Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection

One Winter Street Boston, MA 02108 • 617-292-5500

December 20, 2011

Dear Interested Party:

The Massachusetts Department of Environmental Protection (MassDEP) is pleased to announce the publication of the "Interim Final Vapor Intrusion Guidance" (WSC#-11-435). This guidance is provided to parties conducting response actions at disposal sites regulated under the Massachusetts Contingency Plan (MCP), 310 CMR 40.0000, to support the identification, assessment, and mitigation of vapor intrusion and compliance with the related provisions of the MCP.

Vapor intrusion of environmental contaminants into indoor air is widely recognized as an important and complex issue that poses many challenges. Achieving sufficient certainty in the identification and assessment of the vapor intrusion pathway is critical for ensuring health-protective cleanups that can be relied upon now and into the future.

In the course of developing this guidance, MassDEP and external stakeholders have identified provisions in the MCP that could be revised to enhance, expedite and more efficiently assess, mitigate and close disposal sites with vapor intrusion concerns. The Department intends to revise the regulations over the next six months. Following the promulgation of those amendments, MassDEP will revisit this guidance and update it to reflect the regulatory changes, as well as any comments we receive on your experience implementing this interim guidance.

I would like to thank the many program stakeholders who have provided valuable input in the development of this document.

Sincerely,

Benjamin Ericson
Assistant Commissioner
Bureau of Waste Site Cleanup

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Revision Notes:
March 7, 2013 - revisions were made to make consistent the rounding methodology used in the tables in Appendices I and II. These adjustments resulted in slight differences in some of the values in Tables I.2, I.3, II.1 and II.2.
February 22, 2013- revisions were made to Appendix I (Indoor Air Threshold Values) and Appendix II (Sub-Slab Soil Gas Screening Values) to reflect revised toxicity values and correct errors.

Interim Final
Vapor Intrusion Guidance

December 2011

WSC#-11-435

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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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

Soil and groundwater contamination by volatile organic compounds (VOCs) is a well documented problem throughout the United States. In Massachusetts alone, 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 these releases occur 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 only approximately 50 of the 1,500 sites reportable 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).

This document provides guidance on the technical and regulatory approaches recommended by the MassDEP to address the vapor intrusion pathway at residences, schools and daycare facilities, as well as commercial and industrial sites, in conformance with the MCP.

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

1.2 Regulatory Basis of this Policy

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);
- The Numerical Ranking System (NRS);
- Risk Characterization; and
- MCP Closure at Sites with Vapor Intrusion Pathways.

As noted in the Disclaimer, 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. This section identifies situations or conditions that indicate when a vapor intrusion pathway is probable, and thus require an evaluation to identify and describe the pathway (a vapor intrusion evaluation). When VOCs are released to the subsurface near or migrate through the subsurface to occupied buildings and/or structures, initiation of an assessment of vapor intrusion would be 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.

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.

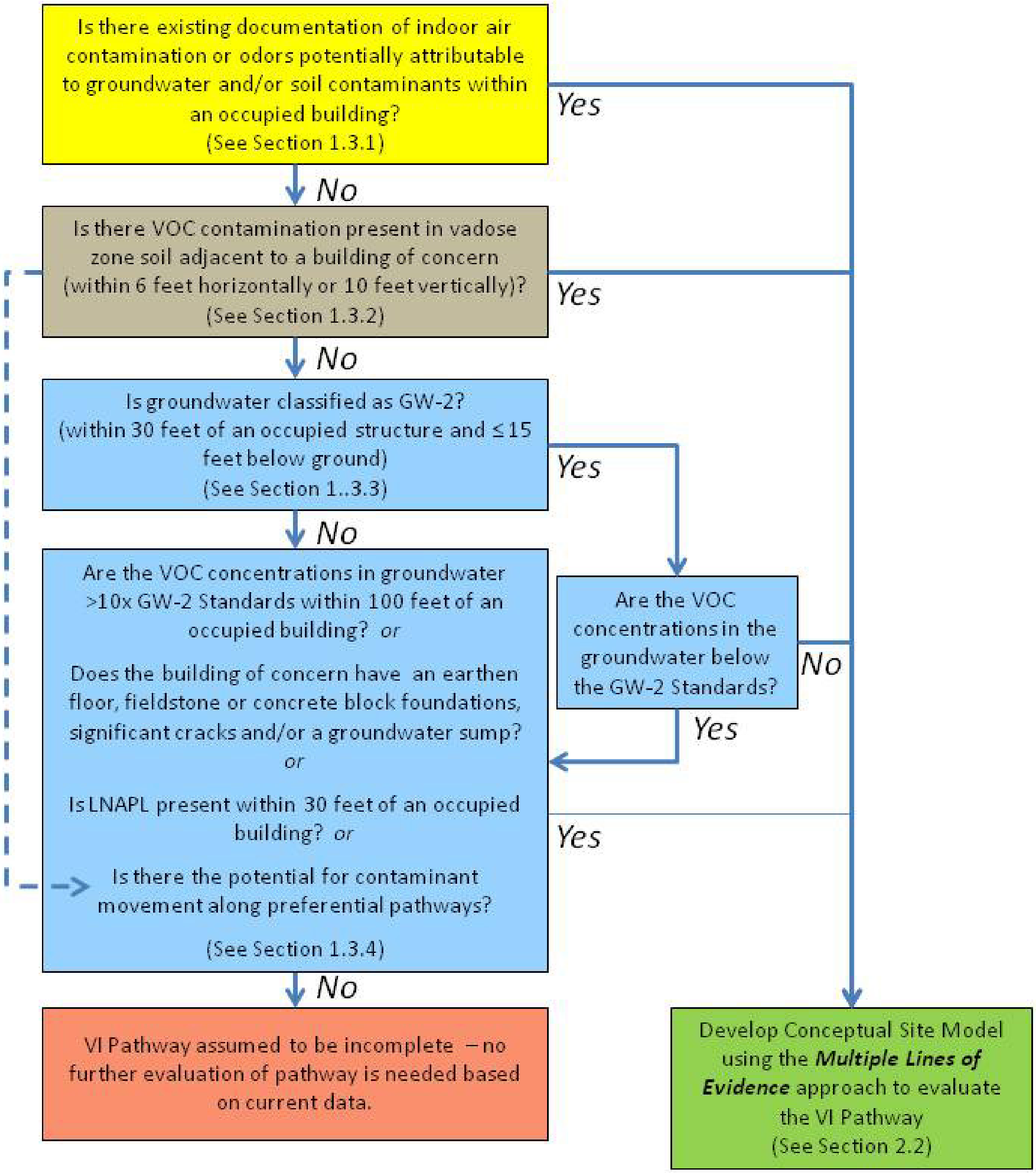
The recommended use of Method 1 GW-2 Standards in determining whether to evaluate the vapor intrusion pathway is presented in more detail below.

However, Method 1 Soil Standards 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 will be 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 Method 1, including the GW-2 Standards and distance criteria, are 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 is used.

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.

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



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 the odor.

1.3.2 VOCs in Soil

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 at the site to determine whether soil contamination could 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 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 (*e.g.*, within six feet horizontally from the wall of the structure, and within ten feet vertically from the basement floor or foundation slab) then the soil has the potential to result in significant indoor air concentrations of OHM…". 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 and Method 1 alone cannot be used to characterize the risk at the disposal site. The potential for vapor intrusion must be evaluated if VOCs are detected in soil within the distances identified above, in accordance with 310 CMR 40.0925.

The regulatory distances identified 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 in the vicinity of an occupied (or planned to be occupied) building (within 30 feet horizontally). 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, since sites that also have soil contamination should be evaluated as indicated in Section 1.3.2 above.

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 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 the groundwater quality from the monitoring wells in the vicinity of the building and structures of concern. As the extent of GW-2 exceedances is developed, 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 site conditions must be well characterized in accordance with 310 CMR 40.0904.

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) states 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 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 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 jurisdictions require evaluation of groundwater at distances up to 100 feet from buildings (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 not consistent with the assumptions used in the derivation of the Method 1 GW-2 Standards. In such cases, additional evaluation of the vapor intrusion pathway would be necessary to determine whether the indoor air is impacted.

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

  These conditions are not consistent with the assumptions used in derivation of the Method 1 GW-2 Standards, and indicate 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.

- *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 the vapor intrusion pathway should be further evaluated.

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 Imminent Hazard evaluation, evaluate a Critical Exposure Pathway (CEP); complete a Phase II Comprehensive Site Assessment and risk characterization; and evaluate whether a remedial system is effective. 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 Work Plan, 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 adequately address these different objectives as well as the performance-based standards of 310 CMR 40.0017, including detection limits appropriate for the intended use.

Sampling plans should also 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 to typical indoor or outdoor concentrations, or (c) estimate exposure point concentrations.

This section focuses primarily on assessment activities conducted to determine whether the vapor intrusion pathway at a 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 a Response Action Outcome (RAO) submittal. These sections also address considerations for Imminent Hazard evaluations.

Assessment of a vapor intrusion pathway should proceed iteratively as site conditions warrant. This assessment typically includes sampling of groundwater, sub-slab soil gas, soil, indoor air and outdoor air. Direct sampling of indoor air without gathering other 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 site, including those relevant to vapor intrusion. It provides a framework for assessing risks from contaminants, controlling or eliminating sources, developing response action strategies, and determining whether those strategies have been effective in achieving desired endpoints.

