures addressing the elimination, prevention or mitigation of CEP(s) have been completed.

As required by 310 CMR 40.0427(1)(c), one of four conditions must be met and documented in a LSP Opinion to support the completion of response actions to address a CEP pursuant to this provision. These conditions are:

1. the CEP has been eliminated using passive measures;

2. a feasibility study, as specified at 310 40.0414(3) and (4), supports the conclusion that it is not feasible to eliminate, prevent, or mitigate the CEP;

3. a feasibility study, conducted as part of a Phase III evaluation of Comprehensive Remedial Alternatives as specified in 310 CMR 40.0860, supports the conclusion that it is not feasible to eliminate, prevent, or mitigate the CEP(s) as part of the Comprehensive Remedial Alternative; or

4. mitigation of CEP(s) is continuing by incorporation of ongoing response actions to address the CEP(s) into the Phase IV Remedy Implementation Plan for the disposal site.

These four conditions or possible points at which an IRAs implemented to address the CEP may be closed are discussed in more detail below.

4.3.6.1 CEP Elimination is Feasible

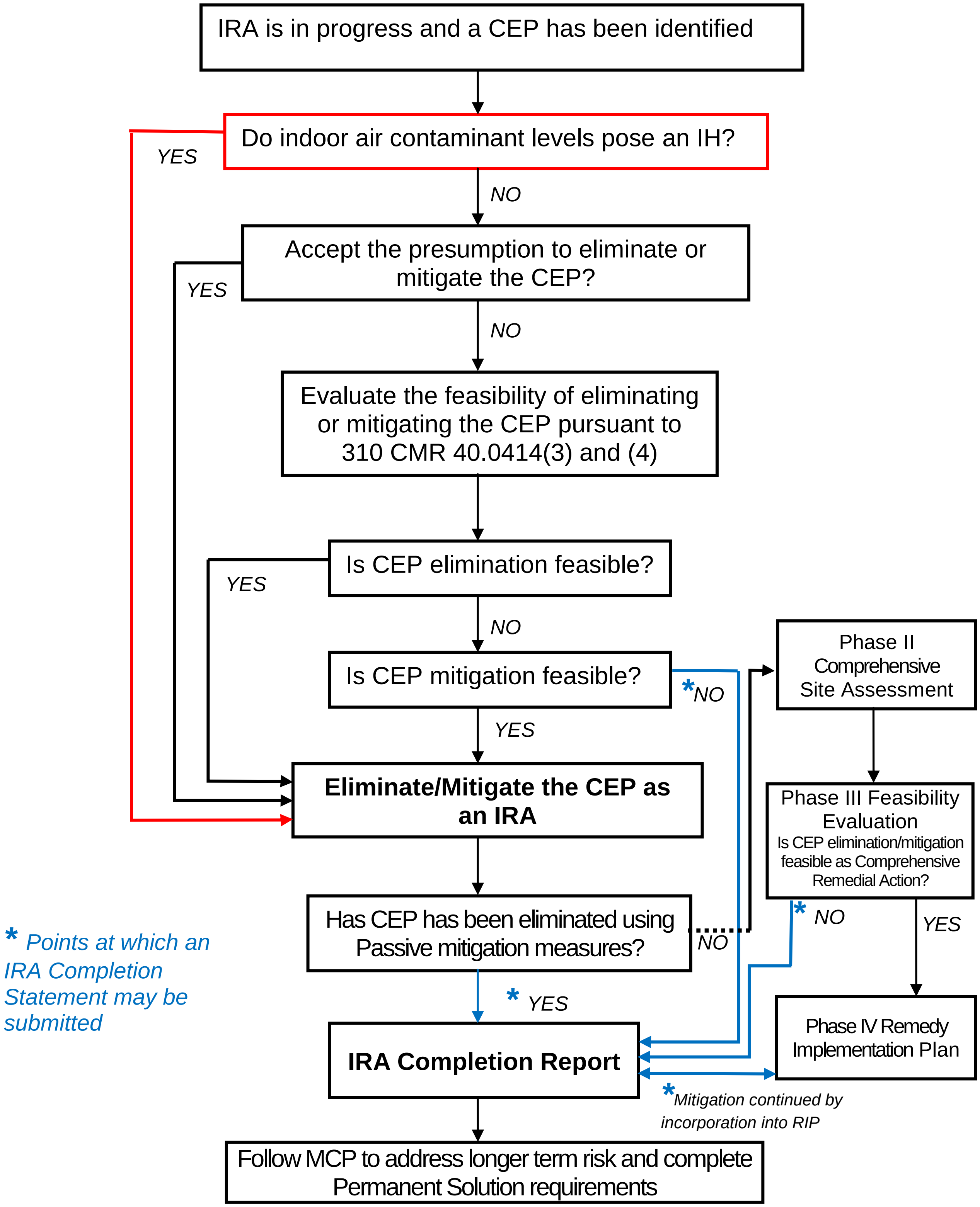
When the CEP condition has been eliminated using passive measures (see Section 3.4.2), an IRAC Report may be submitted to document the completion of the IRA activities related to eliminating the CEP. The conclusion that CEP has been eliminated must be supported by indoor air data. Table 3-2 provides recommended Sampling to Demonstrate Effectiveness for passive measures. The IRAC Report can be submitted regardless of the status of other response action activities, assuming there are no other conditions that must be addressed under the IRA. Following submittal of an IRAC Report, assessment and remediation would continue at the site under the MCP process (Figure 4-3).

If the CEP condition has been eliminated with the ongoing operation of an Active Remedial System or AEPMM, an IRAC may not be submitted until after the completion of a Phase II Comprehensive Site Assessment. In cases where the operation of the Active Remedial System or AEPMM is to be continued as part of Comprehensive Remedial Actions, the IRAC Report would be submitted after a Phase III evaluation and selection of a Comprehensive Remedial Action alternative has been conducted and in conjunction with the Phase IV Remedial Implementation Plan (i.e., the IRAC is closed when the work is transferred under the umbrella of Phase IV). The conclusion that CEP has been eliminated through the effective operation of an Active Remedial System or AEPMM must be supported by indoor air data. Table 3-1 provides recommended Sampling to Demonstrate Effectiveness for active measures.

4.3.6.2 It is not Feasible to Eliminate <u>or</u> Mitigate CEP

When vapor intrusion does not pose an IH, a CEP feasibility study may be undertaken to rebut the presumption for conducting IRA response actions to address the CEP condition, as discussed in Section 4.3.4. One possible result of the CEP feasibility study may be that neither elimination nor mitigation of the CEP is feasible, based on consideration of anticipated benefits and costs. In this situation, an IRAC Report would be submitted to document that conclusion. Following submittal of an IRAC Report, assessment and remediation would continue at the site under the MCP process (Figure 4-3). Long-term risk from the CEP condition would need to be part of the disposal site-wide evaluation of Comprehensive Remedial alternatives in the Phase III feasibility evaluation.

Figure 4-3: Addressing Critical Exposure Pathways from Vapor Intrusion



4.3.6.3 CEP Elimination is not Feasible, but CEP Mitigation is Feasible

If the CEP feasibility study concludes that CEP elimination was not feasible (i.e., the vapor intrusion impacts cannot be completely interrupted or prevented), but CEP mitigation that results in some reduction of OHM in indoor air is feasible, mitigation activities would be required. These activities should be evaluated and monitored for effectiveness with consideration given to the sampling recommendations outlined in Tables 3-1 and 3-2. If monitoring indicates that indoor air contaminant levels are above NSR without continued operation of the mitigation system, the CEP mitigation would need to be continued and may be incorporated into Comprehensive Response Actions for the disposal site (see Section 4.3.6.4 below).

4.3.6.4 CEP Mitigation is Incorporated into Comprehensive Response Actions

Ongoing response actions to monitor and mitigate CEP conditions will generally be incorporated into the Comprehensive Response Actions for the disposal site, including a Phase II Comprehensive Site Assessment and a Phase III Identification, Selection and Evaluation of Comprehensive Remedial Action Alternatives. The IRA addressing CEP may be closed with an IRAC Report upon submittal of a Phase IV Remedy Implementation Plan. The IRAC Report cannot be submitted before the Phase III Feasibility Evaluation if response actions were taken to eliminate or mitigate a CEP. If the CEP condition hasn't been eliminated, the IRA could continue to mitigate the CEP during Phase II and Phase III until the Phase III Feasibility Evaluation is completed. If initial testing results indicate that the CEP mitigation is effective, continued monitoring may be performed as part of Phase IV activities. The continued operation of the mitigation measure would move forward as part of Comprehensive Response Actions.

4.3.6.5 CEP Elimination or Mitigation is Concluded with a Permanent Solution for a Portion of a Disposal Site

In MassDEP's experience, there is a potential for significant variability in groundwater, soil gas and indoor air contaminant concentrations at disposal sites where vapor intrusion is a pathway of concern. This variability raises concerns about Permanent Solution for individual buildings (i.e., Permanent Solutions for a portion of a disposal site) with CEP conditions that are the result of a groundwater contaminant plume where a Permanent Solution has not yet been achieved for the entire disposal site. A Permanent Solution for an individual building may only be supported when the requirements related to Source Elimination and Control, Migration Control and NAPL (310 CMR 40.1003(5) through (7)) have been met *for the disposal site* and when indoor air concentrations of disposal site-related OHM are shown to pose NSR, (with or without the post-closure operation of an AEPMM) based on adequate data collected to reflect any temporal variability of contaminant levels in indoor air, sub-slab soil gas, and groundwater considering the recommended sampling to support closure provided in Tables 3-1 and 3-2, as applicable. For more discussion of requirements related to Permanent Solutions, see Section 4.6.

4.4 Tier Classification and the Indoor Air Pathway

Tier Classification of a disposal site as either Tier I or Tier II is required within one year from the initial release notification after the completion of a Phase I Initial Site Investigation. Disposal sites are classified as Tier I if they found to meet one or more of the criteria specified at 310 CMR 40.0520(2). These criteria generally reflect conditions that may be indicative of a higher level of risk or warrant closer oversight by the Department. Disposal sites that do not meet any of the Tier I criteria are classified as Tier II disposal sites.

Conditions related to the vapor intrusion pathway that will, based on the Tier I Criteria, result in a Tier I Classification include:

- OHM levels in indoor air pose an IH (310 CMR 40.0520(2)(b));
- one or more remedial actions are required as part of an IRA to address the indoor air pathway (310 CMR 40.0520(2)(c)); or
- if there is an IRA ongoing (whether it involves assessment or remedial actions) to eliminate or mitigate a CEP related to vapor intrusion (310 CMR 40.0520(2)(d)).

4.4.1 Reclassification after an Initial Tier Classification

Pursuant to 310 CMR 40.0530(1), at any point new or additional data is obtained after the initial Tier Classification that is reasonably likely to result in a reclassification of a disposal site from Tier II to Tier I, the disposal site must be re-evaluated using the Tier I Criteria at 310 CMR 40.0520(2). Reclassification of a disposal site from Tier II to Tier I must occur within 60 days of obtaining knowledge that the disposal site meets the Tier I Criteria (310 CMR 40.0530(2)). Reclassification may be done to downgrade a disposal site from Tier I to Tier II at any point that the disposal site is determined to no longer meet any of the Tier I Criteria (310 CMR 40.0530(3)).

Example Vapor Intrusion Scenario 1

At the time of the initial Tier Classification based on a Phase I Site Investigation, a disposal site was classified as Tier II because it was determined that none of the Tier I Criteria at 310 CMR 40.0520(2) applied.

During subsequent site characterization, VOCs were detected above GW-2 Standards within 30 feet of an occupied Residential Dwelling where the depth to groundwater was 10 feet and a 72-hour notification was made for this Condition of SRM. An assessment–only IRA was undertaken. Thus far, reclassification of the disposal site is not required because the IRA did not included remedial actions (no containment or removal actions were taken) and no other Tier I criteria are (as of yet) met.

Additional assessment performed as part of the IRA (collection of sub-slab soil gas and indoor air samples) reveals OHM in indoor air attributable to the disposal site (measurable concentrations in Living or Working Space) and therefore a CEP is present. At this point, the disposal site must be reclassified as Tier I within 60 days of obtaining such knowledge, pursuant to 310 CMR 40.530(2).

4.5 Comprehensive Response Actions at Vapor Intrusion Sites

4.5.1 Considerations for Phase III Feasibility Evaluations

Phase III feasibility evaluations for addressing vapor intrusion pathways are based on the same statutory and regulatory technical and cost/benefit feasibility criteria used to evaluate feasibility of response action related to other exposure pathways and disposal site conditions. Section 3A of M.G.L. c. 21E defines Permanent Solutions as including measures that reduce contaminant concentrations to Background, where feasible. At disposal sites and portions of disposal sites (which would include buildings impacted by vapor intrusion) where one or more remedial actions are taken to achieve a Permanent Solution, the level of OHM concentrations in the environment must be reduced to as close to Background levels as feasible, except where it can be demonstrated that Background levels have been met, as specified at 310 CMR 40.1020. The criteria for feasibility evaluations are described in 310 CMR 40.0860; guidance is also provided in MassDEP Policy #WSC-04-160, *Conducting Feasibility Evaluations under the MCP*.

For sites where prior to Phase III, CEP elimination/mitigation was determined to be feasible (see Section 4.3.1) and initiated as an IRA, the subsequent Phase III feasibility evaluation should consider those mitigation measures in the context of the overall remedy or combination of measures that are comprise the Comprehensive Remedial Action alternatives for achieving a Permanent Solution. The Phase III feasibility evaluation addresses both the feasibility of remedial alternatives to achieve NSR and a Permanent Solution, including measures to remediate or control Sources of OHM, as well as the feasibility of reducing contaminant concentrations to Background. The Phase III feasibility evaluation may conclude that continuation of the CEP mitigation as part of Comprehensive Response Actions (see below) is feasible and should be continued as part of the Comprehensive Remedy or, conclude that the costs of continued vapor intrusion mitigation outweigh the benefits and therefore, is no longer feasible (see Figure 4-3).

For disposal sites with a vapor intrusion pathway but no IH or CEP condition (i.e., the feasibility of addressing the pathway was not previously required as part of an IRA), the Phase III feasibility evaluation would similarly look at addressing the vapor intrusion pathway along with all other conditions at the site as part of the Comprehensive Remedial Action Alternative.

> A Permanent Solution cannot rely upon the use of air purifying units or operational changes to building ventilation to maintain a condition of NSR.

In some circumstances, the necessary and appropriate actions initially taken to address IH or CEP conditions are of a short-term or temporary nature, such as the use of any mechanical devices to over-pressurize a living space, running air purifying units, operational changes to heating, venting, and air conditioning systems in buildings, sealing of cracks in walls and foundations, and placing seals in sumps. The efficacy and permanence of these actions would need to be evaluated as part of the Phase III assessment (if performed) and prior to the submittal of a Permanent Solution Statement. As discussed in Section 3, a Permanent Solution cannot rely upon the use of air purifying units or operational changes to building ventilation to maintain NSR because such measures are not sufficiently reliable or suitable for long term mitigation.

Example Vapor Intrusion Scenario 2

An SSD system was installed at a commercial building to mitigate Imminent Hazard concentrations of VOCs in indoor air. Because the system alone did not adequately reduce indoor air contaminant levels, the fresh air intake in the HVAC system was adjusted upwards. The HVAC system modification is not an acceptable long-term option to achieve a Permanent Solution. It should be considered only a temporary measure in the Phase III evaluation of Comprehensive Remedial Action alternatives.

4.5.2 Transitioning Preliminary Response Actions to Comprehensive Response Actions

IRAs are required at vapor intrusion sites to address an IH, or SRM/CEP condition. At disposal sites where IRAs are not otherwise triggered (e.g., vapor intrusion below IH levels at locations that do not meet the definition of CEP such as industrial or commercial buildings), a Release Abatement Measure (RAM) may be performed to address vapor intrusion. Because RAMs may be performed at any point in the response action process, they may be used to initiate vapor intrusion mitigation prior to the completion of the full Phase II and Phase III (which must be completed before implementation of a Comprehensive Remedial Action alternative in Phase IV). MassDEP encourages consideration of such early action.

If the IRA or RAM is not completed prior to the implementation of the Comprehensive Remedial Alternative, the IRA/RAM response action may be incorporated into the Comprehensive Remedial Alternative recommended following a Phase II Assessment and a Phase III evaluation of Comprehensive Remedial Alternatives (310 CMR 40.0429(3)). At this point, with the submittal of a Phase IV Remedy Implementation Plan (310 CMR 40.0874) and an IRA or RAM Completion Statement, the IRA or RAM will be closed or completed, and the ongoing operation of the vapor intrusion mitigation would continue as part of Comprehensive Response Actions.

4.5.3 Addressing Vapor Intrusion through Comprehensive Response Actions

Comprehensive Response Actions to address the vapor intrusion pathway may have started as IRAs or RAMs or may be initiated following a Phase III Evaluation. These actions take place as part of Phase IV – Implementation of the Selected Remedial Alternative and Phase V - Operation, Maintenance and/or Monitoring activities.

Several MCP submittal requirements apply in cases where the Comprehensive Remedial Alternative requires operation, maintenance, and/or monitoring activities. The operation and maintenance of Comprehensive Remedial Alternatives is documented in the Remedy Implementation Plan and/or an Operation, Maintenance and/or Monitoring Plan. Phase IV Status Reports are required if Active Operation and Maintenance of a remedial action is conducted prior to the submittal of a Final Inspection Report and Phase IV Completion Statement. Upon completion of Phase IV activities, possible outcomes include: (a) submittal of a Permanent Solution Statement; (b) submittal of a Permanent Solution with Conditions Statement, for sites with AEPMMs; (c) submittal of a Temporary Solution Statement; or (d) continuation of remedial actions as operation and maintenance of the Comprehensive Response Action under Phase V, including Remedy Operation Status (ROS).

4.5.3.1 Remedy Operation Status

ROS is a regulatory status within Phase V that is an option for conducting Comprehensive Response Actions at disposal sites where Active Operation and Maintenance is underway for the purpose of achieving a Permanent Solution. As specified at 310 CMR 40.0893(2), ROS requires: that the remedy be designed to achieve the requirements of a Permanent Solution, source elimination or control, the elimination of substantial hazards, meeting applicable requirements for any AEPMMs (if employed as part of the remedy), and the ongoing submittal of status and remedial monitoring reports. ROS is effective upon submission of the materials outlined at 310 CMR 40.0893(3), including a ROS Opinion by an LSP. ROS has the effect of staying the five-year deadline for achieving a Permanent Solution and Tier Classification Extensions are not required while ROS is maintained. See Section 4.7.4.1 for operation and reporting requirements when an AEPMM is implemented as part of ROS.

ROS is an appropriate option for disposal sites where the Active Operation and Maintenance of an Active Remedial System or Active Remedial Monitoring Program that was designed and has been implemented to achieve a Permanent Solution is ongoing. That is, the remedy that has been selected and implemented is one that will eventually, with continued operation and/or monitoring, remediate the disposal site to a condition that meets the requirements of a Permanent Solution. In the case of vapor intrusion sites, ROS may apply to disposal sites where an Active Remedial System is remediating the OHM in source areas and/or controlling plume migration or where an Active Remedial Monitoring Program (e.g., monitored natural attenuation) is being conducted to document the reduction of contaminant levels over time. Where a complete vapor intrusion pathway is present, an AEPMM can be operated as part of the Comprehensive Response Actions conducted under Remedy Operation Status.

4.6 Requirements and Considerations for Closure at Sites with Vapor Intrusion Pathways or Concerns

This section of the guidance addresses aspects related to MCP closure for disposal sites with vapor intrusion pathways, including considerations for assessments and submittals provided in support of Permanent and Temporary Solutions, and the general requirements of and distinction between Permanent Solutions and Temporary Solutions as they relate to disposal sites with vapor intrusion concerns.

Requirements to achieve and document a Permanent or Temporary Solution are provided in 310 CMR 40.1000. The General Provisions for Permanent and Temporary Solutions are listed at 310 CMR 40.1003 and the performance standards are listed at 310 CMR 40.1004.

Both Permanent and Temporary Solutions achieved at a disposal site must be supported by assessments and evaluations that demonstrate that the respective requirements pursuant to 310 CMR 40.1000 have been met. Such assessments must be:

- of sufficient scope, detail, and level of effort to characterize the risk of harm to health, safety, public welfare and the environment posed by the site or disposal site pursuant to 310 CMR 40.0900;
- consistent with the Response Action Performance Standard described in 310 CMR 40.0191; and
- commensurate with the nature and extent of the release or threat of release and complexity of site conditions.

Assessments and evaluations conducted toward the achievement of a Permanent or Temporary Solution must be supported by the disposal site CSM and any assessment findings that are inconsistent or contrary to the CSM adequately explained. A succinct summary of the CSM for the disposal site is required as part of the Permanent (310 CMR 40.1056(2)(b)) and Temporary (310 CMR 40.1057(2)(b)) Solution Statements; Further, a Data Usability Assessment and Representativeness Evaluation must be conducted and documented as part of these submittals. The Data Usability Assessment and Representativeness Evaluation must demonstrate, respectively, that the data relied upon to support the Permanent or Temporary Solution is of sufficient precision, accuracy and completeness, and provide adequate spatial and temporal information to support the conclusion that a Permanent or Temporary Solution has been achieved.