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 site assessment, risk characterization, and remediation process. Its complexity is directly related to the complexity of disposal site conditions.

Figure 2-1 shows the basic elements of the vapor intrusion pathway. It is important for the CSM to describe or illustrate other 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:

- 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.

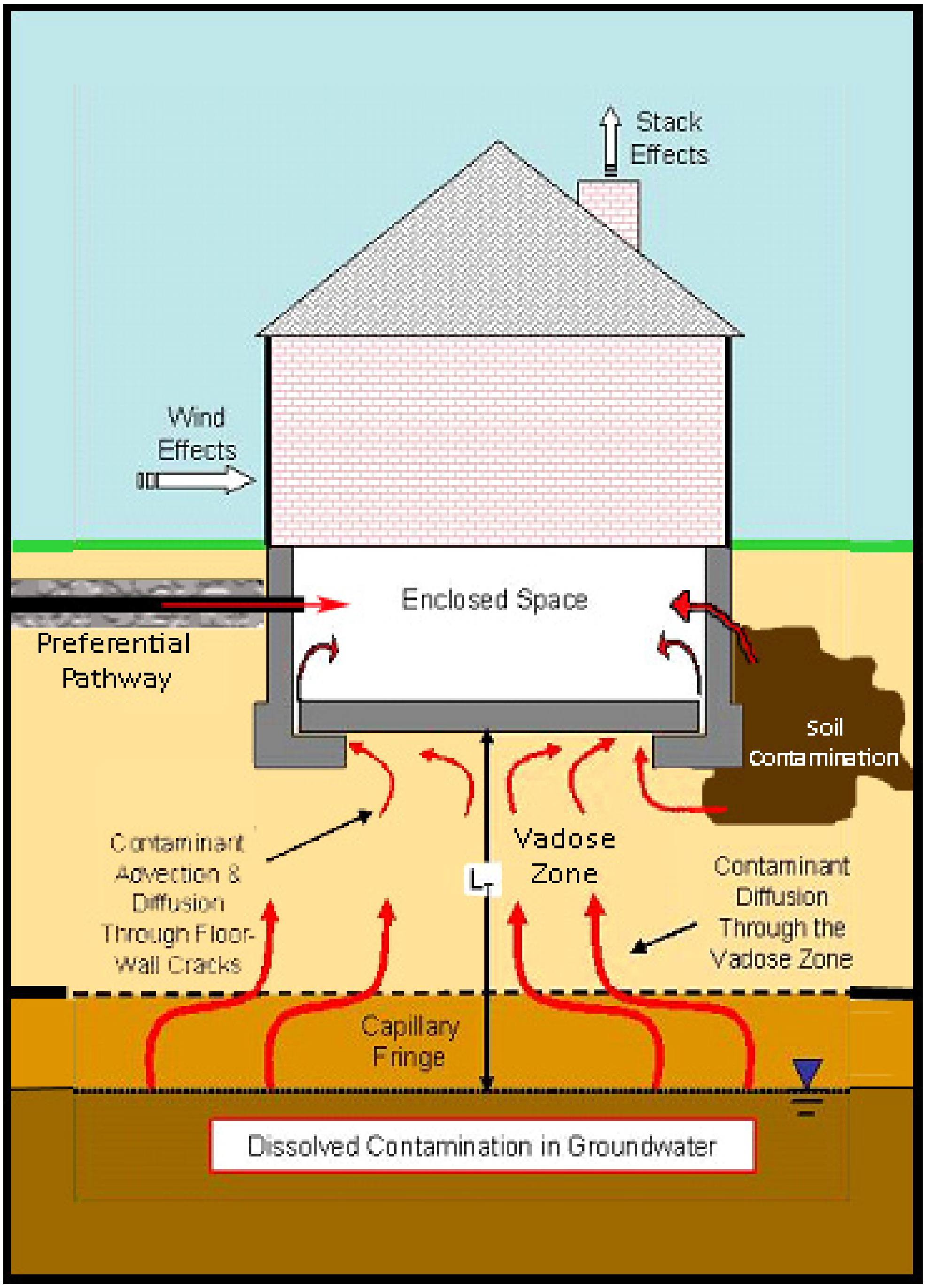
These and other site characteristics important to the assessment and remediation of vapor intrusion are described in Sections 2.2, 2.3, and 3.2.

The continual validation of the CSM is integral to the site assessment, mitigation and remediation process, and the validation process should be conducted from the initial site characterization through each data gathering episode during the implementation of remedial response actions and up to site closure. The CSM validation process should include identification and evaluation of data gaps, further investigation to eliminate significant data gaps, and an evaluation of other hypotheses that may be supported by the data.

With each MCP submittal, the CSM should present the information collected in a manner that demonstrates that the approach taken was logical. The CSM should include a discussion of relevant hypotheses that were explored and ruled out, document the technical justification for adopting one hypothesis over the other hypotheses, and a statement as to whether or not the objectives were achieved.

Further discussion of important components of the CSM is provided in MassDEP (2008), *MCP Representativeness Evaluations and Data Usability Assessments* (MassDEP Policy #WSC-07-350).

Figure 2-1: Basic elements of the vapor intrusion pathway



2.2 Vapor Intrusion Pathway Assessment

This section provides guidance on developing appropriate Lines of Evidence for assessing the vapor intrusion pathway under 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. A vapor intrusion pathway is considered complete if a source and a migration pathway have been identified, and contaminants from the source exist in the indoor air of an occupied building, or a building where there are specific plans for occupation. A source of vapor intrusion could be the original spill or release location of OHM, but may also be any media (soil or groundwater) subsequently impacted through contaminant migration that releases contaminant vapors into the subsurface.

> ***The term "sources of vapor intrusion" referred to in this guidance document is used in a general sense as "the environmental media that are contributing contaminants to indoor air." In this context, "sources of vapor intrusion" may not meet the definition of source described at 310 CMR 40.1003(5), which describes sources that must be eliminated to achieve an RAO. This issue is discussed further in Section 3.1.***

In some cases, a complete pathway is sufficient to warrant further action, such as when a Critical Exposure Pathway (CEP) is identified. However, 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.

MassDEP recommends a Lines of Evidence approach for determining if the vapor intrusion pathway is complete and likely to be of concern. This approach considers a number of types of information in drawing this conclusion. The specific Lines of Evidence and the extent of data required to draw conclusions regarding vapor intrusion will vary depending upon site conditions and setting. The sampling plan should consider relevant information from the CSM, as well as data gaps that may be relevant to 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 site, including those listed below.

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
- The presence of LNAPL or DNAPL
- The presence of preferential pathways for vapors
- The presence of outdoor sources
- The presence of indoor sources

These Lines of Evidence are developed through site observations as well as sampling activities. The Lines of Evidence needed will depend on site-specific characteristics, but should be adequate to support the conclusion regarding the vapor intrusion pathway. Factors that might influence vapor intrusion, such as specific building characteristics and sub-slab soil type, may be relevant to vapor intrusion conclusions, but are not considered distinct Lines of Evidence.

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. In addition, the use of sampling data in a Lines of Evidence evaluation is discussed.

2.2.1 Groundwater

Groundwater data is often one of the early indicators of potential vapor intrusion, based on a comparison to MCP Method 1 GW-2 Standards found 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. A vapor intrusion pathway should not be ruled out using groundwater data alone without the consideration of the factors identified in Section 1.3.3 and 1.3.4.

2.2.1.1 Data Considerations

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

Sampling locations should be selected based on knowledge of site-specific conditions and should include consideration of areal representation, depth, proximity to inhabited 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 the source area(s), in hot spots, and in close proximity to buildings.

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.

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 in the contaminant concentrations at various sampling locations within the contaminated area. 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 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 selected as inputs for the model to cover a wide variety of buildings. Therefore, barring certain site-specific conditions, GW-2 Standards can be used to evaluate groundwater conditions in a Lines of Evidence evaluation, as identified in Table 2-1 and 2-2.

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).

2.2.2 Indoor Air

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 site-related contaminants (present in groundwater, soil, 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 (groundwater, soil, or sub-slab soil gas) are detected in indoor air, it may be reasonable to conclude that the vapor intrusion pathway is complete.

2.2.2.1 Data Considerations

Indoor air 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, such as basements, crawlspaces, or areas closest to the source(s), and when conditions are most conducive to vapor intrusion. It may be difficult to rule out the pathway without such data, especially if other Lines of Evidence suggest the potential for vapor intrusion.

The consideration of other sources to indoor air than vapor intrusion 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 include:

- Not conducting indoor air sampling while contaminant-generating activities are occurring, especially if the same contaminants will be generated as those being monitored (e.g., collect indoor air samples on days when a nearby dry cleaner is not using the dry cleaning machines). Smoking and use of sprays, solvents, paints, etc. should be suspended 48 hours prior to sampling.
- Removing items that might contain site-related compounds and thus act as potential confounding sources of VOCs to the indoor air. Examples of these sources include recently dry-cleaned clothing, solvents or other similar products. Household 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, 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 exposure conditions.