To meet the requirements for a Permanent or Temporary Solution for the entire disposal site, specific activities must have been completed, including:

- delineation of the extent of contamination in affected media;
- a risk characterization that documents whether NSH and NSR exists or has been achieved;
- an evaluation of whether remedial actions are necessary to achieve NSR and whether it is feasible to achieve a Permanent Solution;

- *if remedial actions are necessary and feasible* to achieve NSR, an evaluation of the feasibility of implementing actions to achieve or approach Background;

- Sources of OHM contamination have been adequately identified, characterized and addressed through response actions to eliminate or control them (310 CMR 40.1003(5));

- the migration of subsurface OHM (dissolved OHM in groundwater and vapor-phase OHM in the Vadose Zone) has been assessed and determined to be stable or contracting (Permanent Solution) and/or otherwise controlled or mitigated (Temporary Solution (310 CMR 40.1003(6)); and

- the nature, extent and mobility of any NAPL have been adequately assessed and where necessary, remedial actions have been taken to adequately contain or remove NAPL (310 CMR 40.1003(7)).

To support a Permanent or Temporary Solution at a disposal site with vapor intrusion, the disposal site assessment must provide a sufficient level of certainty that site conditions are stable and will not worsen. For a Permanent Solution, there should be certainty that contaminant levels in indoor air affected by the disposal site will remain at or below a level of NSR. Consideration must be given to whether adequate sampling has been conducted to demonstrate with sufficient certainty that COCs in groundwater, soil gas and indoor air are stable or decreasing and whether changes to building conditions as the result of aging or renovation, could impact indoor air contaminant concentrations from contamination remaining in groundwater and/or soil gas.

The variability and uncertainty associated with vapor intrusion disposal sites add a level of complexity to documenting that the closure requirements have been met. The variability associated with vapor intrusion generally warrants a more robust sampling plan over a longer period of time than at disposal sites without a vapor intrusion pathway.

The burden of proof to demonstrate that the source elimination and control requirement has been met is significantly greater at disposal sites with elevated concentrations of contaminated soil, groundwater or NAPL remaining than at those disposal sites with lower concentrations of residual contamination, as such elevated concentrations may indicate the existence of an uncontrolled source.

> Remedial measures that maximize reduction of the VOC contamination source, reduce groundwater contaminant concentrations, and minimize downgradient migration provide the greatest certainty in terms of reducing the potential for long-term vapor intrusion impacts to both existing and future buildings.

4.6.1 Closure at a Portion of a Disposal Site

The MCP Permanent and Temporary Solution provisions may be applied to portions of disposal sites as well as entire disposal sites (i.e., the entire area affected by the release and where the contamination has come to be located). At disposal sites with vapor intrusion impacts to buildings, a building affected by vapor intrusion could represent a portion of a larger disposal site. Achievement of a Permanent or Temporary Solution for a portion of a disposal site requires the delineation and assessment of the full nature and extent of the disposal site, and demonstrating the applicable Source Elimination and Control, Migration Control and NAPL closure requirements for the disposal site have been met (310 CMR 40.1003(5) through (7)).

4.6.2 Closure Prior to Tier Classification at Sites with Vapor Intrusion Mitigation

Disposal Sites with a vapor intrusion pathway are generally too complex to achieve Permanent Solutions prior to Tier Classification (i.e., within one year from notification). The assessment of vapor intrusion impacts typically involves multiple rounds of sampling over time to account for temporal/seasonal fluctuations in soil vapor concentrations and/or groundwater elevations. Temporal/seasonal sampling is also warranted for indoor air characterization, including sampling during worst case conditions (see Section 2.2.4.1), which likely precludes achieving closure within one year.

However, there may be vapor intrusion sites with small, discrete OHM sources and relatively simple CSMs where it is possible to support a Permanent Solution prior to Tier Classification. For example, prompt removal or treatment of contaminated soil in the case of a sudden release that impacts a discrete and limited area of subsurface soil may be successful in eliminating a source of vapor intrusion and can be confirmed following remedial actions to remove or treat the source.

4.7 Permanent Solutions and Temporary Solutions

The specific requirements for a Permanent or Temporary Solution vary and an understanding of these requirements, including ongoing obligations under the MCP, is necessary when evaluating which type of Solution is feasible and appropriate for a disposal site. Persons conducting response actions should be cognizant that a Temporary Solution is a milestone in the response action process, but not an endpoint. Further, the specific category of Permanent Solution achieved at the disposal site, or portion of a disposal site, reflects whether specific ongoing obligations for the maintenance of disposal site conditions and/or adherence to post-Permanent Solution procedures related to future activities at the disposal site apply.

Factors relevant to the different types of Permanent or Temporary Solutions are outlined in 310 CMR 40.1030 and include:

- whether the site or disposal site poses NSR;
- whether all Substantial Hazards posed by the disposal site have been eliminated;
- whether the risk characterization depends upon assumed limitations on current or future conditions, activities or uses, including the implementation of Active or Passive Exposure Pathway Mitigation Measures;
- whether one or more AULs are required under the provisions of 310 CMR 40.1012 to maintain NSR;
- whether concentrations of oil and/or hazardous material at a site exceed Upper Concentration Limits in Soil and Groundwater listed at 310 CMR 40.0996(7); and
- whether site conditions are consistent with Natural Background or Anthropogenic Background.

Permanent Solutions apply to disposal sites where: a level of NSR exists or has been achieved; all Sources of OHM contamination have been eliminated or controlled (310 CMR 40.1003(5)(a) and (b)); control of plumes of dissolved OHM in groundwater and vapor-phase OHM in the Vadose Zone has been achieved (310 CMR 40.1003(6)(a)); NAPL, if present, has been addressed (310 CMR 40.1003(7)(a)); all threats of release have been eliminated; and, where remedial actions have been conducted, the level of OHM concentrations in the environment have been reduced to as close to Background levels as feasible.

Temporary Solutions apply to disposal sites where a Phase III evaluation has concluded either: response actions to achieve a Permanent Solution are not currently feasible; or response actions to achieve a Permanent Solution are feasible and shall be continued toward a Permanent Solution. Temporary Solutions require that: a condition of NSH exists or has been achieved; all Sources of OHM Contamination have been identified, characterized, and to the extent feasible, eliminated or controlled (310 CMR 40.1003(5)(a) and (c)); control of plumes of dissolved OHM in groundwater and vapor-phase OHM in the Vadose Zone has been achieved to the extent feasible (310 CMR 40.1003(6)(b)); and (d) NAPL, if present, has been addressed (310 CMR 40.1007(b)).

Disposal sites are not eligible for a Permanent Solution if ongoing Active Operation and Maintenance of an Active Remedial System or an Active Remedial Program is required (i.e., if remedies that involve containment, removal or treatment of Sources of OHM or plume control, or monitoring toward the achievement of the Permanent Solution performance standards are still ongoing). A Permanent Solution may be achieved, however, if the only ongoing Active Operation and Maintenance is limited to the operation of an Active Exposure Pathway Mitigation Measure or AEPMM (310 CMR 40.1040(2)(a)).

An active sub-slab depressurization system that is an AEPMM addressing a vapor intrusion exposure pathway may be operated as part of a Permanent Solution with Conditions. By contrast, while a soil vapor extraction system designed to remove OHM from the environment may also provide some mitigating effect on the vapor intrusion pathway, it is not operating solely for the purpose of exposure pathway mitigation. A soil vapor extraction system is therefore considered an Active Remedial System and may not be operated as part of a Permanent Solution with Conditions. (The terms Active Operation and Maintenance, Active Remedial System, Active Remedial Monitoring Program, Exposure Pathway Mitigation Measures and Active Exposure Pathway Mitigation Measure are defined at 310 CMR 40.0006(12).) As discussed in Section 3, air purifying units are also not considered AEPMMs because while they are directed at the exposure pathway, they are temporary mitigation systems and may not be relied upon over a longer period of time to maintain a level of NSR.

A turbine ventilator used as an added component to passive sub-slab ventilation (SSV) systems is not considered to make the system an AEPMM (i.e., make it an active measure) unless it is determined to be necessary to achieve of a level of NSR. Otherwise, SSV systems are considered *Passive* Exposure Pathway Mitigation Measures.

Example Vapor Intrusion Scenario 3 – Active Remedial System

A building previously used for commercial dry cleaning has documented PCE vapor intrusion from contaminated soil beneath the building slab. A soil vapor extraction (SVE) system is in operation to address the contaminant source by removing PCE mass from the soils beneath the building slab; when the system is operating, it also reduces the PCE concentrations in indoor air to a level below NSR. A Permanent Solution cannot be achieved for the site because Active Operation and Maintenance of an Active Remedial System is still necessary to remove the PCE source. A Temporary Solution or Remedy Operation Status may be appropriate while the feasible response actions (operation and monitoring of the SVE system) are continued toward a Permanent Solution.

4.7.1 Permanent Solutions with No Conditions

As outlined in 310 CMR 40.1041(1), Permanent Solution with No Conditions apply to disposal sites or portions of a disposal site where a level of NSR exists and will be maintained for all current and foreseeable future use of the site *without relying upon*: (1) assumed limitations on current or future site activities, uses or conditions that require an AUL as specified in 310 CMR 40.1012(2)); or (2) assumed limitations on current or future site activities, uses or conditions, that do not require an AULs pursuant to 310 CMR 40.1013.

For disposal sites where a vapor intrusion pathway had been identified, a Permanent Solution with No Conditions would apply to those cases: where the presence of OHM in indoor air was determined to be at a level of NSR for residential use and no remedial actions were necessary, or remedial actions were effective in reducing OHM to a level of (and to the extent feasible below) NSR; no ongoing maintenance is required to maintain NSR; <u>and</u> no limitations or conditions on future site use or redevelopment are necessary.

Note that the voluntary ongoing operation of an active SSD system (where it is not necessary for maintaining NSR) *outside the MCP process* (see Section 4.8.1) following the submittal of a Permanent Solution would not prevent a party from achieving site closure with a Permanent Solution with No Conditions.

> *Example Vapor Intrusion Scenario 4 - Permanent Solution with No Conditions*
>
> A release from an UST containing No. 2 fuel oil impacted the soil, soil gas, groundwater and indoor air at a residential property. The release was addressed through excavation of accessible soil, in-situ chemical oxidation of contaminated media adjacent to and beneath the building, and operation of an SSD system. Response actions continued until sampling in all affected media without ongoing remedial actions or the operation of the SSD system showed that site conditions were at a level of NSR. The disposal site conditions met the requirements for a Permanent Solution with No Conditions. The homeowner kept the SSD in operation on a voluntary basis; it was not needed to maintain a Permanent Solution.

4.7.2 Permanent Solutions with Conditions

A Permanent Solution with Conditions may be appropriate at a wide variety of vapor intrusion sites. As outlined in 310 CMR 40.1041(2), Permanent Solution with Conditions apply to disposal sites or portions of a disposal site where maintaining a level of NSR for foreseeable future use of the site relies upon either: (1) assumed limitations on future site activities or uses *that require AULs*, as specified in 310 CMR 40.1012; or (2) assumed limitations on current or future site activities, uses or conditions *that do not require an AUL* pursuant to 310 CMR 40.1013.

4.7.2.1 Permanent Solutions with Conditions where an AUL is Required

310 CMR 40.1012(2) specifies the conditions under which AULs are required. Permanent Solutions with Conditions with an AUL where the AUL is required include: AULs that are necessary to limit site use to commercial or industrial use (310 CMR 40.1012(2)(a)2.) or to require maintenance of building conditions that ensure NSR; AULs that are required to maintain the integrity of Passive Exposure Pathway Mitigation Measures such as barrier systems, passive venting systems, sealed sumps, and sealed cracks that are preventing elevated sub-slab soil gas from impacting indoor air (310 CMR 40.1012(2)(b)1.); or AULs that are required to document the presence and ongoing obligations for the operation of an Active Exposure Pathway Mitigation Measure or AEPMM that is maintaining, at a minimum, a level of NSR (310 CMR 40.1012(2)(b)2.). Pursuant to 310 CMR 40.0923(3)(c), AULs are also required when future Site Activities and Uses are eliminated from consideration in the risk characterization. Permanent Solution with Conditions that require an AUL are subject to

the post-Permanent Solution provisions for remedial actions occurring after the Permanent Solution specified at 310 CMR 40.1067(4).

4.7.2.2 General AUL Requirements

The MCP provides specific requirements related to the content of AULs, procedures and forms to be used for implementing, amending and terminating AULs and requirements for ensuring that the AUL is followed over time to maintain a condition of NSR and the Permanent Solution (310 CMR 40.1070). For a comprehensive summary of the requirements for implementing AULs, see MassDEP's *Guidance on Implementing Activity and Use Limitations* #WSC-XX-300.[7] This section focuses on important content provided by the AUL in the context of disposal sites where the vapor intrusion pathway is present or of potential future concern.

<u>Exhibit C</u> - One key component of a Notice of AUL is the information specified at 310 CMR 40.1074(2)(e) through (g) that is included in Exhibit C. Exhibit C is intended to provide a non-technical reader with a clear understanding of how the contaminant conditions came to be, the location and nature of the remaining contamination, and how the limitations set forth in the AUL are related to ensuring that conditions at the property remain at a level of NSR. The contents of Exhibit C specified at 310 CMR 40.1074(2)(e) through (g) are:

> *(e) a statement that specifies why the Notice of Activity and Use Limitation is appropriate to maintain a Permanent Solution and condition of No Significant Risk or maintain a Temporary Solution and condition of No Substantial Hazard;*
>
> *(f) a concise summary of the oil and/or hazardous material release event(s) or site history (i.e., date of the release(s), to the extent known, release volumes(s), and response actions taken to address the release(s)) that resulted in the contaminated media subject to the Notice of Activity and Use Limitation;*
>
> *(g) a description of the contaminated media (i.e., media type(s), contaminant type(s), approximate vertical and horizontal extent) subject to the Notice of Activity and Use Limitation;*

In the case of an AUL that addresses the vapor intrusion pathway and measures to prevent future exposures, Exhibit C should describe the how the VOC contamination occurred (i.e., what event(s)/releases occurred), the assessment and remedial actions that have been taken to achieve both source and migration control and the location of the remaining VOC contamination that has resulted in or presents a potential concern for vapor intrusion. The description must identify what environmental media are affected

[7] Note, the *Guidance on Implementing Activity and Use Limitations* is also currently undergoing public review and comment; this reference is a placeholder.

(e.g., indoor air, soil, soil gas, and/or groundwater and the “approximate vertical and horizontal extent” of the contamination. While it is helpful and appropriate to reference supporting material, maps and tables in a Permanent or Temporary Solution Statement, those references cannot be used in lieu of directly providing the required information in Exhibit C. The statement as to why the AUL is appropriate for maintaining the Permanent or Temporary Solution should plainly explain what measures must be maintained to protect the building against vapor intrusion (or in the case of future construction, to guard against potential vapor intrusion).

Consistent and Inconsistent Uses - This component of the AUL lists and describes what Site Activities and Uses are consistent with maintaining a Permanent Solution or Temporary Solution. This would include, with respect to a building affected by vapor intrusion, whether it may be used for any use or if its use is limited to less sensitive uses, such as office space or commercial/industrial use. Included in Inconsistent Uses for those Permanent or Temporary Solutions that rely on the maintenance of barriers, mitigation systems and/or existing building conditions, would be activities that compromise the integrity of such barriers, systems or building conditions.

Obligations and/or Conditions - This component of the AUL lists the specific measures that are to be taken to ensure that the objectives of the AUL (i.e., maintaining a Permanent or Temporary Solution) continue to be met. This includes specifying the type and frequency of activities for the inspection and maintenance of passive and active Exposure Pathway Mitigation Measures, including periodic indoor air monitoring, where warranted.

Where an AEPMM is implemented as part of a Permanent Solution pursuant to 310 CMR 40.1025, specific Obligations and Conditions must be included in the AUL related to inspection, operation, and maintenance of the AEPMM, remote monitoring and notification. This text appears in the Obligations and Conditions portion of Form 1075 as the bracketed items i through iv after “For a Permanent Solution with Conditions that relies upon the operation and maintenance of an Active Exposure Pathway Mitigation Measure pursuant to 310 CMR 40.1025 ...” This text must be included as it appears in the MCP. Additional obligations and conditions, whether related or unrelated to the AEPMM (e.g., soil management procedures) should be listed after items i through iv. Such additional obligations may not conflict with items i through iv.

Proposed Changes in Activities and Uses

The MCP requires that any proposed change in activities and uses which may result in higher levels of OHM exposure than the activities and uses specifically provided for in an AUL be evaluated by an LSP prior to such change in activity or use occurring. This requirement is also stated in Form 1075. 310 CMR 40.1080 specifies that this evaluation include a risk characterization, plan for any additional response actions needed to make conditions at the disposal site acceptable for the new use or activity, where applicable, and an LSP Opinion. For additional discussion about activities after a Permanent Solution with an AUL has been achieved, see Section 4.8.

Violations of a Permanent or Temporary Solution

Changes to site activities or uses or exposures at a disposal site subject to an AUL that could create a condition of exposure or increase potential human or environmental exposure that occur without the appropriate evaluation by an LSP and additional response actions in accordance with 310 CMR 40.1080, require that the property owner and operator provide notice to the Department immediately upon gaining knowledge of such changes pursuant to the provisions of 310 CMR 40.0020(1) and the performance of necessary response actions to ensure compliance with the requirements of the Permanent or Temporary Solution.

4.7.2.3 Examples of Permanent Solutions with Conditions that Require an AUL

Permanent Solutions with Conditions with an AUL – Limitation on Future Site Use or Activities

An AUL can be implemented as part of a Permanent Solution with Conditions to limit the use of an existing building to its existing commercial/industrial use where NSR has been demonstrated for shorter exposure durations under commercial/industrial use of the building, but has not been demonstrated for residential use. In such case, the AUL would be implemented consistent with the provisions at 310 CMR 40.1012(2)(a)2. to document the limitations on the use of the building.

Example Vapor Intrusion Scenario 5 – Permanent Solution with Conditions, AUL Implemented to Limit Use of Building to Commercial/Industrial Use

A multi-year monitoring program documents that a commercial building has consistently low but detectable levels of OHM in indoor air. A condition of NSR has not been demonstrated for future use of the building as a residence. A condition of NSR has been demonstrated, however, for continued commercial use of the building. If all other closure requirements are met and an AUL is implemented to prohibit future building use as a school, residence, or daycare facility, a Permanent Solution with Conditions could apply.

Example Vapor Intrusion Scenario 6 – Permanent Solution with Conditions, Remedial Actions and AUL Implemented

Following a Phase III Feasibility evaluation, a Phase IV remedy is selected that includes contamination source removal through soil excavation and an active SSD system is installed to address vapor contaminant levels in indoor air that pose Significant Risk for commercial use of the building as outlined in a Phase IV Remedy Implementation Plan. The remedial goals outlined in the Phase IV RIP (310 CMR 40.0874(3)), are the reduction of contaminant levels in indoor air to a level of NSR for commercial use without reliance on the operation of the SSD system to below NSR for commercial use. The SSD system operates for three years under Remedy Operation Status following the completion of the source removal actions. Indoor air monitoring is conducted following temporary system shut-downs conducted twice a year. The results indicate that indoor air contaminant concentrations, with the SSD shut off, are consistently less than the NSR level for commercial use over the last two years of operation. The system operation is discontinued and a Permanent Solution with Conditions is submitted, with an AUL. The AUL prohibits residential, school or daycare use of the property.

Note, continued operation of the SSD system is still encouraged in this case. As it has been demonstrated to not be necessary to maintain NSR for the commercial use of the building, its operation is optional and not a requirement of the Permanent Solution with Conditions (see discussion at 4.8.1).

<u>Permanent Solution with Conditions with an AUL – Maintenance of Building Conditions to Prevent Future Vapor Intrusion Pathway</u>

An AUL is also required if an assessment of future exposure in an existing building indicates the potential for significant risk if building conditions are not maintained. As discussed in Section 2.3, where the concentration of VOCs in subslab soil gas are found to pose a future significant risk as the result of building alteration (in the course of building repair or renovation) or through the development of cracks or other preferential pathways as the structure settles and ages, an AUL is appropriate to provide notice of the sub-slab soil gas contamination, ensure maintenance of the building to prevent the introduction of a vapor intrusion pathway, and to condition building renovations to ensure measures are taken to restore the integrity of the slab if it is affected during such renovations and to evaluate the effectiveness of such measures.

Example Vapor Intrusion Scenario 7 – Permanent Solution with Conditions, AUL Implemented to Condition Maintenance of Building Slab or Renovations to Building

A former manufacturing facility has been converted to office space. After remedial actions to remove VOC contaminated soil and an evaluation of exterior soil gas, sub-slab soil gas and indoor air concentrations, it was determined that the indoor air is currently not affected by VOCs from the disposal site. An evaluation of future exposure point concentrations based on sub-slab soil gas levels beneath the building indicate potential for Significant Risk if measures are not taken to maintain the building slab or restore it in the event of alterations to the building. An AUL is implemented to require the maintenance of the building slab and condition any future alteration of the building to ensure that indoor air is not affected by VOCs (i.e., a complete vapor intrusion pathway is not introduced).