Evacuated canisters are recommended for the collection of indoor air samples for the analysis of petroleum-based and chlorinated organic contaminants encountered at most sites. The analytical method selected should be based on historical site information and information on substances detected in other site media, but will generally be MassDEP APH and/or TO-15 CAM methods. Use of method target analyte lists may provide building occupants with important information regarding their general exposure to compounds in the indoor air, however, the indoor air analyte list can be limited to chemicals (and their break-down products) known or likely to be site-related at sites where substantial site use and history information is available to rule-out all but a limited number of contaminants of concern, and/or the site has been well-characterized and initial full-analyte list testing efforts have sufficiently narrowed the list of contaminants of concern. The analyte list selected should be documented and justified based on this information. Details on indoor air sampling and analysis are presented in Appendix III.

In planning the duration of an indoor air sampling event, a balance must be struck between the need to collect samples that are reasonably representative of the desired exposure, and the financial and technical constraints of sampling activities. 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 would provide more representative exposure data, but are sometimes not practical. Shorter sampling periods are inherently less representative of actual human residential exposures. In cases where 24-hour samples cannot be collected due to logistical constraints, the minimum duration is 4 hours.

For commercial buildings, MassDEP recommends an 8 hour sampling period during regular business hours.

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 prevent cross-contamination and, at the same time, make the samples comparable because they were obtained within a similar timeframe and, therefore, 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. It is often the case that two to three sampling rounds, coupled with a robust subsurface dataset, is necessary to adequately characterize the pathway. At least one sampling round conducted during winter is recommended, representative of presumed worst case conditions for vapor intrusion. 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 (when the pressure and temperature gradients between the inside of the building and the outdoor environment are maximized). 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 Conditions	Least Conservative Conditions
Season	Late winter/early spring	Summer
Temperature	Indoor 10^{o}F > than outdoors	Indoor temp < outdoor temp.
Wind	Steady, > ~5 mph	Calm
Soil	Saturated with rain or frozen	Dry
Groundwater	High water table	Low water table
Pressure	Indoor > Outdoor	Indoor < Outdoor
Doors/Windows	Closed	Open
Heating System	Operating	Off

MassDEP recommends greater sampling frequency for more sensitive receptors. For daycares, schools, and residences, 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, two indoor air sampling rounds are recommended to provide sufficient information to make decisions regarding vapor intrusion. 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 provide the investigator with information on any differences in concentrations between the basement and first floor. In multi-unit residential buildings, representative units can be selected for sampling based on location of the source(s) to indoor air and any preferential migration pathways. In order to address both a Lines of Evidence evaluation and exposure assessment, samplers should be situated in the breathing zone, approximately 3-5 feet off the ground (and lower if the receptors of concern are children, as for a daycare center or school). 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 done prior to sampling. Samplers should not be placed adjacent to windows or exterior walls where drafts may be present.

2.2.2.2 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 site-related OHM in indoor air is an indicator that a complete vapor intrusion pathway may exist. In addition, the presence of daughter compounds of substances known to be site-related in indoor air may also be indicative of a complete vapor intrusion pathway. However, the absence of these compounds 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 application of this approach difficult.

Comparisons of concentrations of site-related contaminants between a basement and the first floor can be misleading, which illustrates one reason why developing empirical Lines of Evidence is particularly important in determining whether a pathway is complete. The relative concentrations detected within a building can provide information relevant to conclusions regarding vapor intrusion. Higher concentrations of a site-related chemical in a basement compared to the first floor suggest that vapor intrusion is occurring.

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. These values can aid in the consideration of whether measured indoor air concentrations are within the range of Residential Typical Indoor Air Concentrations (TIACs), and can be used as one of the Lines of Evidence to evaluate the vapor intrusion pathway. The Residential Threshold Values (TV_r), based on Typical Indoor Air Concentrations (TIACs – MassDEP, 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 TV_r's, 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 this Line of Evidence suggests that the pathway is complete and likely to be of concern, any conclusion that discounts the indoor air measurements should be justified through the use of additional Lines of Evidence that demonstrate that indoor air contamination is not 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 may also be a relevant Line of Evidence. The removal and/or quantification of such indoor sources would best support their significance in indoor air sampling results. Either of these Lines of Evidence may support the conclusion that contamination is attributable to a non-site-related source.

The MCP requires that Notification be made to MassDEP if indoor air testing at any point in the assessment process indicates that there is Condition of Substantial Release Migration (310 CMR 40313(5)) or an Imminent Hazard (310 CMR 40.0313(2)). Per 310 CMR 40.0412, Immediate Response Actions are required for both of these conditions. This issue is further discussed in Section 4.1.2.

2.2.3 Soil and Sub-Slab Soil Gas

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

2.2.3.1 Data Considerations

VOC contamination of soil can result in vapor intrusion even when there is no significant groundwater contamination. Due to the heterogeneous nature of soil contamination, as well as the difficulty of sampling soil under buildings, adequately assessing the nature (including location and concentration) and extent of soil contamination under or near a building can be difficult. 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. 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 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 that should be considered for investigation include:

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

The number of samples obtained will be dependent upon the historical data obtained on the above potential release areas.

Sub-slab soil gas concentrations are often a better indicator of vapor intrusion potential than soil data because they are a direct measurement of the vapors entering the building. 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 tend to be more localized than the distribution of VOCs in soil gas from contaminated groundwater, therefore, more samples may be needed to define a potential soil source area.

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 site information and information on substances detected in other site media, but will generally be MassDEP APH and/or TO-15 CAM methods. Sub-slab soil gas analyte lists can be limited to chemicals known or likely to be site-related, as established through site history and sampling of other site media. 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. More sampling events may be warranted if sub-slab soil gas concentrations are highly variable. If two rounds of sub-slab soil gas samples are collected, it is recommended they be collected over two different seasons.

2.2.3.2 Evaluation Considerations

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 Threshold Values (TVs) 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.

Sub-slab screening values are intended to be used in conjunction with soil gas data obtained within a few inches beneath the slab, as described further in Section 2.2.3.1 and Appendix III. 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.

The *VPH/EPH Guidance* (MassDEP, 2002) contains sub-slab soil gas screening values for the petroleum fractions as well as the target analytes toluene, ethylbenzene, and xylenes (VPH/EPH Section 4.3.1.2). The criteria in the VPH/EPH Guidance were developed using a generic dilution factor derived using the J&E model, background information available at that time, and before the U.S. EPA's Vapor Intrusion Database was available. While the EPA data base discussed above includes limited information on petroleum-related attenuation factors, petroleum-related compounds should migrate from the shallow subsurface to indoor air to an extent similar to other volatile compounds.

> The use of total organic vapor instruments (PIDs and FIDs) is no longer recommended for ruling out the vapor intrusion pathway. The soil gas screening levels in the V*PH/EPH Guidance* (MassDEP, 2002) have been superseded by the soil gas screening values in Appendix II.

While total organic vapor measurements may be useful to potentially locate preferential pathways, they are generally not sufficiently chemical-specific to assess vapor intrusion with an appropriate degree of confidence.

2.2.4 Outdoor Sources

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 concentrations are being evaluated to determine whether the pathway is complete and likely to be of concern.

2.2.4.1 Data 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 if an outdoor source of 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 same time as one of the indoor air sampling events. Such outdoor air samples should be collected and analyzed by the same method, and for the same duration as the indoor air samples. Details on outdoor air sampling and analysis are presented in Appendix III.

Assessing spatial variability in outdoor air is difficult. Considerations for outdoor air sampling should include potential sources of VOCs to 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.

2.2.4.2 Evaluation Considerations

If indoor air concentrations of 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 site-related. Consideration would have to be given to whether or not the activities that contribute to the confounding outdoor air sources were in operation. If so, the indoor air contamination might not be site-related. If the outdoor air source activities were suspended during sampling then the indoor air contamination may be site-related. Outdoor air source conditions should be documented such that the appropriate conclusions may be drawn.

If ambient air has been impacted by site releases, resulting in impacts to indoor air, these impacts may indicate the need for response actions under the MCP, although they are not a result of vapor intrusion.

2.2.5 Household Products

Another important source of indoor air contaminants are chemicals present in many of the household products used in typical residential settings, as well as in products used in commercial and industrial buildings. These chemicals are commonly found in indoor air even in buildings not affected by vapor intrusion from environmental sources. A list of residential materials and activities that potentially release chemicals can be found at http://householdproducts.nlm.nih.gov/. Materials used in building construction can also be a source of indoor air contamination. If a building material is suspected of being a confounding source of contamination, it should be confirmed using documentation such as Material Safety and Data Sheets (MSDSs).

The contribution of indoor sources to indoor air can be minimized by surveying and documenting items that could contain the same types of chemicals present in the subsurface and removing those items during sampling. Since it may not be possible to remove all sources prior to sampling, comparison of detected indoor air concentrations to the TVs can provide an indication of whether the indoor air concentrations are likely to be from indoor sources rather than the release in question, as discussed in Section 2.2.2.2.

In some cases, indoor air may be affected by a site-specific indoor air source that is not considered or accounted for in the TVs. In this case, such a source should be documented and quantified to the extent possible to support conclusions that the contaminant(s) in indoor air are not site-related.

2.2.6 Non-Aqueous Phase Liquids

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

The presence of Dense Non-Aqueous Phase Liquids (DNAPL) is generally reflected in groundwater concentrations. However, DNAPL can result in greater uncertainty when characterizing groundwater. DNAPL can serve as a source of groundwater contamination and result in unpredictable fluctuations in groundwater contaminant levels. This unpredictability should be accounted for in the CSM, and reflected in the sampling plan.

NAPL as a source of contamination in accordance with 310 CMR 40.1003(5) must be eliminated or controlled prior to the achievement of a Class A or B Response Action Outcome, regardless of its potential for vapor intrusion. These provisions are described further in Section 4.

2.2.7 Preferential Pathways

The presence of preferential pathways such as utility lines, elevator shafts, sumps, etc. that might result in annular spaces connecting the sub-slab 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 that may be inconsistent with other Lines 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

Conclusions regarding whether or not the vapor intrusion pathway is complete and likely to be of concern under current use 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, consider the magnitude of contaminant concentrations in groundwater, sub-slab soil gas, indoor air, and identify recommended conclusions regarding whether the pathway is complete and likely to be of concern, and whether notification for a Condition of Substantial Release Migration (SRM, as defined at 310 CMR 40.0006) is likely to be necessary. The matrices apply to scenarios under which the potential for vapor intrusion has already been identified, as described in Section 1.

Data used for a Lines of Evidence evaluation, as shown in Tables 2-2 and 2-3, should be representative of site conditions and should not be averaged over sampling locations. Averaging the results of samples from the same location over time is appropriate only when concentrations are not increasing, and an adequate number of samples is used in averaging (310 CMR 40.0926). The most representative time period can be selected for comparison to the criteria in Tables 2-2 and 2-3, provided the data selected represents seasonal and other time-related variability.

Tables 2-2 and 2-3 focus on groundwater, sub-slab soil gas and indoor air sample results as the dominant Lines of Evidence. The tables identify some circumstances when consideration of other Lines of Evidence may be important. However, decisions to consider or exclude other Lines of Evidence should be supported and documented.

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

LINES OF EVIDENCE						
Groundwater Contaminant Levels	≤ 2x GW-2 **AND**			> 2x GW-2 **OR**		
Sub-Slab Soil Gas Contaminant Levels[#]	≤ SG Screening Criteria[#] **AND**			> SG Screening Criteria[#] **AND**		
Indoor Air Contaminant Levels	Not Tested	≤ TV_r	> TV_r	Not Tested	≤ TV_r	> TV_r
LIKELY CURRENT PATHWAY OF CONCERN?	No	No	Undetermined[†]	Undetermined[+++]	No	Yes
SRM NOTIFICATION?	No	No	See Footnote[††]	See Footnote[+++]	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	≤ 2x GW-2 **AND**			> 2x GW-2 **OR**		
Sub-Slab Soil Gas Contaminant Levels[#]	≤ SG Screening Criteria[#] **AND**			> SG Screening Criteria[#] **AND**		
Indoor Air Contaminant Levels	Not Tested	≤ $TV_{c/i}$	> $TV_{c/i}$	Not Tested	≤ $TV_{c/i}$	> $TV_{c/i}$
LIKELY CURRENT PATHWAY OF CONCERN?	No	No	Undetermined†	Undetermined[+++]	No	Yes

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

- TV_r - refers to residential Threshold Values contained in Appendix I.
- $TV_{c/i}$ - refers to commercial/industrial Threshold Values contained in Appendix I.
- # - soil gas screening levels provided in Appendix II.
- † - Evaluate potential indoor air sources and/or preferential migration pathways. Indoor air results are not consistent with low groundwater contamination and low sub-slab gas contamination, which raises the possibility of indoor air source that has not been identified.

†† - Depends upon the results of the additional evaluation. These results could indicate either potential indoor or outdoor air sources and/or preferential migration pathways. Consult with MassDEP on ambiguous results.

+++ - Due to the presence of high levels of subsurface contamination, indoor air sampling is necessary to determine whether or not a vapor intrusion pathway is complete and likely to be of concern

There is no SRM notification row for Table 2-3 because it is not applicable for commercial/industrial settings.

Recommendations provided in Tables 2-2 and 2-3 are based on the assumption that the site characterization is appropriate and adequate.

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 (≤ 2x GW-2 Standard and ≤ SG screening criterion, respectively), the possibility of a preferential migration pathway should also be considered before concluding that the vapor intrusion pathway is not likely to be of concern, as such a preferential pathway could result in indoor air concentrations. If in applying the Lines of Evidence matrix, the current pathway is determined to be complete and likely to be a concern, additional evaluation is generally necessary to evaluate and/or mitigate CEP in a residential, school or daycare setting, evaluate potential exposure and risks in commercial/industrial settings, and determine if additional response actions are necessary.

The matrix presented in Table 2-3 should be used with caution when conducting a vapor intrusion assessment at commercial locations that use 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

Under the MCP, 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). Such an assessment must address exposures under current uses and, in some cases, reasonably foreseeable uses if such uses could result in exposures greater than the current exposures ((310 CMR 40.9023(3).

The following sections provide guidance on exposure assessment for the vapor intrusion pathway, including recommendations on the identification of relevant oil and/or hazardous material (i.e., 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 would be documented in the risk characterization for the site, but indoor air exposure and risk would not be quantified.

2.3.1 Contaminants of Concern

The first step in the indoor air exposure assessment is to determine which contaminants should be considered as Contaminants of Concern (COCs) in the risk characterization. The general process for selecting COCs is described in the MassDEP (1995) *Guidance for Disposal Site Risk Characterization*. 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 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 Risk Characterization Guidance.

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

2.3.2 Site Receptors, Activities, and Uses

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

2.3.2.1 Current Activities and Uses

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. 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. Exposure assumptions for these activities and uses are discussed in Section 2.3.4.

2.3.2.2 Future Activities and Uses

To this point, the focus of this guidance document has been on vapor intrusion evaluations for current site conditions and use. However, risk characterizations conducted as part of Phase II Comprehensive Site Assessments and to support Class A or B Response Action Outcomes (RAOs), must consider reasonably foreseeable site activities and uses. Per 310 CMR 40.0923(3), reasonably foreseeable site activities and uses shall 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, residential use represents the greatest exposure potential. Therefore, if current use is commercial or industrial, future residential use should be assessed unless it is precluded by an Activity and Use Limitation (AUL), as allowed by 310 CMR 40.0923(3)(b). If there are no buildings that are currently occupied or that are planned to be occupied onsite, evaluation of the potential for vapor intrusion is not required under the MCP. However, MassDEP recommends the consideration of a future site building. Further discussion of this issue is provided in Section 4.7.

The following table summarizes the selection of future activities and uses based upon the current site use.

Table 2-4: Selection of Site Activities and Uses to be Evaluated for the Vapor Intrusion Pathway

Current Use and Activity	Future Use and Activity
Residential	No additional evaluation necessary if no future use would receive greater exposure
Commercial or Industrial	Residential
Undeveloped property	Residential*

*Recommended, not required – See Section 4.7

There are a several important exceptions to the above table:

- In cases where the site use is commercial/industrial or vacant, future exposure due to vapor intrusion need not be evaluated if soil contamination is not a concern and groundwater concentrations do not exceed GW-2 Standards (e.g., the original release has been successfully remediated).
- In cases where the site use is commercial or industrial, assessment of future residential exposure via vapor intrusion is not necessary if an Activity and Use Limitation is used to preclude residential use at a commercial/industrial site.

2.3.3 Exposure Point Concentrations

Per 310 CMR 40.0926, Exposure Point Concentrations (EPCs) must be developed for each Exposure Point and must 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. In a residence, this would be areas of the building that are living or working space. Exposure in various locations could 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;
- Any basement with at least seven feet of head room in an occupied residential dwelling should be considered a potential living or working space; and
- Basements of any height which show evidence of current activity should be considered living or working space. Crawlspaces would not apply to this definition of living or working space.

2.3.3.1 Exposure Point Concentrations – Current Use

When possible, indoor air testing results should be used to develop EPCs for current exposures. MassDEP has long-standing guidance on the use and utility of modeled data, and a stated preference for the use of measured values over modeled values to develop EPCs when it is feasible to obtain direct measurements of contaminant concentrations in indoor air (MassDEP, 1995, *Guidance for Disposal Site Risk Characterization*, Sections 6.3.1 and 7.3.3.5). Specific recommendations for EPC development using indoor air data are described below.

The method of estimating EPCs is contingent upon the goal of the risk characterization. When determining whether or not a Condition of No Significant Risk exists, or when evaluating Substantial Hazards, EPCs should be developed to represent a longer-term exposure (e.g., greater than 5 years). For Imminent Hazard evaluations, a shorter-term exposure (e.g., 5 years) should be the basis for EPC development.

- *EPCs for No Significant Risk and Substantial Hazard Evaluations*

  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 (1995) *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". If sufficient rounds of consistent and representative data exist, such that a good case can be made that the average value is a representative and reasonably conservative value, then average concentrations can be used for EPCs. When data is variable or limited, a maximum or 95th upper confidence limit on the mean should be used to develop an EPC per 310 CMR 40.0926(3)(c).

  EPCs calculated using the criteria above apply to current scenarios and should use the total concentration of a COC measured in indoor air (levels believed to be from non-release sources should not be deducted).

- *EPCs for Imminent Hazard Evaluations*

  It is important to quickly identify if site conditions constitute an Imminent Hazard. As a result, Imminent Hazard evaluations often occur during the initial investigation into vapor intrusion and can be based upon a limited data set. If an Imminent Hazard is suspected, the EPC can 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.