Permanent Solutions with Conditions with an AUL to Maintain a Passive Exposure Pathway Elimination Measure

In cases where a Permanent Solution is dependent on the installation and maintenance of a vapor barrier (which may or may not include a sump closure) or a passive venting system installed in an existing building to address vapor intrusion, consistent with 310 CMR 40.1012(2)(b), an AUL is required to document the barrier as a Passive Exposure Pathway Mitigation Measure. An AUL in such cases documents the presence of the measure, and specifies that the integrity of the barrier or venting system must be maintained and periodically monitored to ensure and confirm its effectiveness. Contingencies should be provided in the AUL for the repair of the barrier and re-evaluation of its effectiveness in the event of any future renovation/activity that has or has the potential to compromise the measure.

Permanent Solutions with Conditions with an AUL to Maintain an Active Exposure Pathway Elimination Measure

A Permanent Solution with Conditions requiring an AUL also applies to disposal sites where the ongoing operation of an active SSD system as an AEPMM is necessary to maintain a level of NSR and where all other requirements for a Permanent Solution have been met. In such cases, the AEPMM must be operated pursuant to the requirements at 310 CMR 40.1025. Section 4.7.3 summarizes operation, monitoring and reporting requirements for an AEPMM that is a necessary condition of a Permanent Solution with Conditions.

> *Example Vapor Intrusion Scenario 8 – Permanent Solution with Conditions, AEPMM & AUL*
>
> An SSD system is installed to address vapor intrusion at a day care center located over a VOC groundwater plume. Groundwater and vapor phase migration has been shown to be stable and no longer expanding. The source, a dry well and surrounding soils, at an upgradient industrial property has been eliminated and the groundwater has been treated to the extent feasible. Indoor air contaminant concentrations meet NSR with the SSD system in operation, but sampling during vacation shut-downs indicates that system operation is necessary to maintain a condition of NSR. The SSD system can be operated as an AEPMM with an AUL, in accordance with all of the requirements of 310 CMR 40.1025, as part of a Permanent Solution with Conditions for the day care portion of the disposal site.

AULs that are not required pursuant to 310 CMR 40.1012(2), but are implemented optionally as part of a Permanent Solution consistent with 310 CMR 40.1012(3), are also considered Permanent Solution with Conditions, as a property owner is obligated to follow all AULs to maintain compliance with the MCP pursuant to 310 CMR 40.1070(2).

Table 4-1 summarizes and provides guidance on required and optional uses of AULs for common vapor intrusion disposal site scenarios.

4.7.2.4 Permanent Solutions with Conditions Based on Limitations on Activities, Conditions or Uses that do not Require/Include an AUL

Permanent Solutions with Conditions that do not require an AUL, but are based upon limitations on activities, conditions or uses as set forth in 310 CMR 40.1013, *do* require documentation of the conditions as part of the Permanent Solution Statement and are subject to post-Permanent Solution requirements at 310 CMR 40.1067(5). Of these provisions, 310 CMR 40.1013(1)(d) is specifically applicable to disposal sites or portions of disposal sites where vapor intrusion is of potential concern. It applies to locations with groundwater contamination above the GW-2 Standards and no current occupied buildings or structures where the average annual depth to groundwater of 15 feet or less (i.e., groundwater is not currently categorized as GW-2).

As specified at 310 CMR 40.1056(2)(j)(4), where a Permanent Solution with Conditions applies to a location without existing buildings, but a vapor intrusion concern for future construction (as defined by the criteria described above), the Permanent Solution Statement must document "information related to the presence of the groundwater contamination and the obligation to ensure any future construction at the disposal site does not result in OHM impacts to indoor air in newly constructed buildings or structures."

Information included in the Permanent Solution Statement should provide: an explanation of the nature of the disposal site conditions that are of concern for future construction that reflects the disposal site CSM, references to disposal site maps that delineate the areas of groundwater contamination and VOC concentrations, and the direction of groundwater flow, a statement that the property owner and persons constructing the building are obligated to ensure future development at the property does not result in the introduction of OHM from the disposal site into the indoor air of newly-constructed buildings and a reference to the requirements for remedial actions after a Permanent Solution has been submitted to MassDEP at 310 CMR 40.1067(5).

Future construction of a building that results in exposure to OHM from the disposal site in indoor air in the new building is subject to notification requirements of 310 CMR 40.0300 and requires additional response actions to ensure that the requirements of a Permanent Solution are met for the change in conditions and exposure that resulted from the building construction (310 CMR 40.1067(5)(e)). The Permanent Solution Statement, therefore, should reference measures that can be employed in the new construction to ensure that such construction does not result in vapor intrusion, including: installation of an SSD system or passive venting system (that can be activated) and post-construction indoor air sampling to ensure the effectiveness of such measures, or construction of a ventilated parking garage or open air level below the occupied floors to protect against a complete vapor intrusion pathway. Section 4.8.3

Table 4-1: AULs Use for Vapor Intrusion Scenarios

Vapor Intrusion/AUL Use Scenario	AUL Required or Optional?	Consistent/Inconsistent Uses	Obligations and Conditions
Permanent Solution is dependent on limiting the use of an existing building to its existing commercial/industrial use; NSR has been demonstrated for commercial/industrial use. NSR for use as residence/school/day care/unrestricted use has not been demonstrated or has not been evaluated.	Required	Consistent: Use of building for commercial/industrial use. Inconsistent: Use of building as residence, school, daycare/child care.	• No change in use or activities to an inconsistent use or activity without the prior evaluation by an LSP and if necessary, additional response actions.
Permanent Solution is dependent on a Passive Exposure Pathway Mitigation Measure.	Required	Consistent Use depends on what uses are supported by the risk characterization; could be either unrestricted or limited to commercial/industrial. Inconsistent Use would include uses/activities that interfere with or compromise the Passive Exposure Pathway Mitigation Measure without restoration of the Passive Exposure Pathway Mitigation Measure and indoor air testing to confirm effective restoration.	• Maintenance of the Passive Exposure Pathway Mitigation Measure and periodic inspection and monitoring to ensure its effectiveness. • In the event that the Passive Exposure Pathway Mitigation Measure is compromised or found to be ineffective, the Passive Exposure Pathway Mitigation Measure must be immediately restored and indoor air testing must be conducted to confirm effective restoration. • No change in use or activities to an inconsistent use or activity without the prior evaluation by an LSP and if necessary, additional response actions.
Permanent Solution is dependent on maintaining building conditions to prevent potential vapor intrusion where sub-slab soil gas levels remain and either: future EPCs show Significant Risk, or future EPCs were not developed and potential pathway was ruled out with an AUL; NSR has been demonstrated for current conditions and use.	Required	Consistent Use depends on what uses are supported by the risk characterization; could be either unrestricted or limited to commercial/industrial. Inconsistent Use would include uses/activities that compromise or alter the building slab without restoration of the slab and indoor air testing to confirm effective restoration.	• Maintenance of building slab and periodic inspection. • In the event that the building slab is compromised or altered (such as through the installation of subsurface utilities or building renovation), the building slab must be restored, subsurface conduits sealed and indoor air testing conducted to confirm effective restoration. • No change in use or activities to an inconsistent use or activity without the prior evaluation by an LSP and if necessary, additional response actions.
Permanent Solution is dependent on the ongoing operation of an active SSD system as an AEPMM to maintain NSR and where all other requirements for a Permanent Solution have been met.	Required	Consistent Use depends on what uses are supported by the risk characterization based on the AEPMM in operation; could be either unrestricted or limited to commercial/industrial. Inconsistent Use would include uses/activities that interfere with or compromise effective operation of the AEPMM	• The mandatory Obligations and Conditions i through iv listed in the bracketed text of Form 1075 after "For a Permanent Solution with Conditions that relies upon the operation and maintenance of an Active Exposure Pathway Mitigation Measure pursuant to 310 CMR 40.1025 ..." These include: o operating AEPMM following the specific regimen in the Permanent Solution Statement, o employing remote monitoring, o taking immediate measures to restore the system in event of suspension/failure, and o providing written notice to MassDEP and any non-transient building occupant who may have experienced exposure to OHM as the result of the system failure or suspension that lasts 30 days • No change in use or activities to an inconsistent use or activity without the prior evaluation by an LSP and if necessary, additional response actions.
Permanent Solution is achieved at a disposal site where GW-2 Standards are exceeded but there is no current occupied building at the location where concentrations are above the GW-2 Standards; AUL is used to specify that buildings constructed on the property or portion of the property where groundwater concentrations are above GW-2 standard incorporate a vapor intrusion barrier and SSD system.	*Optional** * If, once the building is constructed, ongoing operation of the system is found to be necessary to maintain NSR, the AUL must be amended and kept in place (i.e., the AUL is no longer optional)	Consistent Use would include construction of new buildings provided a vapor intrusion barrier and SSD system is incorporated into the building and indoor air testing is conducted to confirm its effectiveness. Inconsistent Use would include construction of new buildings without a vapor intrusion barrier and SSD system.	• Indoor air testing in the new building to determine whether operating the system is necessary to maintain NSR *(if operation of the system is determined to be necessary, the requirements for operating the system as AEPMM as part of a Permanent Solution with Conditions would apply).* • No change in use or activities to an inconsistent use or activity without the prior evaluation by an LSP and if necessary, additional response actions.
Permanent Solution is achieved at a disposal site where GW-2 Standards are exceeded but there is no current occupied building at the location where concentrations are above the GW-2 Standards; AUL is used to require construction on the property or portion of the property where groundwater concentrations are above GW-2 standard to include a ventilated parking garage or an open air structure on the bottom or ground level to prevent vapor intrusion into occupied levels of new buildings.	*Optional*	Consistent Use would include construction of new buildings provided that a ventilated parking garage or an open air structure on the bottom or ground level to prevent vapor intrusion into occupied levels of new buildings. Inconsistent Use would include construction of new buildings without either a ventilated parking garage or an open air structure on the bottom or ground level to prevent vapor intrusion into occupied levels of new buildings or conversion of the ventilated garage or open air structure to into occupied space.	• No change in use or activities to an inconsistent use or activity without the prior evaluation by an LSP and if necessary, additional response actions.

Vapor Intrusion/AUL Use Scenario	AUL Required or Optional?	Consistent/Inconsistent Uses	Obligations and Conditions
Permanent Solution is achieved at a disposal site where GW-2 Standards are exceeded but there is no current occupied building at the location where concentrations are above the GW-2 Standards; AUL is used to preclude construction on the property or portion of the property where groundwater concentrations are above GW-2 standard.	*Optional*	Consistent Use would include construction of new buildings outside of the area that exceeds the GW-2 Standards. Inconsistent Use would include construction of new buildings in the area that exceeds the GW-2 Standards.	• No change in use or activities to an inconsistent use or activity without the prior evaluation by an LSP and if necessary, additional response actions.
Permanent Solution is achieved where exterior soil gas VOCs at undeveloped site may represent a risk of vapor intrusion to future buildings. AUL is used to obligate construction of the building with measures, such as a vapor intrusion barrier and SSD system to prevent vapor intrusion and post-construction monitoring to confirm the effectiveness of the measures.	*Optional** * If, once the building is constructed, ongoing operation of the system is found to be necessary to maintain NSR, the AUL must be amended and kept in place (i.e., the AUL is no longer optional)	Consistent Use would include construction of new buildings provided that a vapor intrusion barrier and SSD system is incorporated into the building and indoor air testing is conducted to confirm its effectiveness. Inconsistent Use would include construction of new buildings without a vapor intrusion barrier and SSD system.	• Indoor air testing in the new building to determine whether operating the system is necessary to maintain NSR *(if operation of the system is determined to be necessary, the requirements for operating the system as AEPMM as part of a Permanent Solution with Conditions would apply).* • No change in use or activities to an inconsistent use or activity without the prior evaluation by an LSP and if necessary, additional response actions.
Temporary Solution includes the ongoing operation of an active SSD system as an AEPMM operated in accordance with the requirements of 310 CMR 40.1026.	*Optional*	Consistent Use depends on what uses are supported by the risk characterization based on the AEPMM in operation; could be either unrestricted or limited to commercial/industrial. Inconsistent Use would include uses/activities that interfere with or compromise effective operation of the AEPMM.	AUL obligations and conditions could be modeled after those that apply to a Permanent Solution with an AEPMM, e.g., referencing the operating regimen in the Temporary Solution Statement. • No change in use or activities to an inconsistent use or activity without the prior evaluation by an LSP and if necessary, additional response actions.
Temporary Solution at an operating facility that uses VOCs in its operations (e.g., active dry cleaner, gasoline station) that correspond with the disposal site COCs where an assessment of vapor intrusion cannot be successfully concluded given confounding sources in indoor air, an AUL may be used as a means of ensuring that the facility is not converted to another use without additional investigation of the potential for vapor intrusion. It should be noted that the AUL would only be appropriate to address the 21E issues at the facility arising from disposal site COCs.	*Optional*	Consistent Use includes ongoing use as a commercial/industrial facility using VOCs. Inconsistent Use any other use without prior evaluation of potential vapor intrusion impacts and necessary response actions.	• No change in use or activities to an inconsistent use or activity without the prior evaluation by an LSP and if necessary, additional response actions.

provides more discussion of Post-Permanent Solution activities and requirements at disposal sites where a Permanent Solution with Conditions (but no AUL) is achieved where 310 CMR 40.1013(d) applies.

Example Vapor Intrusion Scenario 9 – Permanent Solution with Conditions, No AUL Required

A stable plume of VOC contamination exceeds GW-2 levels in an area of the disposal site without existing or planned buildings. If all other closure requirements are met, this site could qualify for a Permanent Solution with Conditions. No AUL is necessary, but the concern about potential vapor intrusion will be documented in the Permanent Solution with Conditions Statement to inform future land use decisions and guide any future construction at the property. The provisions of 310 CMR 40.1067(5) would be applicable to future development of the disposal site.

4.7.2.5 Voluntary Use of an AUL to Protect Future Buildings

As discussed above, the use of an AUL is not required to condition future building construction at a disposal site where there is no current occupied building at the location where concentrations are above the GW-2 Standards. An AUL is also not required where residual VOCs in soil are shown to meet NSR for unrestricted site use. In either case an AUL may optionally be used to outline specific measures to be taken at the time of building construction or to limit construction at a property to locations outside of areas with VOC contamination. An AUL in such cases, while not required, has the benefit of providing future owners notice in the property deed as to the risks and obligations associated with future site development.

An AUL is also not required in the case of Temporary Solutions, but may be used in the same manner as an AUL that is used for Permanent Solutions, to provide notice of disposal site conditions, limit site use and activities, specify obligation and maintenance measures to maintain NSH, and to document obligations related to property development. An AUL is also not required but may be used when an AEPMM is implemented as part of a Temporary Solution pursuant to 310 CMR 40.1026.

As previously noted, AULs that are not required pursuant to 310 CMR 40.1012(2), but are implemented optionally as part of a Permanent Solution consistent with 310 CMR 40.1012(3), are also considered Permanent Solution with Conditions, and the property owner is obligated to follow all AULs to maintain compliance with the MCP pursuant to 310 CMR 40.1070(2).

Voluntary AUL use examples are included in **Table 4-1** above.

4.7.3 Implementing and Operating an AEPMM as part of a Permanent Solution with Conditions

The requirements for operation, monitoring and reporting for an AEPMM that is a necessary condition of a Permanent Solution with Conditions are outlined in 310 CMR 40.1025. It is important to note that AEPMMs are not permitted to be used as part of a Permanent Solution with Conditions if suspension or failure of the AEPMM (i.e., if the SSD system were not operating or not operating effectively) for 60 consecutive days would result in a Receptor exposure to OHM that would pose an IH (310 CMR 40.1025(4)).

An evaluation as to whether the restriction at 310 CMR 40.1025(4) applies should be based on representative indoor air EPCs in the building when the SSD system is not in operation assuming current use conditions. Where exposure of 60 days or less would represent an IH, a Permanent Solution is not an option. Such cases may be suitable, however, for either Remedy Operation Status or a Temporary Solution, however.

Another threshold requirement for use of AEPMMs as part of a Permanent Solution with Conditions is that the property owner, at the time of implementation, provide a certification that financial resources have been made available for the immediate repair and/or replacement of AEPMM components if the AEPMM experiences failure and implement an AUL that includes the obligation to operate and maintain the system and repair or replace it if necessary to continue its operation.

The text below outlines the steps that are necessary *before* and *after* submitting a Permanent Solution Statement for a Permanent Solution with Conditions where the operation of an SSD system is a required condition.

<u>Before submitting a Permanent Solution Statement for a Permanent Solution with Conditions that relies on operation of an SSD system as an AEPMM:</u>

1. demonstrate that the AEPMM eliminates exposure to OHM to the extent feasible and at a minimum, ensures that NSR is achieved and maintained for the Receptor(s) of concern. The effectiveness of the AEPMM shall be demonstrated through monitoring of EPCs under normal operating conditions and over a period of time sufficient to account for temporal variability;

2. establish an operating regimen of the AEPMM that ensures, at a minimum, that NSR is maintained for the Receptor(s) of concern under normal operating conditions (310 CMR 40.1025(3)(b));

3. equip the SSD system with remote monitoring (a.k.a. telemetry) technology that will alert the owner and operator of the building protected by the AEPMM and the Department immediately upon failure of the system (such as loss of power, mechanical failure or other significant disruption of the effectiveness of the system)(310 CMR 40.1025(3)(d));

4. register the remote monitoring technology with MassDEP (as described in Section 3.5.8;

5. document in the Permanent Solution Statement the
   a. the operating regimen of the SSD System (as established in 2. above) that includes the parameters for operating the AEPMM and the methods and frequency for monitoring to ensure consistent operation within the required parameters; and
   b. the longest duration of a shutdown that would be consistent with (1) a level of exposure that does not pose an IH, and (2) the level of exposure that poses;

6. demonstrate and document in the Permanent Solution Statement that all other requirements of a Permanent Solution are met, (including, but not limited to, disposal site and Sources of OHM assessment and delineation, risk characterization, Source Elimination and Control, Migration Control, NAPL removal to the extent feasible, documentation of the disposal site CSM, Representativeness Evaluation and Data Usability Assessment);

7. include a certification by the owner of the property where the AEPMM is located in the Permanent Solution Statement that the financial resources for the immediate repair and/or replacement of AEPMM or AEPMM components have been made available if the AEPMM experiences failure; and

8. record an AUL that includes the required Obligations and Conditions for the operation of the SSD System as an AEPMM in Form 1075 and references the operating regimen in the Permanent Solution Statement;

A Permanent Solution with Conditions Statement may be submitted upon completion of the steps/requirements above. Once a Permanent Solution with Conditions Statement is submitted, Status Reports and Remedial Monitoring Reports for the operation of the AEPMM are no longer required.

<u>After submitting a Permanent Solution Statement for a Permanent Solution with Conditions that relies on operation of an SSD system as an AEPMM:</u>

- As a condition of maintaining such a Permanent Solution, continued operation of the SSD system according to the AUL and the operating regimen as documented in the Permanent Solution Statement is required. When the property where the AEPMM is located is sold, the obligation for maintaining the AEPMM transfers with the property to the subsequent property owner as do all requirements specified in an AUL. Any subsequent property owner is required to ensure the system's ongoing operation according to the conditions of the AUL and Permanent Solution Statement *unless and until* it is demonstrated that the AEPMM is not necessary to maintain NSR, the AUL is terminated, and a revised

Permanent Solution is submitted to the Department that documents the change in conditions associated with the revised Permanent Solution;

- Following suspension or failure of an AEPMM, the owner of a property with an AEPMM must undertake immediate steps to return the AEPMM to full operating condition. If the suspension or failure of the system lasts 30 consecutive days, the owner of the property must provide a written notice to both the MassDEP and any non-transient occupants of the affected building. This notice must include the reason for the failure, the steps being taken to resume operation and the expected timeframe for resuming operation (310 CMR 40.1025(6)). Note, this requirement is *in addition to* maintaining a remote monitoring technology as part of the AEPMM that alerts the owner and operator of the building protected by the AEPMM and MassDEP immediately upon failure of the system;
- The owner of the property with an AEPMM must annually certify in response to receipt of a form sent to the current property owner by MassDEP that (a) the property owner is aware of his/her obligation to operate, maintain and repair the AEPMM, (b) MassDEP may inspect the AEPMM upon reasonable notice, (c) financial resources are available for immediate repair and/or replacement of AEPMM components, as needed, and (d) the AEPMM is operating following the operating regimen established in the AUL and Permanent Solution Statement.

4.7.4 Temporary Solutions

The requirements for a Temporary Solution are summarized in Section 4.6. At disposal sites with vapor intrusion pathways, a Temporary Solution can often be achieved where implementation of a Permanent Solution is not currently feasible, but where a condition of NSH has been met and is being maintained. Temporary Solutions must be supported by a Phase II assessment of the nature and extent of the entire disposal site and corresponding risk characterization and a Phase III feasibility evaluation that supports the implementation of Temporary Solution rather than a Permanent Solution.

Examples of disposal site conditions that would not meet the requirements of a Permanent Solution but could qualify for a Temporary Solution include:

- where OHM plumes in groundwater or vapor phase cannot be demonstrated to be stable or contracting, but are controlled;
- where Non-stable NAPL has not been eliminated, but is controlled to the extent feasible;
- where the Active Operation and Maintenance of an Active Remedial System (e.g., a soil vapor extraction system) or Active Remedial Monitoring Program is ongoing to maintain NSH and/or treat/control Sources of OHM or control plume migration; and/or
- where another condition that may be unrelated to vapor intrusion, such an exceedance of an Upper Concentration Limit or exceedance of a GW-1 standard

in a current or potential drinking water source area preclude the achievement of a Permanent Solution.