Consideration of potential Imminent Hazards is not a one-time exercise. Until the site is fully assessed and an RAO is achieved, the investigator must note and act on new information that may indicate the potential for an Imminent Hazard.

- *EPCs for Ongoing Permitted Commercial Operations*

  In buildings with ongoing commercial or industrial operations where OHM are released to indoor air, it is difficult to evaluate vapor intrusion for current receptors. Examples of such situations include active dry cleaners and active petroleum dispensing operations. In such cases, it does not make sense to implement a remedial measure (e.g., sub-slab depressurization (SSD) system) if ongoing and legally permissible occupational exposures to the same chemical are substantially higher than that resulting from vapor intrusion. Emissions from operations are addressed under the Air Quality Program.

  There are some cases where EPCs cannot be based on indoor air sampling, such as at buildings that contain active indoor air sources. In these cases, indoor air EPCs can be developed for current exposures using sub-slab soil gas data and the application of the attenuation factor identified in Section 2.2.3.

  In such cases, the following approach is recommended:

  - The vapor intrusion pathway need NOT be considered in an Imminent Hazard or Substantial Hazard evaluation in areas of an ongoing commercial or industrial operation where permitted uses and discharges of the chemical(s) of concern are present within the indoor air, at concentrations at least one order of magnitude higher than the levels that would be present in that space based upon the vapor intrusion pathway alone. This is consistent with the focus of the Imminent and Substantial Hazard evaluations in 310 CMR 40.0953 and 40.0956 on current site uses and current site conditions.
  - The vapor intrusion pathway should be considered a relevant foreseeable exposure pathway in such ongoing commercial or industrial operations for the purposes of evaluating a site for a condition of No Significant Risk.

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. Under these circumstances it is generally not possible to achieve a Permanent Solution because it is not possible to ascertain the significance of the vapor intrusion pathway. However, it may be possible to achieve a Temporary Solution.

Vapor discharges into neighboring buildings or spaces that are NOT licensed and permitted to operate such processes and do not use such chemicals should be considered in an Imminent Hazard and Substantial Hazard evaluation. (e.g., neighboring/common-wall businesses in a strip mall containing a dry cleaner should be evaluated for Imminent and Substantial Hazards via this pathway).

The approach described above would no longer be relevant if and when the site use changes (e.g., when an active dry cleaning operation is terminated). At that point, in the absence of the ongoing commercial operation, as assessment of the vapor intrusion pathway can be completed using the Multiple Lines of Evidence approach.

2.3.3.2 Exposure Point Concentrations – Future Use

Determining EPCs for future residential use is challenging because it is not possible to sample future indoor air or sub-slab soil gas under conditions equivalent to the future residence when the site is currently commercial/industrial or vacant. If the site is currently commercial or industrial, existing data for these media has limited efficacy for evaluating future use as residential because the building changes that would be required to convert to residential use could result in substantial changes to vapor intrusion conditions. If an existing building is renovated, movement of vapors between the shallow sub-slab and indoor air will likely be altered and have an unknown impact on contaminant concentrations in each media.

At sites without existing or planned buildings, it is not required that EPCs be established for future buildings. Where buildings are planned or parties otherwise elect to estimate future indoor air EPCs associated with groundwater contamination, MassDEP recommends the use of current groundwater data in conjunction with the Johnson and Ettinger (1991) modeling approach used by MassDEP (2008) in the development of GW-2 Standards. The modeling approach should use the generic assumptions provided in MassDEP's spreadsheets; site-specific assumptions should not be used. MassDEP has determined that the protectiveness of site-specific assumptions is not supported by empirical evidence.

If necessary, future indoor air EPCs associated with soil contamination can be estimated by a generic approach similar to that for groundwater contamination. However, because migration from soil contamination into indoor air is poorly understood, professional judgment should be used to determine whether or not future indoor air EPCs should be estimated from soil data.

2.3.4 Exposure Assumptions

Exposure assumptions vary depending on the receptor being evaluated and the purpose of the risk assessment. In order to demonstrate that a level of No Significant Risk exists or has been achieved (No Significant Risk) for residential use, the appropriate exposure assumptions used in calculating an average daily exposure should be 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. For the evaluation of 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 No Significant Risk for commercial or industrial use, MassDEP recommends assuming 8 hours per day, 250 days per year, for 27 years, as shown in Table 2-5.

Table 2-5: Recommended Indoor Air Exposure Assumptions

Site Use/Receptor	Exposure Duration	Exposure Frequency	Exposure Period
Residential/Homebound Adult	24 hours per day	365 days per year	30 years, 5 years for IH Evaluation
Student (School) Teacher (School)	8 hr/day 8 hr/day	180 days/yr 180 days/yr	6 yrs (5 for IH) 27 yrs (5 for IH)
Commercial/Industrial Worker	8 hours per day	250 days per year	27 years, 5 years for IH Evaluation

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 listed above can be subdivided accordingly in order to develop a time-weighted average exposure point concentration provided there is sufficient data to develop location-specific EPCs as described in Section 2.3.3. Exposure assumptions will be based on current use. For future use in residential buildings, MassDEP recommends assuming 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.

Exposure assumptions for Imminent Hazard Evaluations should be based on actual current building use. The values shown in Table 2-5 can be used as defaults, but the site-specific duration and frequency of building use should be determined and used to estimate exposure associated with an exposure period of 5 years.

2.4 Risk Characterization

2.4.1 General Risk Characterization Requirements

Achieving a Permanent Solution at a site requires, in part, that a level of No Significant Risk 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* (July, 1995). 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 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, as described in Sections 2.2. 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.

Method 1 used for sites in locations that are not currently GW-2 can consider the potential for vapor intrusion in the future by comparing groundwater exposure point concentrations to GW-2 Standards. This approach would eliminate concerns with a change in use in the future that would result in a change in the groundwater classification.

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 a Condition of No Significant Risk does <u>*not*</u> 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. Method 2 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 "shall be protective of migration of oil and/or hazardous material into indoor air". Alternatively, site specific information can be used to demonstrate that the Method 1 GW-2 Standard is not applicable.

The MCP requires that Method 2 GW-2 Standards be developed using 1) site-specific fate and transport modeling and/or 2) site-specific information using soil gas, indoor air and other site data to demonstrate that groundwater concentrations do not pose a risk of vapor intrusion. Use of these two approaches must be scientifically justified and well documented. Method 2 modifications to the Method 1 Standards that are based upon building-specific conditions address current conditions, but not potential future conditions. Therefore, any such Method 2 modifications would need to be "locked-in" with an appropriate AUL. As indicated in Section 2.3.3.2, 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 and is not recommended.

MassDEP recommends limiting the use of Method 2 Risk Assessment to document disposal sites where it has been concluded that the vapor intrusion pathway is unlikely to be of concern, as described in Section 2.2.8. 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 No Significant Risk under a Method 2 Risk Characterization.

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. 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.

Detailed guidance for each of these steps is presented above in Section 2.3.

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 elimination or mitigation of 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 (potential Imminent Hazards, prior to completion of Comprehensive Response Actions, etc.).

3.1 VOC Source Elimination or Control

While many effective and reliable technical approaches exist to eliminate or mitigate the vapor intrusion pathway, the most effective and reliable long-term approach to eliminate the impact to indoor air and to ultimately achieve site closure is to eliminate or control each sub-surface source of contamination that is contributing to an increase of VOC concentrations in the soil gas and indoor air.

One of the requirements of a Permanent Solution under MGL chapter 21 E § 3A(g) includes, where feasible, taking 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 site of concern." In addition, the MCP at 310 CMR 40.1003(5)(c) requires that sources of oil and/or hazardous material be controlled or eliminated in order to achieve a Class A or B RAO.

These requirements apply to sources that are or are likely to result in an increase in OHM concentrations in an environmental medium, either as a consequence of direct discharge or through intermedia transfer and include, without limitation:

1. leaking storage tanks, vessels, drums and other containers;

2. dry wells or wastewater disposal systems that are not in compliance with regulations governing discharges from those systems;

3. contaminated fill, soil, sediment and waste deposits; and

4. non-aqueous phase liquids.

Source elimination or control, as described at 310 CMR 40.1003(5)(c), to the extent feasible, is also a requirement of Remedy Operation Status (ROS) where Active Operation and Maintenance of a remedy is ongoing prior to the achievement of a Permanent Solution; and of Class C Response Action Outcomes where a Temporary Solution is implemented.

Groundwater contaminated with dissolved VOCs, through intermedia transfer, can be a source (as defined at 310 CMR 40.1003(5)(c)) of contaminants to indoor air. Where VOCs in the groundwater, soil, or LNAPL represent such a source, there is a regulatory requirement to eliminate or control the source, as described above. In many cases, however, site conditions may be such that soil or groundwater does not constitute a source in the context of 310 CMR 40.1003(5)(c). VOCs in soil and/or groundwater may be contributing to indoor air concentrations, but may not be resulting in increasing concentrations in soil gas or indoor air. In these cases, remedial goals are based on endpoints consistent with the response action goal, such as eliminating the Imminent Hazard, eliminating or mitigating the CEP, or achieving a level of No Significant Risk.

A variety of soil and groundwater remediation methods exist that may be appropriate to eliminate or control VOC source contamination and achieve indoor air remedial goals. These technologies include: soil vapor extraction; air sparging; in-situ chemical oxidation; bioremediation; multi-phase extraction, groundwater recovery and treatment; removal and disposal of soil; soil washing; in-situ thermal treatment; permeable reactive barriers; soil solidification/stabilization; and phytoremediation.

3.2 Indoor Air Pathway Mitigation

While conducting response actions to address soil and/or groundwater contamination contributing to indoor air concentrations can reduce contaminant concentrations and the overall time period of remediation, measures are often needed to address the vapor intrusion pathway until such actions are complete. These measures are focused on controlling or preventing the migration of soil gas into indoor air. Mitigating the vapor intrusion pathway can be accomplished by a variety of methods. Selection of the best approach will depend on consideration of a variety of building construction and site characteristics as well as the magnitude of the indoor air impact. Several different measures may be sequentially implemented at a specific building. For example, ventilation by opening windows and/or removal of VOCs by indoor air treatment may be the initial approach used to mitigate vapor intrusion while a SSD system is designed and installed. Once the sub-slab depressurization system is operational and the vapor intrusion pathway is eliminated, response actions designed to treat groundwater and/or eliminate or control the source of VOCs to indoor air can be implemented.

Aside from the elimination and control of VOCs in soil or groundwater that are contributing to indoor air concentrations, MassDEP considers active SSD systems to be the most effective means of mitigating vapor intrusion. This recommendation is based on MassDEP's experience overseeing numerous vapor intrusion projects, including many state-funded projects, and more than 20 years worth of data collected from the mitigation of radon-contaminated soil gas.[1] However, in circumstances where concentrations of contaminants in the soil, groundwater and/or soil gas are low, 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 mitigation measure selected, a key element under the MCP is an adequate demonstration that performance standards were achieved at the time of installation, and that those performance standards continue to be met during the period that the mitigation measure is operating. The specifics of the performance standards depend on the objectives of the mitigation measure and should be defined in the plan describing its implementation. Consideration of this requirement is important in developing an adequate monitoring program. Monitoring requirements will vary depending on the mitigation method, with more monitoring of indoor air quality typically needed to demonstrate the effectiveness of passive measures than of active systems, as passive measures are less predictable and less efficient at preventing vapor intrusion than active systems. Table 3-1 contains MassDEP's recommendations for monitoring vapor intrusion mitigation system effectiveness.

Prior to selecting 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.

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

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

	ACTIVE SYSTEMS	PASSIVE MEASURES	COMMENTS
RECOMMENDED USE	Active sub-slab depressurization (SSD) systems are the recommended method to address the vapor intrusion pathway particularly if an Imminent Hazard exists	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 the subsurface contaminant concentrations are low. Passive measures are not recommended for Imminent Hazards.	
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.	Sample indoor air approximately 7 days after system installation.	
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.[3]	**Sampling regimen depends on concentration of contaminants in the groundwater, sub-slab-soil gas and/or indoor air <u>PRIOR</u> 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 appropriate 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 appropriate 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 AUL and Post Class C RAO 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.	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 CLASS A-2 RAO [4]	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, at least one round during any other time that might represent worst-case conditions (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 or with a passive design should conduct sampling with the vent exhaust stack capped to determine indoor air concentrations without a functioning passive measure.[5]	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 exhaust stack should be capped during sampling to determine indoor air concentrations without a functioning passive measure.[5]	**A review of groundwater and soil gas concentrations should be reviewed to ensure they reasonably coincide with indoor air concentrations and represent a cohesive conceptual site model.**

3.2.1 Building Survey Considerations

Prior to selecting the method to mitigate the vapor intrusion pathway, an inspection of the building foundation should be conducted to identify all potential entry routes for VOC contaminated soil gas, and features of the building that may affect the selection or 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 entry routes include dirt floors, cracks in concrete walls or slabs, gaps in fieldstone foundation 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), ideally that measures in the parts per billion (ppb) range. The use of a PID meter for obtaining sub-slab vapor samples is also advantageous in that it can produce continuous, real-time concentration data, to evaluate trends, and/or detect possible short-circuiting situations. Identification of specific points where vapor intrusion is occurring is sometimes possible with a PID. However, due to the low sensitivity of direct-reading survey instruments and the intermittent nature of some indoor air contaminant situations, a PID survey may fail to detect contamination that is actually present.

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 be also be an asset in vapor intrusion mitigation, as they can be connected into sub-slab depressurization systems and used to depressurize the subsurface around the foundation perimeter. Conversely, if not accounted for prior to system installation they 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 inhibiting uniform depressurization.

Collecting differential pressure measurements within the building may be useful to quantify the 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 house 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 allow rapid soil gas movement, and only a slight vacuum will create sufficient flow rates. Less permeable materials beneath the slab may require higher head fan units 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 (these soil samples can be collected when installing sub-slab soil-gas probes) to assess the relative permeability. The test holes should be executed to collect the material immediately below the slab but no deeper than one foot below the bottom of the slab.

3.2.3 Depth to Groundwater

The depth to groundwater is a consideration in selecting the most appropriate mitigation method. 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. In general, the seasonal high groundwater table should be at least 6 inches below the building slab for an active SSD system to be effective. Installing an aerated floor above an existing slab may be effective at some sites where the seasonal high groundwater table precludes sub-slab depressurization.

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 (executed for the installation of sub-slab soil-gas probes).

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 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 a structure of concern, inducing the flow of VOC vapors to one or more collection points, with the subsequent discharge of 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 to the atmosphere through a series of collection and discharge pipes. In most cases the system creates a pressure field from one or more extraction points in the slab that extend upward adjacent to the foundation walls. In some cases, however, the system may require horizontal extraction point(s) through a foundation wall. The fan or blower should be installed outside 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. 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 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 the operation of heating equipment, vent fans, etc. Diagnostic evaluation of the sub-slab material and survey of heating, cooling, ventilation equipment, and appliances is recommended in order to appropriately design the SSD system. Excessive sub-slab depressurization could result in the back-draft of combustion exhaust. Appendix IV of this document 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 establishment of a sub-slab negative pressure (i.e., vacuum) field. See Section 3.4.2.1 for a discussion of methods recommended for sealing these penetrations. 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.

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 discreetly located as practicable. Determinations of the need for and nature of treatment of emissions from active systems must be in accordance with 310 CMR 40.0049. Additional guidance of the off-gas treatment is provided in MassDEP (1994) Policy #WSC-94-150: *Off-Gas Treatment of Point-Source Remedial Air Emissions*. 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. 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.

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, site remediation, or environmental engineering.

3.3.1.2 Active Drain Tile Depressurization (DTD)

Active Drain Tile Depressurization takes advantage of existing drainage tile networks located at the perimeters of some foundations. Drain tiles are typically located either above or beside perimeter foundation footings, and typically consist of porous clay, perforated rigid plastic (i.e., PVC), or perforated flexible plastic (i.e., polyethylene or polypropylene). These systems may be depressurized by connecting them to suction piping and a blower. Interior drain tiles are located on the side of the footings toward the structure while exterior drain tiles are located toward the exterior, away from the structure.

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 one or two sides. 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 aggregate that provides good communication beneath the slab.

For buildings equipped with 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, thereby short-circuiting the system. A DTD system may not be the most appropriate option for addressing the vapor mitigation pathway when the basement is finished; when piping needs to be inserted into the perimeter drains; when communication beneath the slab is poor; and where the building has an exterior drain tile network.

3.3.1.3 Active Block-Wall Depressurization (BWD)

Active block-wall depressurization (BWD) is a method of mitigating vapor intrusion that is occurring as soil gas migrates vertically or horizontally within the void spaces of block foundation walls. Block walls with open void spaces have been observed to create a stack effect, drawing soil gas up through the void space and into the living space of the building. SSD or DTD systems are designed to depressurize the zone beneath the slab and the adjacent footing which underlies the block wall, to prevent soil gas migration through porous foundation walls. In cases where the SSD or DTD does not accomplish this, BWD can be installed as a modification to an existing SSD or DTD system.

BWD uses suction 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 suction 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) 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. For SMD systems, extraction points are typically installed vertically through the membrane and connected to a fan to divert contaminated sub-membrane soil gas to the atmosphere. A tee or various lengths of perforated piping are often used horizontally beneath the membrane depending upon the size of the area that needs to be depressurized.

Proper sealing of the membrane to perimeter walls, piers or membrane seams is especially important for SMD systems to function effectively. Soil gas entry into the crawl space or basement can be reduced or eliminated if sufficient suction is created beneath the membrane. Sufficient suction beneath the membrane will also ensure that the flow of gas/air through tears or seams will be toward the sub-membrane environment. Pulling the membrane tight during installation could strain seals and seams when the system is turned on and the membrane is pulled tight to the floor. Individual suction points are typically used where concrete footings divide a crawl space or dirt floor.

Membranes used in SMD systems are recommended to be a 40-60-mil (EPA, 2008) membrane material (see Section 3.4.2.3 for additional information about membrane systems). Membranes should cover the entire floor area and be completely sealed to walls, piers, extraction piping, etc. using an adhesive. Vinyl tape has been used to secure the membrane to the extraction piping. Care should be taken to ensure that the membranes are completely sealed and 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.