310 CMR 40.1057 outlines the requirements for Temporary Solution Statements. These requirements include providing documentation of any operation, maintenance, and/or monitoring that will be required to confirm and/or maintain those conditions at the disposal site on which the Temporary Solution is based. Where an SSD system is being operated at a disposal site as part of maintaining a Temporary Solution, additional requirements apply, as discussed below in 4.7.4.1 below.

As previously stated, the use of an AUL is not required as part of a Temporary Solution, but pursuant to 310 CMR 40.1012(3)(g), property owners may elect to implement an AUL to provide notice of the presence and nature disposal site contamination and/or to record obligations and conditions for maintaining remedial systems, barriers and other mitigation measures. Where an optional AUL is used, property owners are required to comply with its terms in order to maintain compliance with the MCP pursuant to 310 CMR 40.1070(2). **Table 4-1** includes examples of AULs used for Temporary Solutions.

310 CMR 40.0897 outlines Post-Temporary Solution operation, maintenance and/or monitoring activities and documentation. The scope of these activities will be based on the remedial action being undertaken. Post-Temporary Solution operation, maintenance and/or monitoring activities must be documented in Post-Temporary Solution Status Reports, as described in 310 CMR 40.0898(2). At a minimum, a Post-Temporary Solution Status Report must be submitted to the Department at 6-month intervals. For disposal sites where active operation and maintenance of a remedial action is being conducted, Remedial Monitoring Reports must be submitted with the first Post-Temporary Solution Status Report and every six months thereafter, in accordance with 310 CMR 40.0898(3).

4.7.4.1 Implementing and Operating an AEPMM as part of a Temporary Solution or Remedy Operation Status

The requirements for operation, monitoring and reporting for an AEPMM as part of a Temporary Solution or as part of measures conducted under Remedy Operation Status are outlined in 310 CMR 40.1026. These requirements are similar to those for an AEPMM in a Permanent Solution with Conditions, as outlined earlier, *except* that with a Temporary Solution or Remedy Operation Status, there is no requirement for an AUL, no limitation on the use of the system to address an indoor air concentration that would pose an IH within 60 days of a system failure, no certification requirement for financial resources for system repair or replacement, and no annual certification process.

Another important difference is that for AEPMMs operated as part of Temporary Solutions or Remedy Operation Status, RMRs and Status Reports are still required; RMRs and Status Reports are not required after submitting a Permanent Solution Statement.

Example Vapor Intrusion Scenario 10 - Temporary Solution with AEPMM; No AUL Required

Following a Phase III evaluation, mitigation of the vapor intrusion pathway in a school is continued with the operation of an SSD system, which was initially installed as an IRA to address the CEP. Monitoring conducted after system shut-downs during school vacations indicates that the SSD system must be operated to maintain NSR. Contaminated soil from the source area was excavated to the extent feasible and Substantial Hazards have been eliminated. A Temporary Solution is submitted while additional source reduction options to address the groundwater contaminant plume and remediate soil remediation to the extent needed to support a Permanent Solution are evaluated.

4.8 Post-Closure Requirements and Considerations for Disposal Sites with Vapor Intrusion Concerns

At disposal sites with a Permanent Solution, there is an obligation to maintain the Permanent Solution and abide by the terms of any AUL that has been implemented. There are also requirements that apply to evaluating changes in site activities and uses and conditions that may pose a Significant Risk and to conducting remedial actions at the disposal site. This section outlines the requirements and considerations for activities occurring at disposal sites where the conditions related to an ongoing or potential vapor intrusion pathway apply to maintaining the Permanent Solution.

4.8.1 Voluntary Continuation of Vapor Intrusion Mitigation

In cases where a Permanent Solution has been achieved that is not dependent on the ongoing operation of an active SSD system installed as an MCP response action, MassDEP recognizes that a building owner or operator may nevertheless want to continue operating the system to reduce or protect against exposure to remaining low levels of contamination and/or for the benefit of mitigating radon, a concern that is not regulated under the MCP[8]. Without the ongoing MCP oversight and submittal costs, the electricity and maintenance costs for active SSD systems are typically very affordable. Such ongoing operation would not be viewed as a mandatory condition of the Permanent Solution. Where ongoing voluntary operation of the system is anticipated at the time that the Permanent Solution is submitted to the Department, it is helpful to discuss it in the Permanent Solution Statement to clarify the voluntary nature of its use with respect to MCP compliance.

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[8] If there is a complete vapor intrusion pathway that is allowing site-related contamination to enter a building, it is reasonable to assume that the natural contaminant radon, if present in the subsurface, is also entering the building. See EPA's *A Citizen's Guide to Radon* at http://www.epa.gov/radon/pubs/citguide.html.

4.8.2 Post-Closure Work at a Disposal Site with a Permanent Solution with Conditions and an AUL

At disposal sites where a Permanent Solution with Conditions has been achieved that includes an AUL, maintaining a Permanent Solution requires ensuring a condition of NSR and abiding by the terms of the AUL. Where the AUL requires maintenance of barriers or systems to prevent or mitigate vapor intrusion, post-closure activities include complying with AUL. In the event that inspections of the systems or barriers indicate that repairs or modifications are needed, remedial actions must be taken.

Where action is required to repair or modify an existing barrier or system or otherwise conduct remedial actions at a disposal site within an AUL area, that work must be performed pursuant to 310 CMR 40.1067(4). These provisions allow for work involving limited soil excavation (excavation of 100 cubic yards or less of soil contaminated with oil or waste oil, or 20 cubic yards or less of soil contaminated with hazardous material) to be conducted without the need to notify the Department or to submit a plan. Otherwise, remedial actions in the AUL area require a RAM Plan, or if the work exceeds the scope of a RAM, a Phase IV Remedy Implementation Plan. These plans must meet the RAM provisions, including the objective of the work, description of assessment and remedial activities, schedule, and plans/sketches of any installations. RAM Status Reports are also required if the work is not completed within 120 days of submitting the RAM Plan. Completion of the work must be documented with a RAM Completion Statement.

If it is determined that new conditions are required for maintaining NSR that are beyond what is provided in the AUL (e.g., a passive venting system must now be operated as an active SSD system or AEPMM), then an AUL Amendment is necessary to document that change in terms. Note, for Permanent Solutions with Conditions that rely on AEPMMS, changes to the operating regimen details which are otherwise not specified in the AUL may be made by revising that information in the Permanent Solution Statement; those changes should also be documented in the RAM Completion Statement.

Post-closure remedial actions at disposal sites with a Permanent Solution may also be performed with the objective of remediating the disposal site further and removing an AUL (i.e., achieving NSR that is not conditioned on an AUL). Activities limited to assessment (e.g., sampling indoor air with systems not operating and/or sampling sub-slab soil gas and groundwater) to demonstrate that an AUL and its obligations and conditions are no longer necessary do not have to be conducted as a RAM, but the results of such assessments would be documented in a revised Permanent Solution Statement. See 3.6 for a discussion of sampling to demonstrate that a mitigation system in no longer needed.

4.8.3 Post-Closure Work at a Disposal Site with a Permanent Solution with Conditions and No AUL

At disposal sites where a Permanent Solution with Conditions has been achieved without an AUL, but based on the condition at 310 CMR 40.1013(1)(d) related to residual contamination in groundwater above the GW-2 standards, maintaining the Permanent Solution requires ensuring that future building construction does not create a vapor intrusion pathway. Post-closure remedial activities at disposal sites with a Permanent Solution with Conditions but no AUL must be conducted pursuant to 310 CMR 40.1067(5), which parallels the provisions at 310 CMR 40.1067(4) for disposal sites with an AUL. As specified in 310 CMR 40.1067(5)(e), in the event that a building is constructed and indoor air is found to be impacted by VOCs from the disposal site, notification to MassDEP is required pursuant to 310 CMR 40.0300.

4.8.4 New Buildings Constructed at a Disposal Site Where the Potential for the Vapor Intrusion Pathway Exists

To avoid creating new exposures, new construction should include measures to eliminate or minimize the possibility of vapor intrusion. The measures taken should be commensurate the disposal site CSM and the level of contamination remaining at the site. It is recommended, therefore, if many years have passed since a Permanent Solution was achieved, that groundwater be sampled to evaluate current conditions, including whether the potential for vapor intrusion remains a concern.

Some measures that minimize the possibility of vapor intrusion have become standard construction practices, such as the use of vapor barriers or passive radon systems. A building's design may include features which preclude or limit the transfer of contaminated vapor to an occupied space, such as the use of a garage at or below ground level. Standard construction practices including "soil gas safe" building design components do not need to be undertaken following MCP requirements, provided that they do not require the management of Remediation Waste during construction or any ongoing operation, maintenance, or monitoring in the completed building. Operation of garage ventilation systems that is required by building code would have no further MCP requirements.

It is recommended that sampling of indoor air once construction of a new building has been completed be conducted before the building is occupied. This will avoid, in the event that vapor intrusion is found, of having to notify for IH and Conditions of SRM (that are triggered by current exposures to current occupants) and will allow the work to mitigate the pathway to be performed as a RAM (pursuant to 310 CMR 40.1067(4) or (5)). Where the new building is determined to rely on a Passive or Active Exposure Pathway Mitigation Measure to ensure maintenance of a level of NSR, an AUL must be implemented to document that maintenance of those measures is a requirement of maintaining the Permanent Solution and the Permanent Solution Statement must be revised to reflect the applicable conditions.

5. COMMUNICATION AND PUBLIC INVOLVEMENT

5.1 Introduction

The purpose of public involvement activities under the MCP is to inform the public about risks posed by the disposal site, present information about the status of response actions, and provide opportunities to obtain additional information. Public involvement can be particularly important at sites where vapor intrusion issues exist because vapor intrusion is not well understood by many members of the public, and affected structures can include residences, schools and workplaces. Residents and users of affected building will naturally have concerns about potential risks to their health and questions about assessment and mitigation activities. MassDEP's experience confirms that providing information to the public in a timely and straight-forward manner is a key element of a successful project and building trust with the public. Information that is made understandable for a non-technical audience and anticipates likely questions can be effective in addressing concerns and fostering cooperation during the response action process.

The vapor intrusion pathway can be a difficult and sensitive environmental issue to communicate to the public. Complicating aspects of vapor intrusion include: (1) the unavoidable nature of indoor air inhalation exposure while vapor intrusion is present; (2) the logistical issues surrounding sub-slab soil gas and indoor air sampling in buildings; and (3) the potential for detecting indoor air contamination unrelated to the environmental release under investigation (for example, from smoking, household products or hobby chemicals); such findings are often challenging to explain to building inhabitants and users.

In light of these challenges, MassDEP encourages early, clear and frequent communication with property owners and other concerned individuals about vapor intrusion issues.

This section identifies:

- MCP public involvement **requirements** related to vapor intrusion investigation and mitigation; and
- Additional **optional tools** that may be useful in communication with the public on vapor intrusion issues.

The MCP public involvement requirements are outlined in 310 CMR 40.1400 as well as cross-referenced elsewhere in the MCP where they are required in connection with specific response actions or phases of work. Sections 5.2 and 5.3 below summarize specific MCP public notification requirements that may be triggered under when conducting assessment or cleanup/mitigation actions at vapor intrusion sites. Section 5.4 discusses optional public involvement considerations.

5.2 Requirements for Notification of Property Owners and Affected Individuals

The MCP contains several specific requirements for notifying property owners who are not otherwise conducting response actions, and for notifying Affected Individuals at a site. Property owners include public entities (e.g., municipalities, federal and state agencies) in the case of publicly owned property. Standardized forms (available at http://www.mass.gov/dep/cleanup/approvals/trforms.htm#trans) have been developed and must be used for providing these notifications. These requirements and related forms are described below.

5.2.1 Notice of Environmental Sampling (Form BWSC123)

Providing property owners with a written notification of sampling and the analytical results once they become available is required any time environmental samples are taken as part of response actions under the MCP at a property on behalf of someone other than the owner of the property (310 CMR 40.1403(10)). This written notice, titled *Notice of Environmental Sampling*, is made using Form BWSC123. The purpose of this notice is to: inform the property owner that he/she will be receiving the results of the sampling and analysis, and to ensure that such results are subsequently provided to the property owner within a specific timeframe from the date the laboratory issues the analytical data. These requirements apply to indoor air sampling, as well as other environmental media (sub-slab soil gas, groundwater, soil, etc.).

310 CMR 40.1403(10) specifies additional details about the required timing of the Notice of Environmental Sampling and documentation. Analytical results provided to the property owner must include the number and type of samples (i.e. environmental medium sampled and analyzed), the chemicals identified, and the measured concentrations of the chemicals identified.

Information on optional communication related to environmental sampling results is provided in Section 5.4.

5.2.2 Notice Related to Immediate Response Actions (Form BWSC124)

When conducting a remedial action as part of an Immediate Response Action to address an IH or CEP, 310 CMR 40.1403(11) requires the person conducting the action to provide notification to owners, operators and other persons that may experience "significant health or safety impacts (i.e. Affected Individuals as defined in 310 CMR 40.0006)" from the disposal site that is being addressed by an IRA. Notification is required within 72 hours of commencing the remedial action. The initial notification may be made verbally, but must be followed by a written notice. The written notice, titled *Information Notice about Immediate Response Actions*, is made using Form BWSC124. The purpose of this notice is to inform its recipients of the scope and nature of the remedial actions that are being performed given that such activities may raise logistical questions and/or health concerns. This notice is not required in cases where the IRA is limited to assessment only.

For vapor intrusion sites, "Affected Individuals" who may experience health or safety impacts can include residents of affected residential buildings and workers in commercial or industrial space where a remedial action is being conducted as part of an IRA to address an IH or CEP. In addition to notifying Affected Individuals, 310 CMR 40.1403(11)(d) contains an additional requirement applicable to multi-unit or industrial or commercial buildings that requires the person conducting the IRA to request that the owners and/or operators of the buildings post the notice where it will be visible to individuals who are routinely present in such building(s).

Once the IRA is completed, written notice that includes a copy of the IRA Completion Statement must be sent to the same Affected Individuals who received earlier notice of the remedial action; this notice must again be provided using Form BWSC124. A copy of this notice must also be submitted to the Department with the IRA Completion Statement.

5.2.2.1 Notice Related to Immediate Response Actions Where TCE in Indoor Air poses an Imminent Hazard – Special Case

Because of the specific nature of the potential short term exposure risk of fetal heart malformations in developing fetuses posed by exposure to trichloroethylene, MassDEP has developed detailed fact sheets to use as part of the Notice to inform residents and workers where TCE is measured in indoor air at IH levels. These fact sheets are titled "Important Information about Trichloroethylene (TCE) in Residential Indoor Air" (http://www.mass.gov/eea/docs/dep/cleanup/laws/tceresin.pdf) and "Important Information on Trichloroethylene (TCE) in Workplace Indoor Air" (http://www.mass.gov/eea/docs/dep/cleanup/laws/tcewkin.pdf), respectively. At disposal sites where indoor air concentrations of TCE indicate an IH, these facts sheets should be provided along with the written Notice required by 310 CMR 40.1403(11).

5.2.2.2 Notice to Local Officials of Immediate Response Actions

The MCP also requires that local officials (the Chief Municipal Officer and Board of Health) be informed of specific IRA response action milestones and activities at disposal sites in their community, including: implementation of an IRA for an IH or CEP Pathway; submittal of a completion statement for an IRA for an IH; and implementation of field work involving the use of respirators or Level A, B or C protective clothing.

Information on optional communication related to notice related to IRA remedial actions is provided in Section 5.4.

5.2.3 Notification of Owners of Property within the Boundaries of a Disposal Site (Form BWSC122)

310 CMR 40.1406 outlines the requirements for notification at specific points in the response action process to property owners with property located wholly or partially within the disposal site boundaries. This requirement applies to notification of owners of properties with buildings where vapor intrusion has been identified. This written notice, titled *Informational Notice to Property Owners*, is made using Form BWSC122.

The person conducting response actions is required to provide this written notice to all applicable property owners at two points in the response action process – at the time the Phase II Report is submitted, and at the time the Permanent or Temporary Solution Statement is submitted. In the event that additional investigation later determines that a property is in fact not within the boundaries of the disposal site, subsequent notice must be given to provide the updated information to the property owner. 310 CMR 40.1406(4) provides an alternative means of providing notice to property owners within the boundaries of disposal site when the number of affected properties exceeds 50. In such cases, MassDEP approval of the alternative approach is required and the local Board of Health must be informed prior to providing the notice. An example of alternative approach is publishing a public notice in the local newspaper.

5.3 General Public Notification and Involvement

The MCP's general public notice (i.e., newspaper notices) requirements and public involvement opportunities apply to vapor intrusion sites. They serve to inform both local officials and the public about risks posed by a disposal site, the status of response actions, and opportunities for public involvement that are provided by the regulations. General public involvement information is summarized in a fact sheet available on MassDEP's website (http://www.mass.gov/dep/cleanup/factpi2.pdf).

5.3.1 Other Notifications of Local Officials

In addition to the requirements to notify the Chief Municipal Officer and Board of Health of IRA activities, other common activities and events at vapor intrusion sites which require notification of the local officials include:

- Implementation of Release Abatement Measures;
- Sampling of indoor air or soil at residential property "at, adjacent to, or down-gradient from any contamination or suspected contamination…";
- Availability of Phase Reports, Phase III Remedial Action Plans, Phase IV Remedy Implementation Plans, Permanent or Temporary Solution and Downgradient Property Status (DPS) Opinions; and
- Recording/registering, amendment, release or termination of a Notice of an AUL.

5.3.2 Public Involvement Opportunities During Preliminary Response Actions

310 CMR 40.1403(9) specifies the process local officials and the public may use to become involved with disposal sites in their community during Preliminary Response Actions (IRAs and RAMs). MassDEP's fact sheet, "*Opportunities for Public Involvement in Preliminary Response Actions,*" at http://www.mass.gov/eea/agencies/massdep/cleanup/regulations/mcp-public-involvement-in-preliminary-response-actions.html outlines this process. Local officials and residents may send a written request for information to the party conducting an IRA or RAM, and that party in turn is required to respond to the request and provide "appropriate opportunities for public comment." The regulations provide some flexibility as to what activities are identified as public comment opportunities, but indicate that activities may include a public meeting or opportunity for the public to submit written comments.

5.3.3 Public Involvement Plan (PIP) Designation for Disposal Sites

The MCP provides community members and local officials with an opportunity, through the filing of a petition signed by ten or more residents, to designate a tier classified disposal site as a Public Involvement Plan site or "PIP site." PIP site designation in turn triggers additional required public involvement activities, including the development of a Public Involvement Plan, which must be performed by the party conducting response actions. These additional activities include holding a public meeting, and providing for public comment on response action submittals. The designation of a disposal site as a PIP site provides an opportunity for community residents to ask questions about disposal sites and receive documented responses. The process and requirements for designating a disposal site as a PIP site are located within 310 CMR 40.1404. Additional information may be found in MassDEP's fact sheet "*Tips on PIPs: Understanding and Using the Public Involvement Processes*" at http://www.mass.gov/eea/agencies/massdep/cleanup/sites/understanding-and-using-the-public-involvement-processes.html.

5.4 Optional Public Involvement Activities

In addition to the public involvement requirements in the MCP, other optional communication tools may be useful during the assessment and/or mitigation of a vapor intrusion site to facilitate effective communication. To the extent additional communication tools and efforts improve understanding of the response actions and risk issues by concerned parties, misunderstandings, anxiety and delays that can arise from incomplete, untimely or otherwise ineffective communication can be avoided.

When vapor intrusion occurs at school or daycare buildings, additional efforts to communicate effectively with school officials/day care directors are often the key to identifying and addressing concerns in a timely way and planning and scheduling response actions. MassDEP strongly encourages parties conducting response actions to work directly with the School Department personnel and the school principal or daycare director to develop a risk communication strategy for informing staff, parents and students about the investigation, remedial actions, and potential risk. MassDEP is often able to assist with risk communication regarding investigations and remedial actions at schools and daycare facilities.

Abutters and neighbors who do not meet the MCP definition of Affected Individuals may have an interest in the site, especially when dealing with a large groundwater plume. If future investigations indicate that contamination is also affecting those properties, such previous communication about the investigation may make access to those properties easier to obtain. It may be useful to consider general communication about the nature of vapor intrusion investigations prior to the required notifications, for example during the implementation of the Phase II Scope of Work.

In anticipation of a property owner's potential concerns with indoor air sampling results, parties performing the sampling and communicating the results should consider providing the property owner with some context and/or timely assistance in interpreting analytical results. Such efforts could include providing an explanatory cover letter with the results, a comparison to other concentrations (e.g., standards, risk-based concentrations, or background) and/or a telephone call prior to or shortly after sending the results to the property owner.

Fact sheets are a useful tool for communicating information about vapor intrusion, investigation techniques, and mitigation options. MassDEP has published a general vapor intrusion fact sheet at http://www.mass.gov/eea/agencies/massdep/cleanup/regulations/vapor-intrusion-and-indoor-air-contamination-waste-sites.html that may be provided to the public at locations where vapor intrusion is being investigated or mitigated. This fact sheet may be helpful in cases requiring notice pursuant to 310 CMR 40.1403(10) and (11) discussed above. This fact sheet also explains that indoor air testing may find chemicals that are attributable to chemicals in use in the building (i.e., not the result of vapor intrusion).