3.3.2 Indoor Air Treatment

Indoor air treatment refers to treatment equipment used to remove contaminants that are already present in indoor air. Indoor air treatment equipment typically uses zeolite and activated carbon adsorption, ozone oxidation or photocatalytic oxidation to remove contaminants. Technologies that rely on injecting ozone into the indoor air are not recommended because ozone may cause adverse health effects. Mitigation methods that employ adsorption materials, such as activated carbon, generate waste that must be regenerated or disposed of properly. Mitigation systems that incorporate high surface area sorption filters generally have better removal efficiencies due to the resulting better air-to-sorbent contact. Indoor air treatment may be a good temporary alternative at locations where a high groundwater table precludes the installation of a sub-slab mitigation system. For this mitigation approach it is important to calculate the appropriate air exchange rate based on the size of the space being treated and contaminant concentrations.

3.4 Alternative Mitigation Approaches

Mitigation approaches that are alternatives to depressurization systems, including active pressurization systems and passive techniques, are presented here with the understanding that these approaches 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 cooling (HVAC) system to create positive pressure within at least the lower level of the structure to 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 may not be suitable for older buildings since they may not be as air tight as newer buildings, making this approach more costly. 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.

While HVAC modifications may be effective in controlling vapor intrusion for some interim time period, such modifications are not considered 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. In some buildings, manipulation of the HVAC system may be too complicated to effectively mitigate the vapor intrusion pathway.

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

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 (BWD) when BWD 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. 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 passive venting systems 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 may require additional monitoring to determine their effectiveness. However, if it can be demonstrated through a sufficient amount of indoor-air sampling that passive measures have mitigated the vapor intrusion pathway, and a sufficient amount of monitoring is conducted to ensure that these measures remain intact, these activities may be sufficient to mitigate the vapor intrusion pathway. Periodic evaluation of passive measures intended for long term mitigation is necessary to confirm the passive measure is performing as intended (see Table 3-1).

3.4.2.1 Sealing of Cracks, Sumps and Utility Conduit Penetrations

Regardless of the type of system or 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, for example, tile, wood or carpeted floors and walls prohibit inspection. Therefore, MassDEP does not typically consider the sealing of cracks to be a mitigation measure in and of itself that can be evaluated over time. If the basement has a dirt floor, an impermeable membrane barrier, vent piping and permeable venting material or aerated floor system should be installed beneath a concrete slab as part of the measure selected to mitigate vapor intrusion. If active sub-slab depressurization is the chosen mitigation measure, a membrane barrier may not be necessary, but could enhance system performance.

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 can result in a direct connection between groundwater and indoor air. In addition, sumps can significantly short-circuit negative pressures created by the installation of a SSD system. Sumps should be sealed with an air tight cover 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. 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. This should be done with the knowledge that covering the sump could cause flooding of the basement in the event that water on top of the slab drains toward the sump. Sumps should not drain or pump to a sanitary sewerage system. If necessary, to prevent short-circuiting of an SSD system, a check valve or water trap may be installed on the sump drain/ejection piping.

Floor drains that are not in use 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. This provides a vehicle for soil gas to discharge into these areas, especially in lavatories with fans or vents that 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.

Utility conduits penetrating the slab or foundation should be sealed to prevent soil gas from entering the building. A closed-cell polyurethane foam or other inert gas-impermeable material is recommended. 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, in this context, means opening windows, doors, and vents within a structure to allow natural ventilation to occur. Opening windows, doors and vents increases the amount of outdoor air mixing with indoor air and reduces indoor air contaminant concentrations by dilution. However, ventilation solely in the upper story may exacerbate the stack effect which could 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 caused by ventilation. Ventilation should only be considered as a measure to reduce concentrations of contaminants in indoor air while additional mitigation activities are occurring (i.e., immediately after a residential fuel oil release). The cost of heat or air conditioning will eventually make ventilation an expensive mitigation strategy. In addition, ventilation may be uncomfortable for building occupants. The effects of ventilation on reducing indoor air concentrations are short-lived once windows, doors and vents have been closed.

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 traditional vapor barriers intended to prevent the intrusion of water vapor. Membrane systems intended to address vapor intrusion are installed above a gas-permeable layer to prevent soil gas migration upwards and direct soil gas to the perimeter of the building, or up and out 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 that may be composed of a rubberized asphalt emulsion or epoxy (EPA, 2008). There are currently no standards for membrane thickness, composition, or physical properties that will ensure the membrane's success.

Membrane systems are recommended to have a thickness of at least 40-60-mil (EPA 2008), be composed of materials that are compatible with chemicals they will likely encounter and shown not to significantly absorb VOCs. Using a thicker membrane, 60-100-mil (ITRC, 2007), may help reduce the potential for punctures during construction activities after it is in place, (e.g., cutting or grinding of rebar just above the barrier, installation of stakes for concrete forms, dropping tools, foot traffic, etc.). 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 passive venting system and 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 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. This includes ensuring manufacturer recommended overlap at seams, welds connecting sheet materials are complete, and utility penetrations through the membrane are completely sealed. 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 foundation is constructed is likely to be more straightforward and less expensive than afterward. Because a visual inspection cannot determine whether vapor intrusion is occurring, periodic indoor air monitoring is needed to confirm that the membrane system remains effective in preventing vapor intrusion (see Table 3-1).

3.4.2.4 Passive Venting

Passive venting mitigates the vapor intrusion pathway by intercepting sub-slab soil gas with a series of appropriately-sized perforated pipes (typically 4-in. diameter), bedded in permeable venting material, such as sand or gravel below the slab, that then discharge to the atmosphere. A membrane barrier such as that described above should be used in conjunction with a passive venting system. 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 greater reductions in indoor air concentrations are necessary. Products that create a continuous aerated floor system beneath the slab or raised aerated floor above an existing slab, eliminate the need for passive vent piping and permeable venting material and may also be effective in reducing indoor air concentrations.

Although it is possible to install a passive venting system and 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. A passive venting system does not use a fan to remove sub-slab soil gas, and 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. QA/QC of seams, joints, and welds is critical to the performance of a passive barrier.

Some passive ventilation systems incorporate the use a wind-driven turbine on the top of the stack to enhance flow within the passive system. Wind-driven turbines are considered active remedial systems as defined at 310 CMR 40.0006 if the turbine is necessary to maintain a level of No Significant Risk. 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 3-1).

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 Table 3-1 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 confirmation of a negative pressure field across the entire slab in conjunction with indoor air sampling, 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 monitoring the negative pressure field beneath the slab. Indoor air sampling to verify system performance is recommended when differential pressures measured during system monitoring are less than those observed when the system was shown to be effective in preventing vapor intrusion during a previous evaluation, as described in Section 3.5.2.3.

3.5.2.1 Confirmation of Pressure Field of Active Mitigation Systems

The primary performance standard which should be used to confirm effective SSD system operation is the demonstration of a negative pressure field which extends under the entire slab and ideally the foundation footings. This performance standard is also applicable to drain tile pressurization systems. Pressure 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.

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 indoor air testing, indoor air quality should continue to be acceptable as long as adequate negative pressure is maintained at the extraction point(s). As a result, pressure field measurements can be used to monitor the system once its effectiveness has been demonstrated through initial pressure measurements and indoor air testing.

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 is accomplished by reading the manometer value at the primary extraction point(s), and ideally at monitoring points across the slab, using a magnehelic gauge or digital micromanometer with a range suitable for the vacuum encountered. The vacuum should be checked to verify that the sub-slab differential pressure 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. If available, review of the as-built drawing for the system is recommended to ensure the system configuration has not been modified. Mitigation system monitors and alarms, including carbon monoxide alarms, are recommended to be tested during each site visit if they are present. Incorporating a remote telemetry device that sends an electronic notification when the system malfunctions may help reduce the down-times for the system. 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. It may be helpful to use a mitigation system Completion Report with an as-built drawing of the mitigation system during routine inspections to identify changes to the system. An example of a 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 in walls and floors 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 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 system installed or measures taken are not effective, for example new openings are found in the foundation/slab, piping is broken or blocked, etc., the necessary repairs should be made and the indoor air should be sampled immediately. This is particularly important in the case of SMD systems. If it is determined that the system is no longer effective, it should be augmented or modified, or another approach selected that will achieve response actions goals.

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. Passive measures should not be used for mitigating Imminent Hazards. 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.

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 are provided in Table 3-1 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 concentration is equal to or less than 2 times the appropriate soil gas screening value (Appendix II); 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 concentration is greater than 2 times the appropriate soil gas screening value; 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. Once effectiveness has been demonstrated, monitoring should be conducted according to the guidelines outlined in Table 3-1 and 3.5.3.2 below.

If a passive measure is converted to an active system, sampling to demonstrate effectiveness and maintenance should follow 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 were 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 sufficient to ensure their effective performance and integrity as recommended in Table 3-1. 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 due to identification of new penetrations in the foundation/slab, broken or blocked piping, etc., the necessary repairs should be made and the indoor air should be sampled immediately. 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.

3.6 Closure Sampling

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 and at least one round during other times that might represent worst-case conditions (shallow groundwater) .