The development of site-specific fact sheets may be appropriate for a disposal site that affects or is of interest to a large number of individuals. A site-specific fact sheet can provide an overview of the site conditions, and a description of the general response action plan. It may be helpful in providing a consistent and reliable source of basic information about a site that can be made available in response to specific inquiries or distributed with the help of local officials or others who are in contact with the interested public.

Chemical-specific fact sheets are available from the Agency for Toxic Substances and Disease Registry (ATSDR) (http://www.atsdr.cdc.gov/toxfaqs/index.asp) and the New York State Department of Health (http://www.nyhealth.gov/environmental/investigations/soil_gas/svi_guidance/docs/svi_appendh.pdf).

6. OBTAINING ACCESS AT VAPOR INTRUSION SITES

Site investigations to assess potential vapor intrusion often require conducting assessment and mitigation activities at properties adjacent to or downgradient of the source property. In these cases, permission in the form of a written access agreement between the person conducting response actions and the adjacent/downgradient property owner is usually obtained prior to entering the potentially impacted property to perform assessment. Typical components of the access agreement include the purpose of the assessment, the activities that will be performed, the duration of the work, and the date(s) when the person conducting response actions would like to perform the activities.

All attempts by the person conducting response actions to gain access to a property should be documented. If the initial attempts to gain access are not successful, such persons may, consistent with the provisions of the MCP, request MassDEP's assistance in gaining access. The provisions at 310 CMR 40.0173(1) and (2) outline the steps a person conducting response actions must follow to request assistance from MassDEP. If, after reasonable efforts, the person conducting response action is unable to obtain access, he or she should send a notice, by certified mail (return receipt requested) to each person who owns and operates the property to which access is being sought indicating that a request to provide assistance to gain access will be submitted to MassDEP. This correspondence to the property owner/operator must contain a statement informing such owner/operator that they may file a response to the access request directly with MassDEP.

Once the notice is sent to the property owner, a request for access assistance letter for the purpose of performing one or more necessary response actions may be submitted to the MassDEP. The following information must be included in the request:

1. the identity of the person making the request and his or her relationship to the site or location;

2. the nature and location of the response action intended; the duration of the response action; and the reason the response action is necessary;

3. the identity of the owner/operator of the property for which access is sought;

4. the results of prior attempts to gain access; and

5. certification that a copy of the access assistance letter to MassDEP has been sent to every owner/operator of the site for which access is sought.

Upon receiving the request for access assistance letter, MassDEP will contact the adjacent/downgradient property owner(s) to assist in obtaining access. If necessary, MassDEP may use the available administrative approaches outlined in 310 CMR 40.0173 to facilitate further investigation at the property.

Appendix I

Indoor Air Threshold Values for the Evaluation of a Vapor Intrusion Pathway

I.A Introduction

This appendix lists and documents Residential and Commercial/Industrial Threshold Values for evaluating indoor air data as part of a vapor intrusion pathway investigation, as described in Section 2.2. These threshold values, based on MassDEP's Typical Indoor Air Concentrations (2008) and MCP risk management criteria are intended to expedite the evaluation of indoor air data collected as part of MCP response actions.

I.B Typical Indoor Air Concentrations

Large-scale studies of indoor air quality in buildings unaffected by a vapor intrusion pathway are useful in identifying the types and concentrations of chemicals that may typically be expected in indoor air from building-related sources absent a vapor intrusion pathway. In this regard, MassDEP developed a list of Typical Indoor Air Concentrations ("TIACs", Technical Update, 2008, http://www.mass.gov/dep/cleanup/laws/iatu.pdf). This list provides the 50^{th}, 75^{th} and 90^{th} percentile values based on data sets from several recent studies of indoor air quality in residential structures. In the absence of well-documented and generically-applicable commercial TIACs, these values are used to develop both the residential and commercial/industrial Threshold Values (TVs).

In general MassDEP selected TVs to provide a practical screening tool that also protects human health. Choosing a lower percentile value as a TV increases the probability of erroneously concluding that a detected concentration is related to vapor intrusion. For this reason MassDEP has not used percentile values below the 50^{th} percentile. Choosing a higher percentile as a screening value increases the probability of erroneously concluding that a detected concentration is not related to vapor intrusion. Therefore the 90^{th} percentile is the upper bounds for this screening effort. When screening using the 90^{th} percentile the department is confident that detections above the 90^{th} percentile are probably not related to VOCs used or generated in the building, but are at least in part due to vapor intrusion. Conversely, the department acknowledges that roughly 10% of the time this assumption may be incorrect.

I.C Threshold Values

Residential – TV_r

Table I-A lists the Residential Threshold Values. As detailed below, the Residential Threshold Values (TV_rs) combine MassDEP's list of TIACs and risk-based concentrations. Table I-C provides the risk management values and Table I-D provides the Analytical Reporting Limits used in identifying the TV_rs.

MassDEP established the TV_rs for each chemical listed in Table I-A as follows:

- The 90^{th} percentile value from the TIACs was identified [MassDEP chose this value as a starting point because the data suggests that for most sites, concentrations below this are often detected in residential properties];

- The 90th percentile value was compared to the risk-based concentrations (Table I-C) calculated using an ELCR of $1X10^{-6}$ and an HI of 0.2. Cancer and non-cancer risk estimates were based on a conservative residential exposure scenario: 365 days/year for 30 years, including a child aged 1to 8 years for the evaluation of non-cancer risk [This step was used to avoid using a screening value that could pose significant human health risk];

- If the risk-based concentration was higher than the 90th percentile value, then the 90th percentile value was used as the Threshold Value [The 90th is used as the ceiling to avoid concluding that vapor intrusion is not occurring when it may be];

- If a risk-based concentration was lower than the 90th percentile value, but higher than the 50th percentile value, then the risk-based concentration was used as the Threshold Value [This step was taken to provide a practical comparison somewhere between VOC concentrations that are often detected in residential properties (50th) and those that are less frequently detected indoor air concentrations (90th)].

- If the risk-based concentration was lower than the 50th percentile value, then the 50th percentile value was used as the Threshold Value [This step was taken to put a lower limit on the screening value. While this step may screen out some properties where concentrations may pose health risks, this step was included as a measure to limit the number of sites that require assessments at concentrations typically detected in residential properties].

- For chemicals that were either non-detects (NDs) in all of the selected studies or were detected less than 10% of the time (and therefore do not have an associated 50th, 75th or 90th percentile value), the highest analytical Reporting Limit provided for MassDEP APH and TO-15 (Scan Mode) (Table I-D) was used as the Threshold Value, unless the Reporting Limit was higher than risk-based concentration, in which case the risk-based concentration was used as the Threshold Value [This step was implemented to manage the practical limitations of the analytical capabilities while providing a conservative measure of protection against exposures that may pose health risks].

Commercial/Industrial – $TV_{c/i}$

Table I-B lists the Commercial/Industrial Threshold Values and the basis for the $TV_{c/i}$ (e.g., risk-based or 90th percentile value) for each chemical. Table I-C provides the risk management values and Table I-D provides the Analytical Reporting Limits used in identifying the $TV_{c/i}$s.

MassDEP established the $TV_{c/i}$s for each chemical listed in Table I-B as follows:

- The 90th percentile value from the Typical Indoor Air Concentrations (residential) was identified [MassDEP chose this value as a starting point because the data suggests that for most sites, concentrations below this are often detected in residential properties];

- The 90th percentile value was compared to the risk-based concentrations (Table I-C) calculated using an ELCR of $1X10^{-6}$ and an HI of 0.2. Cancer and non-cancer risk estimates were based on a conservative worker exposure scenario: 250 days/year for 30 years, adult exposures only [This step was taken to reflect worker exposure assumptions that are less conservative than residential exposures];

- If the risk-based concentration was ***lower*** than the 90th percentile TIAC value, then the 90th percentile value was used as the Commercial/Industrial Threshold Value [This step was taken to avoid concluding that vapor intrusion is occurring when it might not be. Given that residential TIACs are being used for the commercial scenario, MassDEP wanted to avoid triggering actions to address vapor intrusion at sites that have VOC concentrations that may be related to chemicals used in commercial/industrial operations.];

- If a risk-based concentration was ***higher*** than the 90th percentile TIAC value, then the risk-based concentration was used as the Commercial/Industrial Threshold Value [this was done to reduce the number of vapor intrusion investigations at commercial/industrial sites related to typical VOC concentrations in commercial/industrial settings].

I.D Single-Chemical Exposure Considerations

For Threshold Values (TV_r or $TV_{c/i}$) based on health risk, the listed value represents the estimated concentration which may pose a significant risk, assuming the exposure scenario described ***and*** assuming multiple Contaminants of Concern are present. If there is only a single COC present, it may be appropriate to use the MCP Method 3 Risk Limits of an ELCR = $1X10^{-5}$ and an HI = 1 as target risk levels rather than the more conservative ELCR = $1x10^{-6}$ and HI = 0.2 target levels. These higher risk-based concentrations are also listed in Table I-C.

Table I-A Residential Threshold Values (TVr)

Chemical	CAS No.	Residential Threshold Values		Basis for Value
		ug/m^3	ppbv	
ACETONE	67-64-1	91	38	90th%
BENZENE	71-43-2	2.3	0.72	50th%
BROMODICHLOROMETHANE	75-27-4	0.13	0.02	1.0 x 10^{-6} Cancer Risk
BROMOFORM	75-25-2	2.1	0.2	1.0 x 10^{-6} Cancer Risk
BROMOMETHANE	74-83-9	0.6	0.15	90th%
CARBON TETRACHLORIDE	56-23-5	0.54	0.086	50th%
CHLOROBENZENE	108-90-7	2.3	0.5	Reporting Limit
CHLOROFORM	67-66-3	1.9	0.39	50th%
DIBROMOCHLOROMETHANE	124-48-1	0.097	0.011	1.0 x 10^{-6} Cancer Risk
DICHLOROBENZENE, 1,2- (o-DCB)	95-50-1	0.72	0.12	90th%
DICHLOROBENZENE, 1,3- (m-DCB)	541-73-1	0.6	0.1	90th%
DICHLOROBENZENE, 1,4- (p-DCB)	106-46-7	0.5	0.083	50th%
DICHLOROETHANE, 1,1-	75-34-3	0.8	0.2	Reporting Limit
DICHLOROETHANE, 1,2-	107-06-2	0.09	0.022	1.0 x 10^{-6} Cancer Risk
DICHLOROETHYLENE, 1,1-	75-35-4	0.8	0.2	Reporting Limit
DICHLOROETHYLENE, CIS-1,2-	156-59-2	0.8	0.2	Reporting Limit
DICHLOROETHYLENE, TRANS-1,2-	156-60-5	0.8	0.2	Reporting Limit
DICHLOROMETHANE	75-09-2	11	3.2	90th%
DICHLOROPROPANE, 1,2-	78-87-5	0.12	0.027	1.0 x 10^{-6} Cancer Risk
DICHLOROPROPENE, 1,3-	542-75-6	0.58	0.13	1.0 x 10^{-6} Cancer Risk
DIOXANE, 1,4-	123-91-1	0.57	0.16	1.0 x 10^{-6} Cancer Risk
ETHYLBENZENE	100-41-4	7.4	1.7	90th%
ETHYLENE DIBROMIDE	106-93-4	0.0078	0.001	1.0 x 10^{-6} Cancer Risk
HEXACHLOROBUTADIENE	87-68-3	0.11	0.0099	1.0 x 10^{-6} Cancer Risk
METHYL ETHYL KETONE	78-93-3	12	4.1	90th%
METHYL ISOBUTYL KETONE	108-10-1	2.2	0.54	90th%
METHYL TERT BUTYL ETHER	1634-04-4	39	11	90th%
METHYLNAPHTHALENE, 2-	91-57-6	8	1.4	Reporting Limit
NAPHTHALENE	91-20-3	0.6	0.11	Non-cancer Risk: HI=0.2
Aliphatics C5 to C8	NOS	58	NA	50th%
C9 to C12	NOS	68	NA	50th%
Aromatics C9 to C10	NOS	10	NA	Non-cancer Risk: HI=0.2
STYRENE	100-42-5	1.4	0.32	90th%
TETRACHLOROETHANE, 1,1,2,2-	79-34-5	0.04	0.0059	1.0 x 10^{-6} Cancer Risk
TETRACHLOROETHYLENE	127-18-4	1.4	0.21	50th%
TOLUENE	108-88-3	54	14	90th%
TRICHLOROBENZENE, 1,2,4-	120-82-1	0.4	0.054	Non-cancer Risk: HI=0.2
TRICHLOROETHANE, 1,1,1-	71-55-6	3	0.54	90th%
TRICHLOROETHANE, 1,1,2-	79-00-5	0.15	0.027	1.0 x 10^{-6} Cancer Risk
TRICHLOROETHYLENE	79-01-6	0.4	0.075	Non-cancer Risk: HI=0.2
VINYL CHLORIDE	75-01-4	0.27	0.1	1.0 x 10^{-6} Cancer Risk
XYLENES (Mixed Isomers)	1330-20-7	20	4.6	Non-cancer Risk: HI=0.2

Note*:*
NA- Not Available
NOS – Not Otherwise Specified

Table I-B Commercial/Industrial Threshold Values (TVc/i)

Chemical	CAS No.	Commercial/Industrial Threshold Values		Basis for Value
		ug/m³	ppbv	
ACETONE	67-64-1	710	300	Non-cancer Risk: HI=0.2
BENZENE	71-43-2	11	3.6	90th%
BROMODICHLOROMETHANE	75-27-4	0.65	0.097	1.0 x 10^{-6} Cancer Risk
BROMOFORM	75-25-2	10	1	1.0 x 10^{-6} Cancer Risk
BROMOMETHANE	74-83-9	4.4	1.1	Non-cancer Risk: HI=0.2
CARBON TETRACHLORIDE	56-23-5	1.9	0.3	1.0 x 10^{-6} Cancer Risk
CHLOROBENZENE	108-90-7	44	9.6	Non-cancer Risk: HI=0.2
CHLOROFORM	67-66-3	3	0.62	90th%
DIBROMOCHLOROMETHANE	124-48-1	0.48	0.056	1.0 x 10^{-6} Cancer Risk
DICHLOROBENZENE, 1,2- (o-DCB)	95-50-1	710	120	Non-cancer Risk: HI=0.2
DICHLOROBENZENE, 1,3- (m-DCB)	541-73-1	710	120	Non-cancer Risk: HI=0.2
DICHLOROBENZENE, 1,4- (p-DCB)	106-46-7	1.7	0.28	1.0 x 10^{-6} Cancer Risk
DICHLOROETHANE, 1,1-	75-34-3	710	170	Non-cancer Risk: HI=0.2
DICHLOROETHANE, 1,2-	107-06-2	0.44	0.11	1.0 x 10^{-6} Cancer Risk
DICHLOROETHYLENE, 1,1-	75-35-4	180	45	Non-cancer Risk: HI=0.2
DICHLOROETHYLENE, CIS-1,2-	156-59-2	5.3	1.3	Non-cancer Risk: HI=0.2
DICHLOROETHYLENE, TRANS-1,2-	156-60-5	53	13	Non-cancer Risk: HI=0.2
DICHLOROMETHANE	75-09-2	530	150	Non-cancer Risk: HI=0.2
DICHLOROPROPANE, 1,2-	78-87-5	0.6	0.13	1.0 x 10^{-6} Cancer Risk
DICHLOROPROPENE, 1,3-	542-75-6	2.9	0.63	1.0 x 10^{-6} Cancer Risk
DIOXANE, 1,4-	123-91-1	2.8	0.78	1.0 x 10^{-6} Cancer Risk
ETHYLBENZENE	100-41-4	880	200	Non-cancer Risk: HI=0.2
ETHYLENE DIBROMIDE	106-93-4	0.038	0.005	1.0 x 10^{-6} Cancer Risk
HEXACHLOROBUTADIENE	87-68-3	4.6	0.43	90th%
METHYL ETHYL KETONE	78-93-3	4400	1500	Non-cancer Risk: HI=0.2
METHYL ISOBUTYL KETONE	108-10-1	2700	650	Non-cancer Risk: HI=0.2
METHYL TERT BUTYL ETHER	1634-04-4	2700	740	Non-cancer Risk: HI=0.2
METHYLNAPHTHALENE, 2-	91-57-6	34	5.9	Non-cancer Risk: HI=0.2
NAPHTHALENE	91-20-3	2.7	0.51	90th%
Aliphatics C5 to C8	NOS	330	NA	90th%
C9 to C12	NOS	220	NA	90th%
Aromatics C9 to C10	NOS	44	NA	Non-cancer Risk: HI=0.2
STYRENE	100-42-5	20	4.7	1.0 x 10^{-6} Cancer Risk
TETRACHLOROETHANE, 1,1,2,2-	79-34-5	0.2	0.029	1.0 x 10^{-6} Cancer Risk
TETRACHLOROETHYLENE	127-18-4	4.1	0.6	90th%
TOLUENE	108-88-3	4400	1200	Non-cancer Risk: HI=0.2
TRICHLOROBENZENE, 1,2,4-	120-82-1	3.4	0.46	Non-cancer Risk: HI=0.2
TRICHLOROETHANE, 1,1,1-	71-55-6	4400	810	Non-cancer Risk: HI=0.2
TRICHLOROETHANE, 1,1,2-	79-00-5	0.72	0.13	1.0 x 10^{-6} Cancer Risk
TRICHLOROETHYLENE	79-01-6	1.8	0.33	Non-cancer Risk: HI=0.2
VINYL CHLORIDE	75-01-4	1.3	0.51	1.0 x 10^{-6} Cancer Risk
XYLENES (Mixed Isomers)	1330-20-7	88	20	Non-cancer Risk: HI=0.2

***Note**:*
NA- Not Available
NOS – Not Otherwise Specified

Table I-C Risk Management Criteria Used To Develop the Threshold Values

Chemical	CAS No.	Residential Scenario				Commercial/Industrial Scenario			
		HI = 0.2 (a)	HI= 1.0 (b)	ELCR=1x10^{-6} (c)	ELCR=1x10^{-5} (d)	HI = 0.2 (e)	HI= 1.0 (f)	ELCR=1x10^{-6} (g)	ELCR=1x10^{-5} (h)
		ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3
ACETONE	67-64-1	1.60E+02	800			7.08E+02	3500		
BENZENE	71-43-2	2.00E+00	10	2.99E-01	3	8.85E+00	44	1.47E+00	15
BROMODICHLOROMETHANE	75-27-4	2.00E+00	10	1.32E-01	1.3	8.85E+00	44	6.48E-01	6.5
BROMOFORM	75-25-2	1.40E+01	70	2.12E+00	21	6.19E+01	310	1.04E+01	100
BROMOMETHANE	74-83-9	1.00E+00	5			4.42E+00	22		
CARBON TETRACHLORIDE	56-23-5	2.00E+01	100	3.89E-01	3.9	8.85E+01	440	1.91E+00	19
CHLOROBENZENE	108-90-7	1.00E+01	50			4.42E+01	220		
CHLOROFORM	67-66-3	1.32E+02	660	1.01E-01	1	5.84E+02	2900	4.99E-01	5
DIBROMOCHLOROMETHANE	124-48-1	1.40E+01	70	9.72E-02	0.97	6.19E+01	310	4.78E-01	4.8
DICHLOROBENZENE, 1,2- (o-DCB)	95-50-1	1.60E+02	800			7.08E+02	3500		
DICHLOROBENZENE, 1,3- (m-DCB)	541-73-1	1.60E+02	800			7.08E+02	3500		
DICHLOROBENZENE, 1,4- (p-DCB)	106-46-7	1.60E+02	800	3.40E-01	3.4	7.08E+02	3500	1.67E+00	17
DICHLOROETHANE, 1,1-	75-34-3	1.60E+02	800			7.08E+02	3500		
DICHLOROETHANE, 1,2-	107-06-2	1.40E+00	7	8.97E-02	0.9	6.19E+00	31	4.41E-01	4.4
DICHLOROETHYLENE, 1,1-	75-35-4	4.00E+01	200			1.77E+02	880		
DICHLOROETHYLENE, CIS-1,2-	156-59-2	1.20E+00	6			5.31E+00	27		
DICHLOROETHYLENE, TRANS-1,2-	156-60-5	1.20E+01	60			5.31E+01	270		
DICHLOROMETHANE	75-09-2	1.20E+02	600	2.33E+02	2300	5.31E+02	2700	1.15E+03	11000
DICHLOROPROPANE, 1,2-	78-87-5	8.00E-01	4	1.23E-01	1.2	3.54E+00	18	6.04E-01	6
DICHLOROPROPENE, 1,3-	542-75-6	4.00E+00	20	5.83E-01	5.8	1.77E+01	88	2.87E+00	29
DIOXANE, 1,4-	123-91-1	2.40E+01	120	5.69E-01	5.7	1.06E+02	530	2.80E+00	28
ETHYLBENZENE	100-41-4	2.00E+02	1000			8.85E+02	4400		
ETHYLENE DIBROMIDE	106-93-4	1.80E+00	9	7.78E-03	0.078	7.96E+00	40	3.82E-02	0.38
HEXACHLOROBUTADIENE	87-68-3	8.00E-01	4	1.06E-01	1.1	3.54E+00	18	5.21E-01	5.2
METHYL ETHYL KETONE	78-93-3	1.00E+03	5000			4.42E+03	22000		
METHYL ISOBUTYL KETONE	108-10-1	6.00E+02	3000			2.65E+03	13000		
METHYL TERT BUTYL ETHER	1634-04-4	6.00E+02	3000			2.65E+03	13000		
METHYLNAPHTHALENE, 2-	91-57-6	1.00E+01	50			4.42E+01	220		
NAPHTHALENE	91-20-3	6.00E-01	3			2.65E+00	13		
Aliphatics C5 to C8	NOS	4.00E+01	200			1.77E+02	880		
C9 to C12	NOS	4.00E+01	200			1.77E+02	880		
Aromatics C9 to C10	NOS	1.00E+01	50			4.42E+01	220		
STYRENE	100-42-5	2.00E+02	1000	4.09E+00	41	8.85E+02	4400	2.01E+01	200
TETRACHLOROETHANE, 1,1,2,2-	79-34-5	1.86E+01	93	4.02E-02	0.4	8.23E+01	410	1.98E-01	2
TETRACHLOROETHYLENE	127-18-4	8.00E+00	40	7.78E-01	7.8	3.54E+01	180	3.82E+00	38

Chemical	CAS No.	Residential Scenario				Commercial/Industrial Scenario			
		HI = 0.2 (a)	HI= 1.0 (b)	ELCR=1x10^{-6} (c)	ELCR=1x10^{-5} (d)	HI = 0.2 (e)	HI= 1.0 (f)	ELCR=1x10^{-6} (g)	ELCR=1x10^{-5} (h)
		ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3
TOLUENE	108-88-3	1.00E+03	5000			4.42E+03	22000		
TRICHLOROBENZENE, 1,2,4-	120-82-1	4.00E-01	2			1.77E+00	8.8		
TRICHLOROETHANE, 1,1,1-	71-55-6	1.00E+03	5000			4.42E+03	22000		
TRICHLOROETHANE, 1,1,2-	79-00-5	1.48E+01	74	1.46E-01	1.5	6.55E+01	330	7.17E-01	7.2
TRICHLOROETHYLENE	79-01-6	4.00E-01	2	4.67E-01	4.7	1.77E+00	8.8	2.29E+00	23
VINYL CHLORIDE	75-01-4	2.00E+01	100	2.65E-01	2.7	8.85E+01	440	1.30E+00	13
XYLENES (Mixed Isomers)	1330-20-7	2.00E+01	100			8.85E+01	440		

Note:

(a) = Noncancer risk-based concentration used to develop threshold values in residential settings.
(b) = Noncancer risk-based concentration used to develop single chemical threshold values in residential settings.
(c) = Cancer risk-based concentration used to develop threshold values in residential settings.
(d) = Cancer risk-based concentration used to develop single chemical threshold values in residential settings.
(e) = Noncancer risk-based concentration used to develop threshold values in commercial/industrial settings.
(f) = Noncancer risk-based concentration used to develop single chemical threshold values in commercial/industrial settings.
(g) = Cancer risk-based concentration used to develop threshold values in commercial/industrial settings.
(h) = Cancer risk-based concentration used to develop single chemical threshold and screening values in commercial/industrial settings.

Table I-D Analytical Reporting Limits for MassDEP APH and TO-15 (Scan Mode)

Chemical	CAS No.	Lab 1	Lab 2	Lab 3
		μg/m³	μg/m³	μg/m³
ACETONE	67-64-1	1.2	5.9	1.2
BENZENE	71-43-2	1.6	0.6	0.6
BROMODICHLOROMETHANE	75-27-4	3.3	1.3	1.3
BROMOFORM	75-25-2	5.2	2.1	2.1
BROMOMETHANE	74-83-9	2.2	0.8	0.8
CARBON TETRACHLORIDE	56-23-5	1.3	1.3	1.3
CHLOROBENZENE	108-90-7	2.3	0.9	0.9
CHLOROFORM	67-66-3	2.4	1.0	1.0
DIBROMOCHLOROMETHANE	124-48-1	4.3	1.7	1.7
DICHLOROBENZENE, 1,2- (o-DCB)	95-50-1	3.0	1.2	1.2
DICHLOROBENZENE, 1,3- (m-DCB)	541-73-1	3.0	1.2	1.2
DICHLOROBENZENE, 1,4- (p-DCB)	106-46-7	3.0	1.2	1.2
DICHLOROETHANE, 1,1-	75-34-3	0.8	0.8	0.8
DICHLOROETHANE, 1,2-	107-06-2	0.8	0.8	0.8
DICHLOROETHYLENE, 1,1-	75-35-4	0.8	0.8	0.8
DICHLOROETHYLENE, CIS-1,2-	156-59-2	0.8	0.8	0.8
DICHLOROETHYLENE, T-1,2-	156-60-5	0.8	0.8	0.8
DICHLOROMETHANE (MeCl)	75-09-2	1.7	1.7	1.7
DICHLOROPROPANE, 1,2-	78-87-5	2.3	0.9	0.9
DICHLOROPROPENE, cis, 1,3-	10061-01-5	2.3	0.9	0.9
DICHLOROPROPENE, trans, 1,3-	10061-02-6	2.3	0.9	0.9
DIOXANE, 1,4-	123-91-1	1.8	3.6	18.0
ETHYLBENZENE	100-41-4	2.2	0.9	0.9
ETHYLENE DIBROMIDE	106-93-4	3.8	NR	1.5
HEXACHLOROBUTADIENE	87-68-3	5.3	2.1	2.1
METHYL ETHYL KETONE	78-93-3	1.5	1.5	1.5
METHYL ISOBUTYL KETONE	108-10-1	2.0	2.0	2.0
METHYL TERT BUTYL ETHER	1634-04-4	1.8	0.7	1.8
METHYLNAPHTHALENE, 2-	91-57-6	2.9	8.0	NR
NAPHTHALENE	91-20-3	2.6	2.0	2.6
C5 to C8 Aliphatics	NOS	11	24	NR
C9 to C12 Aliphatics	NOS	18	28	NR
C9 to C10 Aromatics	NOS	13	24.0	NR
STYRENE	100-42-5	2.1	0.9	0.9
TETRACHLOROETHANE, 1,1,2,2-	79-34-5	1.4	1.4	1.4
TETRACHLOROETHYLENE	127-18-4	1.4	1.4	1.4
TOLUENE	108-88-3	1.9	0.8	0.8
TRICHLOROBENZENE, 1,2,4-	120-82-1	3.7	3.7	3.7
TRICHLOROETHANE, 1,1,1-	71-55-6	1.1	1.1	1.1
TRICHLOROETHANE, 1,1,2-	79-00-5	1.1	1.1	1.1
TRICHLOROETHYLENE	79-01-6	1.1	1.1	1.1
VINYL CHLORIDE	75-01-4	0.5	0.5	0.5
XYLENES (Mixed Isomers)	1330-20-7	2.2	1.7	2.2

***Note**:*
NR- Not Reported
NOS – Not Otherwise Specified

Appendix II

Sub-Slab Soil Gas Screening Values

II.A Introduction

MassDEP has developed screening criteria for sub-slab soil gas results to be used in a Lines of Evidence evaluation of vapor intrusion. These screening criteria are based on Threshold Values (TVs) discussed in Appendix I and a generic sub-slab soil gas-to-indoor air dilution factor presented in more detail below.

II.B Derivation of Sub-Slab Soil Gas Screening Values

The sub-slab soil gas screening values were derived by multiplying the TVs by a generic sub-slab soil gas-to-indoor air dilution factor of 70. The dilution factor of 70 is meant to reflect the attenuation of soil gases in the sub-slab. This generic dilution factor corresponds to the inverse of the 80th percentile of the sub-slab soil gas attenuation factors in the U.S. EPA database (Figure 11b, "U.S. EPA's Vapor Intrusion Database: Preliminary Evaluation of Attenuation Factors", Draft, Office of Solid Waste, U.S. EPA, March 4, 2008).

The 80th percentile attenuation value was chosen as a reasonably conservative estimate of sub-slab soil gas attenuation. Choosing the 80th percentile means that roughly 80% or 4 out of 5 sites would be expected to have more sub-slab attenuation, and roughly one out of 5, or 20% would be expected to have less sub-slab attenuation. Sub-slab screening values are intended to be used in conjunction with soil gas data obtained within a few inches beneath the slab.

II.C Use of the Sub-Slab Soil Gas Screening Values

As described in Section 2.2.2, sub-slab screening values are intended to be used in conjunction with soil gas data obtained within a few inches beneath the slab. Sampling techniques are outlined in Appendix III. Soil gas directly beneath a slab or basement is most likely to be representative of what may be entering the building.

The generic attenuation factor of 70 applies equally to all VOCs. This attenuation factor assumes petroleum and non-petroleum VOCs (e.g., vinyl chloride) attenuate similarly in the sub-slab as opposed to the significant attenuation that can occur with petroleum compounds in the deep soil gas. In an effort to determine if petroleum compounds were more likely to be attenuated than other VOCs in the sub-slab, petroleum data presented in the USEPA database discussed above was analyzed. While limited (3% of the USEPA database is comprised of petroleum-related compounds), this data combined with site-related sub-slab data suggest that petroleum compounds do not attenuate differently from the sub-slab than other VOCs. The available information indicates petroleum-related compounds typically migrate from the shallow sub-slab soil gas (directly beneath the slab) to indoor air to an extent similar to other volatile compounds.

In general, representative sub-slab soil gas concentrations less than the soil gas screening values indicate that the vapor intrusion pathway is unlikely to be of concern under current site conditions and use.

Table II-A Residential Sub-Slab Soil Gas Screening Values

Chemical	CAS No.	Residential Sub-Slab Soil Gas Screening Values	
		ug/m^3	ppbv
ACETONE	67-64-1	6400	2700
BENZENE	71-43-2	160	50
BROMODICHLOROMETHANE	75-27-4	9.2	1.4
BROMOFORM	75-25-2	150	14
BROMOMETHANE	74-83-9	42	11
CARBON TETRACHLORIDE	56-23-5	38	6
CHLOROBENZENE	108-90-7	160	35
CHLOROFORM	67-66-3	130	27
DIBROMOCHLOROMETHANE	124-48-1	6.8	0.8
DICHLOROBENZENE, 1,2- (o-DCB)	95-50-1	50	8.4
DICHLOROBENZENE, 1,3- (m-DCB)	541-73-1	42	7
DICHLOROBENZENE, 1,4- (p-DCB)	106-46-7	35	5.8
DICHLOROETHANE, 1,1-	75-34-3	56	14
DICHLOROETHANE, 1,2-	107-06-2	6.3	1.6
DICHLOROETHYLENE, 1,1-	75-35-4	56	14
DICHLOROETHYLENE, CIS-1,2-	156-59-2	56	14
DICHLOROETHYLENE, TRANS-1,2-	156-60-5	56	14
DICHLOROMETHANE	75-09-2	770	220
DICHLOROPROPANE, 1,2-	78-87-5	8.6	1.9
DICHLOROPROPENE, 1,3-	542-75-6	41	9
DIOXANE, 1,4-	123-91-1	40	11
ETHYLBENZENE	100-41-4	520	120
ETHYLENE DIBROMIDE	106-93-4	0.54	0.071
HEXACHLOROBUTADIENE	87-68-3	7.4	0.7
METHYL ETHYL KETONE	78-93-3	850	290
METHYL ISOBUTYL KETONE	108-10-1	150	38
METHYL TERT BUTYL ETHER	1634-04-4	2700	760
METHYLNAPHTHALENE, 2-	91-57-6	560	96
NAPHTHALENE	91-20-3	42	8
Aliphatics C5 to C8	NOS	4100	NA
C9 to C12	NOS	4800	NA
Aromatics C9 to C10	NOS	700	NA
STYRENE	100-42-5	95	22
TETRACHLOROETHANE, 1,1,2,2-	79-34-5	2.8	0.41
TETRACHLOROETHYLENE	127-18-4	98	14
TOLUENE	108-88-3	3800	1000
TRICHLOROBENZENE, 1,2,4-	120-82-1	28	3.8
TRICHLOROETHANE, 1,1,1-	71-55-6	210	38
TRICHLOROETHANE, 1,1,2-	79-00-5	10	1.9
TRICHLOROETHYLENE	79-01-6	28	5.2
VINYL CHLORIDE	75-01-4	19	7.2
XYLENES (Mixed Isomers)	1330-20-7	1400	320

Note:
NA- Not Available
NOS – Not Otherwise Specified

Table II-B Commercial/Industrial Sub-Slab Soil Gas Screening Values

Chemical	CAS No.	Commercial/Industrial Sub-Slab Soil Gas Screening Value	
		ug/m^3	ppbv
ACETONE	67-64-1	50000	21000
BENZENE	71-43-2	800	250
BROMODICHLOROMETHANE	75-27-4	45	6.8
BROMOFORM	75-25-2	730	71
BROMOMETHANE	74-83-9	310	80
CARBON TETRACHLORIDE	56-23-5	130	21
CHLOROBENZENE	108-90-7	3100	670
CHLOROFORM	67-66-3	210	43
DIBROMOCHLOROMETHANE	124-48-1	33	3.9
DICHLOROBENZENE, 1,2- (o-DCB)	95-50-1	50000	8200
DICHLOROBENZENE, 1,3- (m-DCB)	541-73-1	50000	8200
DICHLOROBENZENE, 1,4- (p-DCB)	106-46-7	120	19
DICHLOROETHANE, 1,1-	75-34-3	50000	12000
DICHLOROETHANE, 1,2-	107-06-2	31	7.6
DICHLOROETHYLENE, 1,1-	75-35-4	12000	3100
DICHLOROETHYLENE, CIS-1,2-	156-59-2	370	94
DICHLOROETHYLENE, TRANS-1,2-	156-60-5	3700	940
DICHLOROMETHANE	75-09-2	37000	11000
DICHLOROPROPANE, 1,2-	78-87-5	42	9.1
DICHLOROPROPENE, 1,3-	542-75-6	200	44
DIOXANE, 1,4-	123-91-1	200	54
ETHYLBENZENE	100-41-4	62000	14000
ETHYLENE DIBROMIDE	106-93-4	2.7	0.35
HEXACHLOROBUTADIENE	87-68-3	320	30
METHYL ETHYL KETONE	78-93-3	310000	110000
METHYL ISOBUTYL KETONE	108-10-1	190000	45000
METHYL TERT BUTYL ETHER	1634-04-4	190000	52000
METHYLNAPHTHALENE, 2-	91-57-6	2400	410
NAPHTHALENE	91-20-3	190	36
Aliphatics C5 to C8	NOS	23000	NA
C9 to C12	NOS	16000	NA
Aromatics C9 to C10	NOS	3100	NA
STYRENE	100-42-5	1400	330
TETRACHLOROETHANE, 1,1,2,2-	79-34-5	14	2
TETRACHLOROETHYLENE	127-18-4	290	42
TOLUENE	108-88-3	310000	82000
TRICHLOROBENZENE, 1,2,4-	120-82-1	240	32
TRICHLOROETHANE, 1,1,1-	71-55-6	310000	57000
TRICHLOROETHANE, 1,1,2-	79-00-5	50	9.2
TRICHLOROETHYLENE	79-01-6	120	23
VINYL CHLORIDE	75-01-4	91	35
XYLENES (Mixed Isomers)	1330-20-7	6200	1400

***Note**:*
NA- Not Available
NOS – Not Otherwise Specified

Appendix III

Air Sampling Information

Appendix III

Air Sampling Information

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Appendix III

Air Sampling Information

III.A Introduction

This appendix provides a detailed discussion of air sampling and analysis as part of vapor intrusion investigations, risk characterizations, and monitoring. Air sampling and analysis is used to determine contaminant concentrations in sub-slab soil gas, indoor air and outdoor air. While many methods exist to collect and analyze contamination in air, this appendix discusses some of the more common methods, with an emphasis on those that are recommended by MassDEP. The following sections present information on:

- Sample Collection
- Sample Analytical Methods and
- Sample Quality.

III.B Sample Collection

III.B.1 Indoor Air Product Survey

Before collecting indoor air samples, a survey of the building should be made to locate and remove any VOC-containing products or materials that could contribute to indoor air levels of the Contaminants of Concern. An Indoor Air Building Survey Form that can be used as a checklist when performing an indoor air survey to document information about the building products, materials, conditions and use at the time of sampling is attached to this appendix.

III.B.2 Collection Techniques

Collection techniques implemented in the field can be divided into three categories:

- Real-time sampling and measurement;
- Grab sampling;
- Time-weighted sampling.

Real-time Sampling and Measurement

Real-time sampling and measurement for VOCs typically measures Total Organic Vapors (TOVs), rather than individual chemicals, and combines both air sampling and sample analysis into one procedure. Real-time data is often accomplished with hand held instruments that directly sample and measure TOVs in air instantaneously. Such instruments can have any of several detectors, and often use a Photo-ionization Detector (PID) or Flame Ionization Detector (FID). The use of real time measurement can be especially helpful early in the investigative process in identifying migration pathways into a structure, as well as hot spots within a building. Real-time measurement of TOVs in soil gas can be used to evaluate the extent and relative concentrations of contamination in the sub-surface. This information in turn can provide timely information for making response action decisions, including identifying areas where additional work is needed. As with any sampling and analytical technique, the application of real time total organic vapor instruments must be commensurate with the intended use of the data. The precision, accuracy, representativeness, comparability and sensitivity of the data must be adequate to support decisions made based on that data.

Grab (Short Duration) and Time-Weighted (Long Duration) Sampling

Air samples are usually described as either grab samples or time-weighted samples, depending on the sampling duration. Air grab samples are those collected over a period of several seconds to several minutes. Air time-weighted samples are those collected over many minutes to many hours or days. The definition of a time weighted air sample is “the average concentration of contaminants during a given period”.

Grab samples provide more of a snapshot of chemical concentrations because of the very short duration of the sampling period. Time weighted (or long duration samples) provide an average concentration across the longer period of time.

MassDEP recommends sampling durations of 24-hours for indoor and outdoor air data collection because a longer sampling duration is likely more representative of the actual exposures over time. Shorter sampling durations may be necessary for logistical reasons; in such cases four hours should be considered a minimum sampling duration. For sub-slab soil gas, grab (short duration) samples are often sufficient.

III.B.3 Collection equipment

A variety of collection equipment is available for air sampling. Some commonly used collection techniques are described below.

Evacuated Canisters

Air samples may be collected into evacuated canisters that are under negative pressure relative to the environment. MassDEP considers this method appropriate for the collection of either short duration or long duration samples. Air sampling canisters are generally stainless steel, with silica lined interior, and typically available in 1 liter, 3 liter and 6 liter sizes. Evacuated air sampling canisters are obtained from the laboratory, and are typically ready to collect a sample once a vacuum gauge is installed to the top of the canister. Canisters are fitted with flow controllers that will collect an air sample at a pre-set flow rate.

The canister pressure should be recorded from the vacuum gauge before and after the sampling event. Indoor and outdoor air samples are collected by opening the canister valve. A sample inlet line made of chromatographic-grade stainless steel tubing is used to collect a soil gas sample. Additional information on the procedure for soil gas sampling using a canister is provided in Section III.C of this appendix.

More detailed information regarding the collection of air samples in evacuated canisters can be found in:

- U.S. Environmental Protection Agency (USEPA) Region 1 Laboratory's "*Standard Operating Procedure – Sampling Volatile Organic Compounds Using Summa Polished Stainless Steel Canisters*";

- Sampling procedures included in EPA Methods TO14A and TO15 [see "*Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*" (EPA/625/R-96-010b); and,

- Method IP-1A of the "*Compendium of Methods for the Determination of Air Pollutants in Indoor Air*" (PB90-200288).

Glass Vials

MassDEP has achieved good results collecting grab samples for screening in glass VOA vials. The air sample is collected by flushing the vial using a portable air pump. The sample is typically withdrawn from the vial for analysis by piercing the septum with a syringe. It can then be direct injected into a gas chromatograph. Additional information on the procedure using glass vial for the collection of soil gas samples is provided in Section III.C of this appendix.

Passive Samplers

Passive sampling devices, including sampling badges, typically contain an absorbent media such as charcoal, Carbopak or Tenax. The passive sampler is placed at the sampling location, and contaminants in air are absorbed onto it based on the principle that VOCs in air diffuse from an area of high concentration to an area of low concentration. There is no active pumping to obtain a specific volume of air to be collected by the passive sampler. As a result, the sample volume, and associated chemical concentrations in the sample are estimated by modeling of the diffusion rate.

The advantages of passive samplers include the ability to collect air samples over longer periods of time than some other sampling techniques, and sometimes lower sampling costs. The cost for sample analysis may not be lower. There are several recognized practical application issues with some passive samplers including interferences, the effects of high humidity, and back diffusion off the sampling medium. Passive samplers may be a useful and cost effective tool for screening, but absent Quality Control data regarding sample size and calibration, passive sampling data are likely not sufficient for risk evaluation.

Sorbent Tubes

Sample collection onto sorbent tubes involves the pumping of the air sample through a tube packed with adsorbent media. Types of adsorbent media include charcoal, Tenax, and Carbopak. Tube sample collection flow rates are determined based on the adsorbent used, the target pollutant, and the amount (mass) of adsorbent contained in the trap. Care must be taken to avoid pumping more than the “breakthrough volume” of air into a tube, as sample loss may result. Safe sampling volumes are occasionally suggested by the laboratory supplier or manufacturer or specified for a particular set of parameters in the analytical method. Back-up tubes for detecting breakthrough may be necessary when tube sampling. When conducting tube sampling, pump flow rates should adjusted to make sure the breakthrough volume is not exceeded during the sample collection.

Gas Sampling Bags

Gas sampling bags can be used to collect air samples. Gas sampling bags are generally acceptable for the collection of air samples for screening. If a more rigorous use of the data is intended, commensurate Quality Assurance and Quality Control would be needed. Gas sampling bags have had some application issues associated with contaminants adsorbing to the bag surface, high moisture levels interfering with sample recovery, and bag related contaminant peaks. The potential for these issues should be considered when using bag samplers.

III.B.4 Representative Indoor and Outdoor Air Sampling

Indoor air samples should be collected in a manner that will likely produce a reasonably conservative and representative estimate of the exposure to contaminants by occupants of the building. Therefore, samples should be collected from areas where the highest contamination is likely, with consideration of where the building occupants currently spend their time, and might spend their time in the future. Because lower floors are closer to where contamination is likely entering the building, concentrations are usually higher on lower floors. This is generally due to less air mixing and dilution as compared to upper floors.

Indoor air concentrations vary over time, so longer sampling durations will tend to average this variation and likely produce a better representation of the exposure experienced by building occupants than short duration air samples. Samples that are intended to be representative of "worst case" conditions should be collected when the indoor air concentrations are likely to be higher. This usually includes conditions such as colder weather, with heating system on and doors and windows closed. Samples collected for an IH evaluation should be collected in a timely way as soon as the potential IH has been identified, recognizing that conditions may not be worst case and that additional sampling may be necessary. Some of the factors to be considered in collecting indoor air samples are discussed below.

Weather

When assessing the potential vapor intrusion pathway, sampling should be conducted under weather conditions that are likely to result in a greater amount of vapor intrusion (worst-case conditions). Cold and rainy weather can result in higher indoor contaminant concentrations than warmer, dryer weather. Windy conditions can also result in higher indoor contaminant concentrations. Winds that are steady and exceed about five miles per hour may under-pressurize the building relative to the subsurface. Under these windy conditions, soil gas entry into the building is likely to be greater.

Windows and Doors

Doors and windows should be adjusted to conditions under which vapor intrusion is most likely to occur. The pressure differential between inside and outside a structure is generally greatest when windows and doors are kept closed and the heating system is operating. Therefore, it is recommended that windows and doors to the outside be kept closed during sampling and, if possible, for a period of at least twenty-four to forty-eight hours before sampling is conducted. Gas and oil heating systems often use air in the building (when combustion air is not provided), thereby further increasing the pressure differential and vapor intrusion.

Mechanical Ventilation Systems

The mechanics of a building's heating, venting and air conditioning (HVAC) system should be considered in determining appropriate conditions for sampling. Operation of an HVAC system could affect contaminant infiltration by creating a pressure differential that draws in more, or less, subsurface soil gas or by diluting indoor air levels.

In some heating and cooling systems, air is re-circulated from the basement, thereby rapidly distributing infiltrating soil vapor to other parts of the building. Other ventilation systems have fresh air intakes that are placed on the roof-top of the building, and while operating will temporarily reduce vapor intrusion and dilute indoor air concentrations. Small exhaust fans, such as those found over residential stoves and in bathrooms can reduce the pressure in the house and result in an increase in soil vapor intrusion. On the other hand, very large exhaust fans such as in the kitchens of restaurants, may draw large volumes of clean outside air into the building from around doors and windows, and through roof vents, resulting in a dilution of indoor air VOC levels. The effects of various HVAC systems on vapor intrusion may not be obvious or easy to predict.

Consideration of these issues to the extent possible should be given when evaluating sampling conditions. The sampling plan should be designed to collect samples representative of current and future foreseeable exposure conditions. In some cases, it may be advisable to sample under varying conditions in order to determine the effects of different HVAC configurations. This may be particularly useful with respect to evaluating mitigation measures. HVAC systems should not be operated outside the normal range (i.e., higher than normal rate of air exchanges) during sampling to obtain an indoor air sample representative of typical exposure conditions.

Confounding Sources

Samples to identify and evaluate vapor intrusion should not be collected when there is an indoor source, or nearby outdoor source of the contaminants of concern. Activities such as smoking, and use of sprays, solvents, paints, etc. should be suspended during sampling. Outdoor activities such as lawn mowing, painting, asphalting, sanding, etc. should also be suspended during this time if such activities generate the contaminants of concern. Providing instructions to building residents prior to sampling may help to reduce the presence of contaminants from confounding sources during the sampling period. An example of instructions for building residents is provided as an attachment to this appendix. In addition, an Indoor Air Quality Building Survey should be conducted at the time of sampling. A sample Survey form is also attached to this appendix.

III.C Procedure for the Collection of Sub-Slab Soil Gas Samples

Installation of Sub-Slab Soil Gas Probe

Sub-slab soil gas probes are used to collect soil gas samples from beneath a building floor. Samples can be collected using various techniques and containers. Soil gas probes are typically small (approximately 1 inch in diameter). Soil gas sampling protocols should be designed to collect representative samples. LSPs should use their professional judgment in developing a soil gas collection protocol that ensures the integrity and representativeness of the samples collected. The following measures may be helpful as components of a soil gas sampling protocol: steps to ensure a good seal around sampling tubes, purging with field screening of soil gas, flow rate measurements, vacuum measurements, and leak testing with helium as a tracer gas.

A description of a sub-slab soil gas sampling point installation, and sample collection procedure used by MassDEP is provided as an example below:

- Using an electric hammer drill and masonry drill bit an approximate 1⅛ inch hole is drilled through the foundation floor. Most concrete foundation floors are several inches thick. Many floors have some void space, or permeable fill material such as coarse sand directly under the slab, and soil gas samples can be drawn from this area. The soil gas sampling hole can be fitted with a flush mounted PVC riser and threaded cap with gasket.

- Tightly seal the soil gas sampling point to the floor to avoid short circuiting of indoor air during soil gas sampling. Rocktite® or a similar fast drying expansion cement product, or other non VOC containing sealant, should be used to seal around the outside of the sample point where it penetrates the floor. Permanently installed points are desirable where future sampling may be needed.

A generalized design is depicted in the figure below.

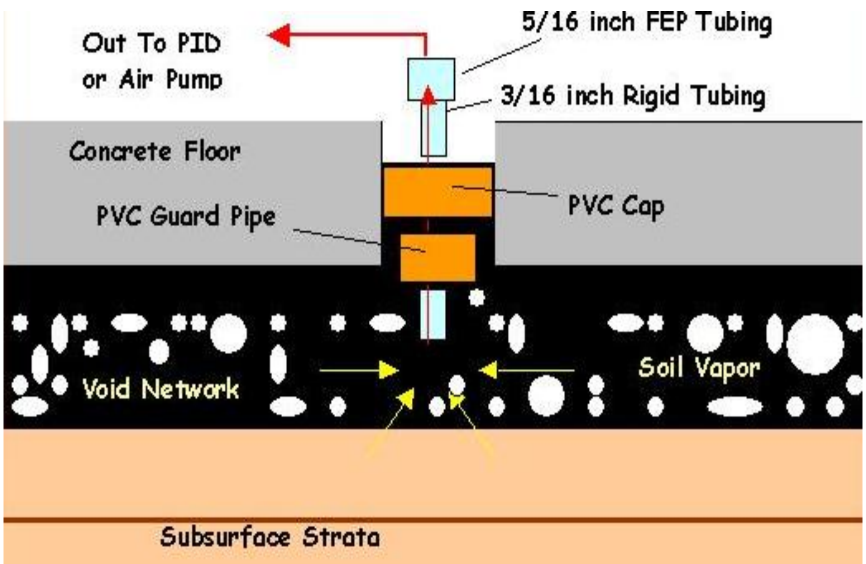

Figure III-A Example of a Soil Gas Sampling Probe

Sample Collection from the Sub-Slab Probe

Sub-slab soil gas points can be sampled using an air pump, evacuated container, or passive absorbent media device. It is usually not necessary to obtain long duration samples when collecting soil gas. A short duration grab sample will suffice. There has been some discussion regarding possible short circuiting if a soil gas sample is collected at too high a sampling rate (i.e. much greater than 200 milliliters per minute). In addition, three to five times the volume of the soil gas probe and collection tubing should be purged prior to collecting the sample.

Sample collection can be accomplished by placing a rubber stopper, with center hole, in the sampling point. A sampling tube is inserted through the hole in the stopper until it is positioned in the area under the floor to be sampled. Alternatively, the sampling port can contain threaded fittings by which sampling tubes can be attached. Shallow soil gas samples are considered more representative than deeper samples because they contain concentrations likely to be entering the building through the cracks in the floor.

There is some concern as to whether a building under positive pressure might contribute indoor air to the sub-slab soil gas, thereby diluting or otherwise changing soil vapor concentrations. This may be checked by making a pressure measurement at the soil vapor sampling point before collecting a soil vapor sample.

Samples may be collected by a variety of methods, including those described in Section III.B.3 of this appendix. Canister sampling is one of the most commonly used methods. When using a canister for sub-slab soil gas sampling, care should be taken to ensure an air tight connection between the sample inlet line and the soil gas sampling points. A sample inlet line made of chromatographic-grade stainless steel tubing is used to collect a soil gas sample. An air tight connection must be made between this sample inlet line and the soil vapor sampling point. The canister pressure should be recorded from the vacuum gauge before and after the sampling event.

If the glass vial sampling method is used, stagnant air should be evacuated from the soil gas sampling point and sample tubing. A flexible soil gas sample collection tube is inserted into a glass Volatile Organic Analysis vial, with a septum cap, and the vial is flushed with pumped soil gas for sufficient time to replace the air in the vial with soil gas. The vial is then capped immediately and the sample is obtained for analysis by using a syringe to withdraw an aliquot through the cap septum.

III.D Sample Analytical Methods

Field Analytical Methods

Field analytical methods are advantageous because data can be obtained quickly and the field investigation can be instantly modified to direct sample collection from the most representative locations. Portable gas chromatographs (GCs) can be brought to the site for same day chemical-specific analyses. Real-time methods such as TOV analyzers provide instant reading of air concentrations. Field analytical methods must have a level of method calibration and quality control commensurate with the intended use of the data.

Laboratory Analytical Methods

Laboratory analytical methods often provide data with a higher level of Quality Assurance and Quality Control than that generated by field analytical methods. There are a variety of laboratory analytical methods available to measure concentrations of contaminants in air. MassDEP recommends the use of the MassDEP's *Compendium of Quality Control Requirements and Performance Standards for Selected Analytical Protocols* (MassDEP Policy WSC #10-320, the "CAM"), particularly the TO-15 (WSC-CAM-IX B) and APH (WSC-CAM-IX A) protocols, to evaluate releases of VOCs and light petroleum mixtures in air. The MassDEP CAM specifies the appropriate quality control for these methods. The CAM TO-15 and APH protocols may be found at:

http://www.mass.gov/eea/agencies/massdep/cleanup/regulations/wsc10-320-compendium--quality-control-reqs.html.

MassDEP strongly recommends use of the full analyte list during the initial stages of site investigations at sites with an unknown or complicated history of uses of oil or hazardous materials. The use of the full analyte list for a chosen analytical method may not be necessary, however, for sites where available sampling data, and substantial site/use history information is available to define the contaminants of concern. Under the CAM it is necessary to document and report use of a reduced analyte list on the MassDEP Analytical Protocol Certification Form.

III.E Sample Quality

The following sections give a brief description of Data Quality Objectives and Sample Quality Assurance and Quality Control. More detailed information on these topics can be found in the MassDEP CAM documents.

Data Quality Objectives

Data quality objectives are sampling goals which must be met to ensure that the data obtained will be adequate for making appropriate decisions about response actions at the site. Factors to consider in setting data quality objectives are: precision, accuracy, representativeness, comparability, completeness and sensitivity. These indicators are used together with data quality control measurements to define the quality of the data collected. More detailed information is provided in the MassDEP CAM documents and Policy #WSC-07-350, *MCP Representativeness and Data Usability Assessments.*

Sample Quality Assurance and Quality Control

In order to monitor the quality of the results obtained in an indoor air monitoring study, it is recommended that quality assurance/quality control (QA/QC) techniques be routinely incorporated into the sampling and analysis for characterizing chemicals in air. QA activities include planning, implementing, documenting, assessing and reporting that assure that data are of known and documented quality. QC activities are technical activities that measure whether and how well the goals established in the quality assurance component were met. Detailed information is located in MassDEP's CAM documents.

Instructions for Residents of Homes to Be Sampled & Indoor Air Quality Building Survey

Instructions for Residents of Homes to Be Sampled

Instructions for Residents (to be followed starting at least 48 hours prior to and during the sampling event)[9]:

- Do not open windows, fireplace openings or vents.
- Do not keep doors open.
- Do not use air fresheners or odor eliminators.
- Do not smoke in the house.
- Do not use wood stoves, fireplace or auxiliary heating equipment (e.g., kerosene heater).
- Do not use paints or varnishes.
- Do not use cleaning products (e.g., bathroom cleaners, furniture polish, appliance cleaners, all-purpose cleaners, floor cleaners).
- Do not use cosmetics, including hair spray, nail polish, nail polish remover, perfume, etc.
- Do not partake in indoor hobbies that use solvents.
- Do not apply pesticides.
- Do not store containers of gasoline, oil or petroleum–based or other solvents within the house or attached garage (except for fuel oil tanks).
- Do not operate or store automobiles in an attached garage.

A list of household products and activities that potentially release volatile chemicals to the indoor air can be found at http://householdproducts.nlm.nih.gov/.

9 Adapted from New Hampshire Department of Environmental Services. October, 1998. "Residential Indoor Air Sampling Form." *Draft Residential Indoor Air Assessment Guidance Document*. Waste Management Division. Site Remediation Programs

Indoor Air Quality Building Survey

Date: ____________________ **ID#:** ________
Address: ____
____

Building Contact: ________________________ **Phone:** Tel: ( )_____________
Cell: ( )_____________
Work: ( )_____________

List of Current Occupants:

INITIALS	AGE	SEX (M/F)

Building Construction Characteristics:

(Circle, Highlight or Underline appropriate responses)

Single Family Multiple Family School Commercial

Ranch	2-Family
Raised Ranch	Duplex
Cape	Apartment House
Colonial	# of units ____
Split Level	Condominium
Colonial	# of units ____
Mobile Home	Other (specify) ________
Other (specify) ________	

General Description of Building Construction Materials: Wood, Brick, Stone, Metal, Other

How many occupied stories does the building have? _____

Has the building been weatherized with any of the following?

Insulation Storm Windows Energy-Efficient Windows Other (specify) ______

What type of basement does the building have?

Full basement Crawlspace Slab-on-Grade Other (specify) ___________

What are the characteristics of the basement?

Finished	Basement Floor:	Foundation Walls:	Moisture:
Unfinished	Concrete	Poured Concrete	Wet
Other (specify)_______	Dirt	Block	Damp
	Layed Up Stone	Dry	

Is a basement sump present? (Y/N) ____

Does the basement have any of the following characteristics (i.e., preferential pathways into the building) that might permit soil vapor entry:

Cracks	Pipes/Utility Conduits	Other (specify) __________
Foundation/slab drainage	Sump pumps	

Heating and Ventilation System(s) Present:

What type of heating system(s) are used in this building?

Hot Air Circulation	Heat Pump	Steam Radiation	Wood Stove
Hot Air Radiation	Unvented Kerosene heater	Electric Baseboard	Other (specify): _____

What type (s) of fuel(s) are used in this building?

Natural Gas	Electric	Coal	Other (specify): __________
Fuel Oil	Wood	Solar	

What type of mechanical ventilation systems are present and/or currently operating in the building?

Central Air Conditioning	Mechanical Fans	Bathroom Ventilation
Fan	Kitchen Range Hood	Open Windows
Individual Air Conditioning Units	Air-to-Air Heat Exchanger	Other (specify):_______

Sources of Chemical Contaminants:

Do one or more smokers occupy this building on a regular basis? ____________

Has anybody smoked in the building in the last 48 hours? ____________

Does the building have an attached garage? ____________

If so, is the garage used for parking cars? ____________

Do the occupants of the building frequently have their clothes dry-cleaned? ____________

Was there any recent remodeling or painting done in the building? ____________

Are there any pressed wood products in the building (e.g., hardwood plywood wall paneling, particleboard, fiberboard)? ____________

Are there any new upholstery, drapes or other textiles in the building? ____________

Has the building been treated with any insecticides/pesticides? If so, what chemicals are used and how often are they applied? ____

Which of these items are present in the building? (Check all that apply)

Potential VOC Source	Location of Source	Removed 48 hours prior to sampling ?(Yes/No/NA)
Paints or paint thinners		
Gas-powered equipment		
Gasoline storage cans		
Cleaning solvents		
Air fresheners		
Oven cleaners		
Carpet/upholstery cleaners		
Hairspray		
Nail polish/polish remover		
Bathroom cleaner		
Appliance cleaner		
Furniture/floor polish		
Moth balls		
Fuel tank		
Wood stove		
Fireplace		
Perfume/colognes		
Hobby supplies (e.g., solvents, paints, lacquers, glues, photographic darkroom chemicals)		
Scented trees, wreaths, potpourri, etc.		
Other		
Other		
Other		
Other		

Outdoor Sources of Contamination:

Do any of the occupants apply pesticides/herbicides in the yard or garden? If so, what chemicals are used and how often are they applied?

Is there any stationary emission source in the vicinity of the building?

Are there any mobile emission sources (e.g., highway, bus stop, high-traffic area) in the vicinity of the building?

Weather Conditions during Sampling:

Outside Temperature (^{o}F):
Prevailing wind direction and approximate wind speed: __________________________
Describe the general weather conditions (e.g., sunny, cloudy, rain): ______________________

Was there any significant precipitation (0.1 inches) within 12 hours preceding the sampling event?________

Type of ground cover (e.g., grass, pavement, etc.) outside the building: ________________________

General Comments:

Is there any other information about the structural features of this building, the habits of its occupants or potential sources of chemical contaminants to the indoor air that may be of importance in facilitating the evaluation of the indoor air quality of the building?

Adapted from

NHDES (New Hampshire Department of Environmental Services. October, 1998. "Residential Indoor Air Sampling Form." *Draft Residential Indoor Air Assessment Guidance Document*. Waste Management Division. Site Remediation Programs.

NYSDOH (New York State Department of Health). 1997. "*Indoor Air Quality Questionnaire and Building Inventory.*" Division of Environmental Health Assessment. Bureau of Toxic Substance Assessment.

VDOH (Vermont Department of Health). June, 1993. "*Indoor Air Study Questionnaire*."

Appendix IV

Guidance on the Design, Installation, Operation, and Monitoring Of Sub-Slab Depressurization Systems

DiPersio, T., Fitzgerald J. (1995)

Appendix IV

Guidance on the Design, Installation, Operation, and Monitoring of Sub-Slab Depressurization Systems

IV.A Introduction

A sub-slab depressurization (SSD) system is a proven technique to eliminate or mitigate vapor intrusion into impacted structures (see Figure IV-A). Based upon traditional radon-mitigation technology, this approach creates a negative pressure field beneath a structure of concern, inducing the flow of VOC vapors to one or more collection points, with subsequent discharge up a stack into the ambient air. In essence, the system "short circuits" the subsurface VOC vapor migration pathway, eliminating or reducing exposures to building occupants.

Figure IV-A: SSD System

A system of this nature can typically be installed at a small building (e.g., single family home) for about $3000 to $6000, depending upon site conditions. Importantly, this is a somewhat invasive, energy & maintenance intensive remedial measure, and therefore an option of secondary resort. Moreover, there are certain site and building conditions (e.g., high groundwater table) that may preclude or limit its application. Therefore, before pursuing this option, it is essential that conclusive evidence exist documenting the presence of a subsurface VOC source and/or migration pathway, and that less invasive steps be initially considered and/or implemented. Where appropriate, this effort should include investigations to identify possible source/source areas, and source control or mitigation measures.

IV.B Purpose/Objective of an SSD System

The purpose of an SSD system is to create a negative pressure field directly under a building and on the outside of the foundation (in relation to building ambient pressure). This negative pressure field becomes a sink for any gases present in the vicinity of the structure. VOCs caught in the advective sweep of this negative pressure field are collected and piped to an ambient air discharge point.

While SSD systems are considered a remedial activity and measure under the MCP, they are typically not a component of a site-wide (soil and groundwater) remediation approach. Rather, their design objective is to prevent soil gases from infiltrating a building. Ideally, the extent of depressurization and soil gas removal should be kept to a minimum, to minimize energy, handling, and/or off-gas treatment costs. This is why these systems are most appropriately termed "depressurization" systems, rather than "ventilation" systems.

Even though site remediation is not a design objective, it is in fact an ancillary effect and benefit. Specifically, by venting soil gases contaminated by VOCs, an SSD system facilitates the mass removal of contaminants from subsurface media. Moreover, every cubic foot of vented soil gas has to be replaced by a cubic foot of air, resulting in an influx of oxygen into contaminated areas, which may facilitate the aerobic biodegradation of contaminants.

The significance of this remediation bonus is site dependent, a function of contaminant type, location, mass, and SSD flow rate. While perhaps most beneficial at residential sites contaminated by a leaking fuel oil tank (limited extent of contamination; directly below slab; aerobically degradable contaminants), in most cases SSD systems will not have an appreciable impact on site contaminant levels.

IV.C Description of an SSD System

A sub-slab depressurization system basically consists of a fan or blower that draws air from the soil beneath a building and discharges it to the atmosphere through a series of collection and discharge pipes. One or more holes are cut through the building slab so that the extraction pipe(s) can be placed in contact with sub grade materials, in order for soil gas to be drawn in from just beneath the slab. In some cases the system may require horizontal extraction point(s) through a foundation wall, although in most cases the pressure field from an extraction point in the slab will extend upward adjacent to the foundation walls.

SSD systems are generally categorized as *Low Pressure/High Flow* or *High Pressure/Low Flow*. Site conditions dictate which approach and system is most appropriate.

Some buildings have pervious fill/soil materials beneath the slab. Soil gas/air movement through such materials is rapid, and only a slight vacuum will create high flowrates. In such cases, the SSD system should utilize a low pressure/high flow fan. Other building slabs are underlain by less pervious materials, and common fan units will not be able to draw the appropriate level of vacuum. In these cases, a high pressure/low flow blower unit is required, capable of creating high vacuum levels.

Low Pressure/High Flow systems generally use 3-4 inch diameter piping; High Pressure/Low Flow systems may use smaller diameter piping. This piping is generally run from the extraction point(s) through an exterior wall to the outside of the building. The piping is connected to a fan/blower, which is mounted either on the outside of the building or in the attic. Placement of the fan/blower in this manner ensures that a pressurized discharge pipe is not present within occupied spaces (in case of leakage). Exhaust piping is run so that the discharge is above the roofline.

IV.D Design and Installation of an SSD System

All SSD systems should be designed in conformance with standard engineering principles and practices. As the work will likely be conducted in close proximity to building inhabitants, safety concerns are a priority. Attempts should be made to minimize noise, dust, and other inconveniences to occupants. Attempts should also be made to minimize alterations in the appearance of the building, by keeping system components as inconspicuously located as practicable.

The installation of an SSD system should be conducted under the direct supervision of a competent professional with specific experience in building vapor mitigation, site remediation, and/or environmental engineering practices. There are many firms that specialize in installing SSD systems for residential radon mitigation, as the same processes described above apply to the intrusion of radon into buildings.

The following sections describe the most important aspects of SSD system design and installation.

IV.D.1 Inspection of the Building Foundation

An inspection of the building foundation should be conducted, with particular attention paid to identifying all potential entry routes for VOC contaminated soil gases, such as cracks in concrete walls or slabs, gaps in fieldstone walls, construction joints between walls and slabs, annular space around utility pipes, open sumps, etc. These potential entry points should be surveyed with a portable PID or FID meter; it is often possible to find discrete "hits" (>1 ppmv) at particular points where vapor intrusion is occurring.

All possible entry routes should be sealed off, if possible, to prevent the entrance of soil gas, and enhance the sub-slab negative pressure field when the SSD system is in operation. Sealing/caulking materials should not contain significant amounts of VOC's. Buildings with no slabs should have an impermeable barrier installed before considering SSD.

A particularly problematic feature of commercial and school buildings is the presence of floor drains in lavatories and other areas. Often, the water seal within the plumbing trap of these drains is ineffective, as the water either leaks out or evaporates. This provides a vehicle for soil gases and/or sewer gases to discharge into these areas (especially true in lavatories with fans or vents which create a negative pressure within these rooms). In such cases, efforts should be made to periodically add water to these traps, or to install a *Dranjer*-type seal (http://www.dranjer.ca/).

IV.D.2 Sub-Slab Materials

Knowledge/information on the fill/soil conditions beneath the slab is desirable. Small diameter test holes can be drilled through the slab at various representative locations to collect sub-slab material for visual inspection. Test holes should be installed above the groundwater table and should not be deeper than one foot. A general evaluation of the material's permeability should be made.

Test holes and visual inspection of sub-slab materials are not essential; however, as system design is based primarily on the results of pressure testing.

IV.D.3 Depth to Groundwater

The depth to groundwater should be ascertained. In general, the groundwater table should be at least 6 inches below the building slab for an SSD system to be effective. Seasonal changes in groundwater elevation should be considered when evaluating the feasibility of SSD systems.

IV.D.4 Diagnostic Tests

The airflow characteristics and capacity of the material(s) beneath the slab should be quantitatively determined by diagnostic testing. This is the most important step in the SSD design process, and should always be performed prior to the design and installation of an SSD system.

Diagnostic testing is conducted by drilling small diameter holes through a building slab, applying a vacuum to one hole, and measuring pressure drops at surrounding test holes. The procedure is analogous to conducting a pump test to gauge aquifer properties and zone of influence. Most reputable and experienced SSD installation contractors have developed empirical (and proprietary) means to conduct and evaluate diagnostic tests. It is not necessary that complete details of this test be provided to MassDEP, as long as overall task and project performance standards are met (i.e., that upon installation and operation of the final system, a negative pressure field is documented beneath all impacted areas).

Within this context, several comments and recommendations are offered:

- The objective of diagnostic testing is to investigate and evaluate the development of a negative pressure field, via the induced movement of soil gases beneath the slab. This information is in turn used to determine whether a Low Pressure/High Flow or High Pressure/Low Flow system is necessary, and to determine the number and location of needed system extraction points.

- Two means are used to monitor and document the development of a negative pressure field: pressure testing and smoke testing. Pressure testing provides a direct and quantitative means to measure a negative pressure field. However, in cases where very pervious fills/subsoils are present, large volumes of air can be moved with relatively little pressure drop, undetectable by even the most sensitive gauge. In these cases, the creation of a negative pressure field can be verified by smoke tests, which demonstrate the (downward) advection of smoke (air) into the ground (i.e., through the slab).

- Generally, the diagnostic extraction hole should be at least 3/4 inches in diameter; the test holes 3/8 to 5/8 inches in diameter (DiGulio and Paul, 2006). Test holes should be placed at representative locations, such that the size of the effective pressure field under the slab may be evaluated. Typically, a shop-vac unit is used to pump soil gas from the extraction hole; the pressure drop and flow rate at this extraction point should be monitored and recorded. Pressure drops at the test holes should be measured quantitatively with a pressure gauge (e.g., a magnehelic gauge). A pressure drop of less than 1 Pa (0.004" of water) is generally not considered significant.

- Extraction and observation holes should be placed in the most unobtrusive locations possible; utility rooms and closets in a finished basement are good choices. Care must be taken to avoid damaging sub-slab utilities or conduits; the oil feed line to a furnace is of particular concern. The discharge from the extraction hole should be vented to the outside air. Following the test, the diagnostic extraction and test holes should be sealed with a Portland cement grout, although at least 1 or 2 holes should remain unsealed until after installation of the final SSD system, in order to provide points to demonstrate establishment of a negative pressure field.

- For larger structures, such as commercial and school buildings, more extensive and involved sub-slab diagnostics are needed. Features such as utility tunnel floors and walls, crawl spaces, internal continuous footings, and/or frost walls should be considered in the diagnostic evaluations, as they can impede airflow.

- Atmospheric pressure may be of importance at sites where diagnostic testing indicates marginal negative pressure readings. In such cases, barometric pressure data should be obtained and reviewed for the day of testing, and the previous several days. A trend of rising barometric pressure tends to promote advection of air into the ground, which may be falsely interpreted as a negative pressure field created during diagnostic tests. Where concern exists in this regard, the testing should be repeated during a time of falling barometric pressures.

IV.D.5 Location and Construction of Extraction Points

Final system extraction points should be properly located, based upon pressure/smoke test results, to ensure a sub-slab negative pressure field under the entire building. For most private residences, especially one to four family houses, only one or two extraction holes should be needed, unless anomalous conditions (e.g. highly impermeable sub-slab material) exist. High Pressure/Low Flow blowers should be used at sites with impervious subsoils, to minimize the number of extraction points necessary.

Extraction points are constructed by drilling or cutting holes through the building slab, making sure that any vapor barriers are breached and the sub-slab materials are encountered. Wherever practicable, extraction points and piping should be placed in the most unobtrusive locations, particularly in residential dwellings with finished basements.

A 10 to 20 inch diameter pit should be excavated at the extraction point(s), to a depth of about 10 inches. This void can be left open (if structurally acceptable) or backfilled with crushed stone (1/2 to 1 inch diameter, washed). The extraction hole is then patched around the piping using mortar or non-shrink grout, to insure a good seal. There are two important advantages gained by such a pit:

- Bonnefous et al. (1992) have reported that a pit of this nature can dramatically improve and extend the pressure field beneath a slab; and

- water vapor condensation within the piping system (a particular concern during winter at sites with external discharge piping runs) can be readily infiltrated back into the subsoil, minimizing effects on soil gas extraction.

As a final note, care should be taken to ensure that extraction points/pits intercept the thin void zone that typically exists directly beneath poured slabs. Specifically, differential settlement over time typically creates a series of interconnected void spaces beneath concrete slabs. While the extent and significance of these voids in transmitting soil gases is site-dependent, it makes sense to use every advantage possible.

IV.D.6 Fan and Piping Design

The type of sub-slab material and pressure field characteristics, as determined by diagnostic tests, should determine the type of fan or blower to be used for the SSD system.

Generally, one of two types of units will be specified:

- **Low Pressure/High Flow**- The most common application, used at sites with relatively permeable

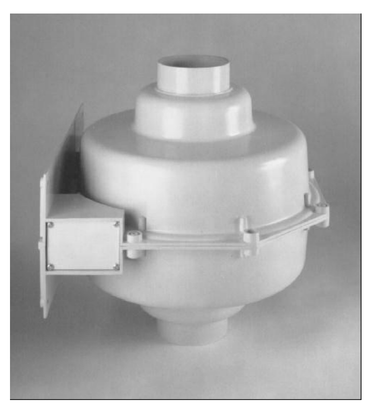

Figure IV-B: SSDS Fan

subsoils, where only low vacuum is needed to produce a negative pressure field beneath impacted areas. Generally, an in-line centrifugal fan unit is used (see Figure IV-B). These units are simple, quiet, inexpensive ($100 -$200), and consume only about 100w of power (the same amount as a 100w light bulb). Typically, these units are capable of inducing 0 - 4 inches of water vacuum, while moving 50 to 300 cubic feet per minute (cfm) of air.

- **High Pressure/Low Flow** - Required at sites with impervious subsoils (fine sands/silts/tills). Generally, a regenerative blower unit is required to produce the needed level of vacuum - typically 5 to 30 inches of water. At this vacuum level, only 5 to 30 cfm of air is moved. Regenerative blowers are relatively expensive ($300 - $500), and require around 300w of power to run. Regenerative blowers can produce a high-pitch whine, which may not be suitable for residential applications without appropriate soundproofing

- Fans and blowers are designed and specified on the basis of flow vs. pressure. In any given unit, flow is proportional to pressure (or vacuum). The greater the flowrate, the less pressure (or vacuum) that can be maintained. Manufacturers provide information of this nature in tabular and graphical form. A fan or blower selected for a site must have performance characteristics suited (or optimally suited) for the application in question.

Four-inch diameter schedule 40 PVC piping is generally used for Low Pressure/High Flow systems; smaller diameter (1.5-2 inch diameter) schedule 40 PVC for High Pressure/Low Flow system. Aluminum downspout conduit can be used in lieu of PVC, in cases where building owners wish to make the piping as discreet as possible. However, the aluminum conduit is more susceptible to condensation freezing in winter. All piping should be installed with a positive pitch back to the extraction point, to ensure that any condensation is directed back to the extraction sump, or some other moisture collection/discharge point.

Figure IV-C:
Fan/blower and discharge piping

Generally, the fan/blower and discharge piping (all piping after the fan) should be kept outside the building (see Figure IV-C). The discharge piping contains VOCs under positive pressure during system operation, and in the event of a failure could leak contaminated soil gases into the building, if kept inside. For SSD systems with a fan/blower outside the building, condensate control devices may be necessary in the cold months and the fan must be weatherproofed. If the fan/blower is inside the building, it must be as near as possible to the outside to minimize the amount of discharge piping inside the building. Fans installed in the attic must either be able to sustain the heat in the summer or provisions for fan cooling must be made (see Figure IV-D).

Units installed in residential buildings must be designed, installed, and operated in a manner that minimizes noise and vibration. This is a particular concern for regenerative blowers and/or units installed in an attic. Special insulation and/or mounting hardware may be necessary in such applications. Attic units should be located as far from sleeping areas as possible.

IV.D.7 System Gauges and Alarms

At a minimum, an in-line pressure gauge or manometer must be installed on every unit. The gauge or manometer must have a clearly marked line or lines showing minimum acceptable vacuum levels (see Figure IV-E).

Figure IV-D: Fan in Attic

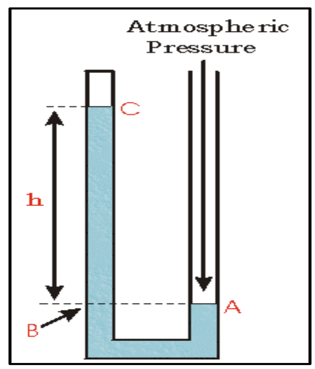

Figure IV-E: Manometer

IV.D.8 Back Drafting

Consideration should be given to the possible occurrence of a flue-gas back drafting situation in a building equipped with an SSD system. Specifically, oil/gas furnaces and wood stoves/fireplaces vent combustion gases to the ambient air, typically by directing the gases up a chimney.

While newer high-efficiency furnaces use a fan to create a positive discharge to the ambient air, older furnaces rely upon the development of a natural draft, in which the flue gases rise up the chimney due to thermal density differences. Back drafting can theoretically occur if negative pressures within a building are stronger than the density differential which drives the combustion gases up the chimney. In such cases, potentially deadly combustion gases (e.g., carbon monoxide) could be discharged into the building.

In some extreme cases, the operation of an SSD system could increase the depressurization level of a basement to a point where back drafting could occur. This is most likely to happen in an energy efficient (air-tight) home, particularly where significant SSD short-circuiting is occurring (via cracks in slab or leak in extraction piping).

The USEPA has recommended the following procedures to investigate and evaluate the possibility of back-drafting:

(1) Close all windows and doors, both internal and external.

(2) Open all HVAC supply and return air duct vents/registers.

(3) Close fireplace and wood stove dampers.

(4) Turn on all exhaust and air distribution fans and combustion appliances EXCEPT the appliance being tested for back-drafting.

(5) Wait 5 minutes.

(6) Test to determine the indoor/outdoor pressure differential in the room where the appliance being tested is located. If the pressure differential is a negative 5 Pascals or more, assume that a potential for back-drafting exists.

(7) To begin a test for actual spillage of flue gases, turn on the appliance being tested. (If the appliance is a forced air furnace, ensure that the blower starts to run before proceeding.)

(8) Wait 5 minutes.

(9) Using either a smoke tube or a carbon dioxide gas analyzer, check for flue gas spillage near the vent hood.

(10) Repeat steps (4) through (9) for each natural draft appliance being tested for back drafting. Extreme or unusual weather conditions need to be considered in evaluating data.

If a back drafting potential is identified, the SSD system should not be installed or operated until a qualified HVAC contractor corrects drafting problems. In addition to improvements in appliances and flues, make-up air can be ducted from the outside to provide for combustion and drafting. Generally, 6-inch diameter ductwork should be adequate for single-family residential homes.

As an added level of comfort, confirm that one or more carbon monoxide detectors are located in the home (as required by law for all dwellings).

Where appropriate, in addition to a manometer or gauge, a visible and/or audible alarm should be considered, indicating loss of system vacuum or power. In all cases, clear instructions, with the name and phone number of a person to be contacted in such event, should be visible at the extraction points.

IV.D.9 Other Considerations

- The presence of a sump in a basement can provide a significant short-circuiting vehicle to the establishment of a sub-slab negative pressure field. In such cases, an air tight cover should be installed over the sump; if a sump pump is present, the cover should be equipped with appropriate fittings or grommets to ensure an air tight seal around piping and wiring, and the cover itself should be fitted with a gasket to ensure an air-tight seal to the slab while facilitating easy access to the pump. Note that it is also possible to use the sump as a soil gas extraction point (where appropriate); a number of manufacturers make equipment for just such applications.

- At buildings where establishment of a negative pressure field is difficult, steps can be taken to improve the effectiveness of the SSD system by reducing the degree of underpressurization occurring within the basement. These include:

  - Ducting make-up air from outside the building for combustion and drafting; and/or

  - Overpressurizing the basement by using fans to direct air from the rest of the building into the basement, or an air/air heat exchanger to direct outside air into the basement.

- Issues regarding piping routes, fan location, vibration and noise concerns, etc., should be discussed with the building owners and occupants. The local municipal Building Department should also be contacted to determine if any permits are required.

- Electrical work for the fan installation will generally require the utilization of a licensed electrician. At locations where extremely high concentrations of combustible VOCs are expected, explosion-proofed equipment must be used.

- Start-up of the system should not occur until several hours after the extraction hole has been grouted, to allow the grout to cure. Otherwise, the fan/blower could draw moisture from the wet grout and cause the patch to shrink and crack.

IV.E Performance Standards

The contractor designing and installing the SSD system should be required to guarantee and demonstrate that the system will effectively prevent the intrusion of VOCs into the building. The specific requirements for demonstrating that performance standards have been met can be set on a case-by-case basis. There are two levels of performance standards for SSD systems: confirmation of pressure field and achievement of indoor air quality goals.

IV.E.1 Confirmation of Pressure Field

The primary performance standard which should be used to confirm effective SSD system operation is the demonstration of a negative pressure field that extends under the impacted area. Pressure and/or smoke testing at representative/worst-case test holes after system startup should provide sufficient information to demonstrate the presence of a negative pressure field. After the pressure field is confirmed following system start-up, monitoring of the in-line manometer or other pressure gauge should be an adequate indicator of satisfactory system operation.

<table>
<tr><td colspan="2">Sub-Slab Depressurization System Completion Report</td><td>Town:
Address:</td></tr>
<tr><td rowspan="2">Personnel</td><td colspan="2">Contractor Name & Address:
Contact: Phone No.:</td></tr>
<tr><td colspan="2">Project Manager Name:</td></tr>
<tr><td>Dates</td><td colspan="2">Date Project Started: | Date Project Completed: | Date of Completion Report:</td></tr>
<tr><td rowspan="6">Building Details</td><td colspan="2">Use of Building: ☐ residential ☐ school ☐ daycare ☐ other:</td></tr>
<tr><td colspan="2">Foundation: ☐ poured concrete ☐ concrete block ☐ fieldstone ☐ other:</td></tr>
<tr><td colspan="2">Basement Type: ☐ full basement ☐ crawlspace ☐ slab-on-grade ☐ other:</td></tr>
<tr><td colspan="2">Basement/Lowest Level: ☐ concrete slab ☐ earthen floor/crawlspace ☐ other</td></tr>
<tr><td colspan="2">Concrete Slab/Floor Cracks: ☐ no cracks ☐ minimal ☐ moderate ☐ substantial</td></tr>
<tr><td colspan="2">Basement Drainage: ☐ no sump/drain ☐ sump with drain ☐ sump with pump ☐ other</td></tr>
<tr><td rowspan="2">Sealing</td><td colspan="2">☐ None ☐ small cracks ☐ large cracks ☐ small area ☐ large area ☐ sump ☐ floor drains</td></tr>
<tr><td colspan="2">Materials: ☐ elastomeric sealant ☐ polyethylene sheeting ☐ grout ☐ concrete ☐ other
Brand name of sealant(s):</td></tr>
<tr><td rowspan="3">Diagnostics</td><td>Negative Pressure (inches w.c.)</td><td>Sub-slab materials:</td></tr>
<tr><td>Probe ID # | Probe ID #</td><td rowspan="2">Estimated Depth of groundwater below slab/floor:
☐ > 6 inches ☐ > 12 inches ☐ other/known:</td></tr>
<tr><td> | </td></tr>
<tr><td rowspan="4">System</td><td>Number Extraction Points:</td><td># Permanent sub-slab probes: ☐ 2 ☐ other:</td></tr>
<tr><td>Number of Fans:</td><td>Feet of PVC pipe used:</td></tr>
<tr><td colspan="2">Monitoring: ☐ manometer ☐ gauge ☐ alarm Range (inches w.c.):</td></tr>
<tr><td colspan="2">Fan Make & Model:</td></tr>
<tr><td rowspan="6">Startup</td><td>Date:</td><td>Negative Pressure (inches of W.C.)</td></tr>
<tr><td rowspan="2">☐ no problems noted
☐ problems encountered & fixed</td><td>Manometer/gauge | Probe # | Probe #</td></tr>
<tr><td> | | </td></tr>
<tr><td rowspan="2">Back Draft Evaluation</td><td>Appliances evaluated: ☐ furnace ☐ water heater ☐ other:</td></tr>
<tr><td>Result: ☐ OK; less than 5 Pascal depressurization ☐ other:</td></tr>
<tr><td colspan="2">Acceptable Range Notated on System Manometer/Gauge:</td></tr>
</table>

Sub-Slab Depressurization System Completion Report	Town: Address:
Notes and Explanations	
Provide any necessary information, detail, explanations or notes: ☐ Nothing to report	
Printed Name: Title: ____ Signature ☐ Additional materials are appended to this report Description:	

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