In the case of an active system, the system should be shut off during these sampling events. The system should be turned off for at least seven days prior to sampling to allow for equilibration. Once the 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 conducted over two years, the system can be shut down

Although a Permanent Solution can be achieved with a passive system, you may want to demonstrate that the passive system is not necessary to achieve and maintain a level of No Significant Risk (and therefore an AUL is not necessary). In this case, the collection of indoor air samples to demonstrate unrestricted closure at sites with passive venting systems and active systems with a passive design should be collected with the exterior vent piping capped to ensure sample results are not influenced by a functioning mitigation system.

Refer to Section 4.5 of this document for additional information about closure at vapor intrusion sites.

4. Regulatory Framework

There are a number of MCP regulatory requirements that are unique or have special implications for the vapor intrusion pathway. This section identifies these requirements specifically related to vapor intrusion identification, response actions, and closure. The following sections address reporting obligations, risk reduction measures, critical exposure pathways, the numerical ranking system, and MCP closure, as well as vapor intrusion mitigation activities conducted outside the MCP process.

4.1 Common Reporting Obligations Related to the Vapor Intrusion Pathway under the MCP

There are no Reportable Concentrations (RCs) for indoor air. The RCs currently exist only for groundwater and soil. However, if concentrations of oil or hazardous material are present in indoor air, this 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 Imminent Hazard, as described in 310 CMR 40.0321 and 40.0950, must be reported to MassDEP within 2 hours. The following releases to the environment that pose or could pose an Imminent Hazard, and are potentially relevant to the vapor intrusion pathway, require reporting to MassDEP within 2 hours of knowledge of the condition:

- A release resulting in OHM in structures at a concentration equal to or greater than 10% of the Lower Explosive Limit (LEL) (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 Imminent Hazard based on risk levels, an Imminent Hazard Evaluation for human health 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* #WSC/ORS-95-141.

4.1.2 72-Hour Notifications for High Concentrations of VOCs in Groundwater near Sensitive Receptors or for Substantial Release Migration (SRM)

The following conditions potentially relevant to the vapor intrusion pathway require reporting to MassDEP within 72 hours of knowledge of the condition:

- A release to the environment indicated by measurement within the groundwater of equal to or greater than five milligrams per liter of total VOCs at any point located within 30 feet of a school or occupied residential structure, where the groundwater table is less than 15 feet below the surface of the ground (310 CMR 40.0313(4)); and
- A Condition of SRM, where such condition is associated 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(5)). One such SRM Condition, defined at 310 CMR 40.0006, is releases to the groundwater or to the vadose zone that have resulted or are within one year likely to result in the discharge of vapors into school buildings[2] or occupied residential dwellings.

The requirement to report a Condition of SRM applies only when there is evidence associating the condition with a release that is otherwise reportable (310 CMR 40.0313(5)). This is an important consideration given the number of other potential sources of indoor air contamination, such as consumer and cleaning products. It also 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.

4.1.3 Notification and Releases to the Interior of Buildings

If a release of oil or hazardous material (OHM) is completely contained within a building (i.e. the OHM never enters the environment), the release is exempt from the MCP's Notification requirements (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.

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[2] As defined at 310 CMR 40.0006(12), "school" means any public or private elementary or secondary school, and any day care center, as defined in M.G.L. Chapter 28A Section 9. Residential dwellings include places where people reside for an extended period of time, such as single and multi-family houses, apartment and condominium buildings, dorms, and assisted living facilities. More transient accommodations like hotels and hospitals are not considered residential dwellings.

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. flow 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 so they require reporting 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*.**

A "120 day" reporting obligation per 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 RC applicable at the site or if environmental releases of hazardous materials in amounts less than the Reportable Quantity contaminate soil or groundwater at levels exceeding a Reportable Concentration applicable at the site.

4.2 Immediate Response Actions (IRAs)

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 Imminent Hazard (310 CMR 40.0412). The MCP requires (310 CMR 40.0411(1)(a)) that an IRA abate, prevent, or eliminate Imminent Hazard conditions.

In addition, pursuant to 310 CMR 40.0414(3), IRAs are presumed to require the elimination and/or mitigation of Critical Exposure Pathways (CEP), which are outlined further in Section 4.3.

Section 3 presents a variety of approaches for the mitigation of vapor intrusion that may be part of an IRA. An IRA conducted under the MCP requires the submittal of an IRA Plan, IRA Status Reports and, possibly Remedial Monitoring Reports to MassDEP. Pursuant to 310 CMR 40.0425(6)(a), Remedial Monitoring Reports must be submitted to the MassDEP with the first IRA Status Report and monthly thereafter if the IRA includes Active Operation and Maintenance of a remedial action to address an Imminent Hazard or Condition of SRM.

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 Imminent Hazard 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 2.2). This is consistent with the focus of the Imminent Hazard 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 licensed and permitted to operate such processes and that do not use such chemicals are exposures that should be considered in an Imminent Hazard 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).

4.3 Critical Exposure Pathways

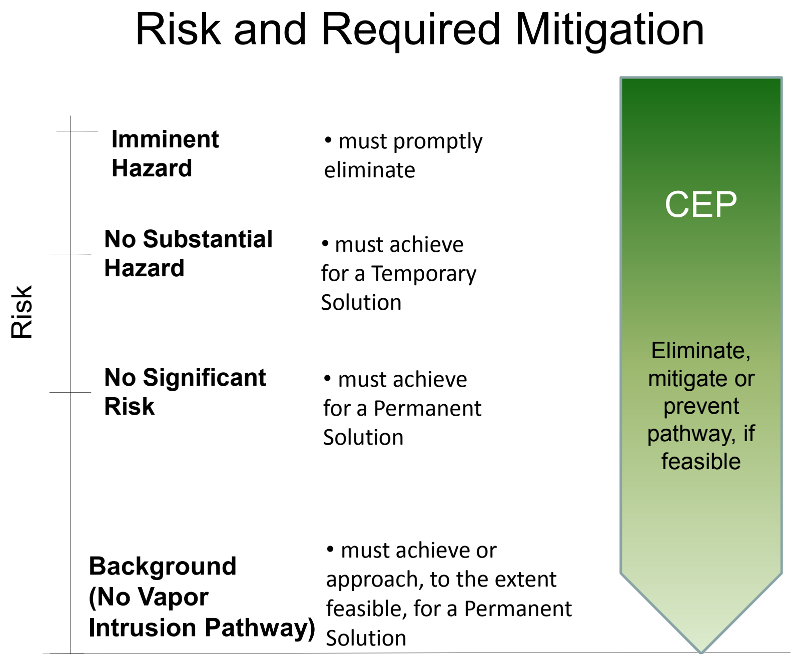
4.3.1 Identification of a Critical Exposure Pathway (CEP)

4.3.1.1 The CEP Concept

The CEP requirements in the MCP ensure that timely action is taken, where feasible, to protect sensitive human receptors from exposures to site-related contaminants in indoor air or in drinking water, while a disposal site is under investigation. When conducting an IRA, the presence of a CEP triggers consideration of expedited action to eliminate and/or mitigate the CEP. This concept assumes that given the toxicological and site characterization uncertainties and the range of relatively low-cost, effective remedial actions available to address the vapor intrusion pathway at most sites, 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.

The requirement to eliminate, mitigate or prevent a CEP, where feasible, as part of an IRA applies regardless of the quantitative level of risk (See Figure 4-1).

Figure 4-1: Risk and Required Remediation



4.3.1.2 Defining CEP

As defined at 310 CMR 40.0006,

> *"Critical Exposure Pathways are those routes by which oil and 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 hazardous materials (OHMs) 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 OHMs from drinking water supply wells located at and servicing a pre-school, daycare, school or occupied residential dwelling."*

This guidance addresses only CEPs related to vapor-phase emissions (i.e. vapor intrusion.) The MCP definition of CEP applies only 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, "the living or working space of a pre-school, daycare, school or occupied residential dwelling." The terms "living or working space" and "daycare" are not defined in the MCP. Therefore, MassDEP offers the following guidance in interpreting these terms:

- **Living or Working Space**
  There is room for interpretation regarding what constitutes living or working space, especially in residential basement areas. Basement areas should be included in CEP evaluations based on the amount of time likely spent there. Crawl spaces and basements with only incidental use, such as for storage or basic laundry, would not be considered living or working spaces. Finished basements and unfinished basements with evidence of more than incidental use (e.g. use for more than an hour at a time), should be considered living or working space.

- **Daycare**
  In general, a daycare that is licensed by the state as a daycare center under M.G.L. Chapter 28A, Section 9 is considered a daycare for the purposes of identifying a CEP under the MCP. This definition does not include other organized childcare services that provide only intermittent or sporadic care, such as during religious services and drop-in child care at gyms or stores.

4.3.2 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 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*.

The conceptual and regulatory tenets of feasibility and feasibility evaluations are contained in the feasibility criteria found in Section 3A(h) of Chapter 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 is available, and whether the costs 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".

This section identifies response actions that MassDEP considers to be generally feasible and generally infeasible, and lists factors to be considered when rebutting the presumption for CEP elimination/mitigation as an IRA. Figure 4-2 illustrates how considerations of feasibility are incorporated into the decision-making process at sites where a CEP has been identified.

4.3.2.1 Generally Feasible Response Actions to Address CEP

The installation of an active SSD system (Section 3.3.1.1) is generally considered a technologically effective 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/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 (see Section 4.3.2.3).

4.3.2.2 Generally Infeasible Response Actions

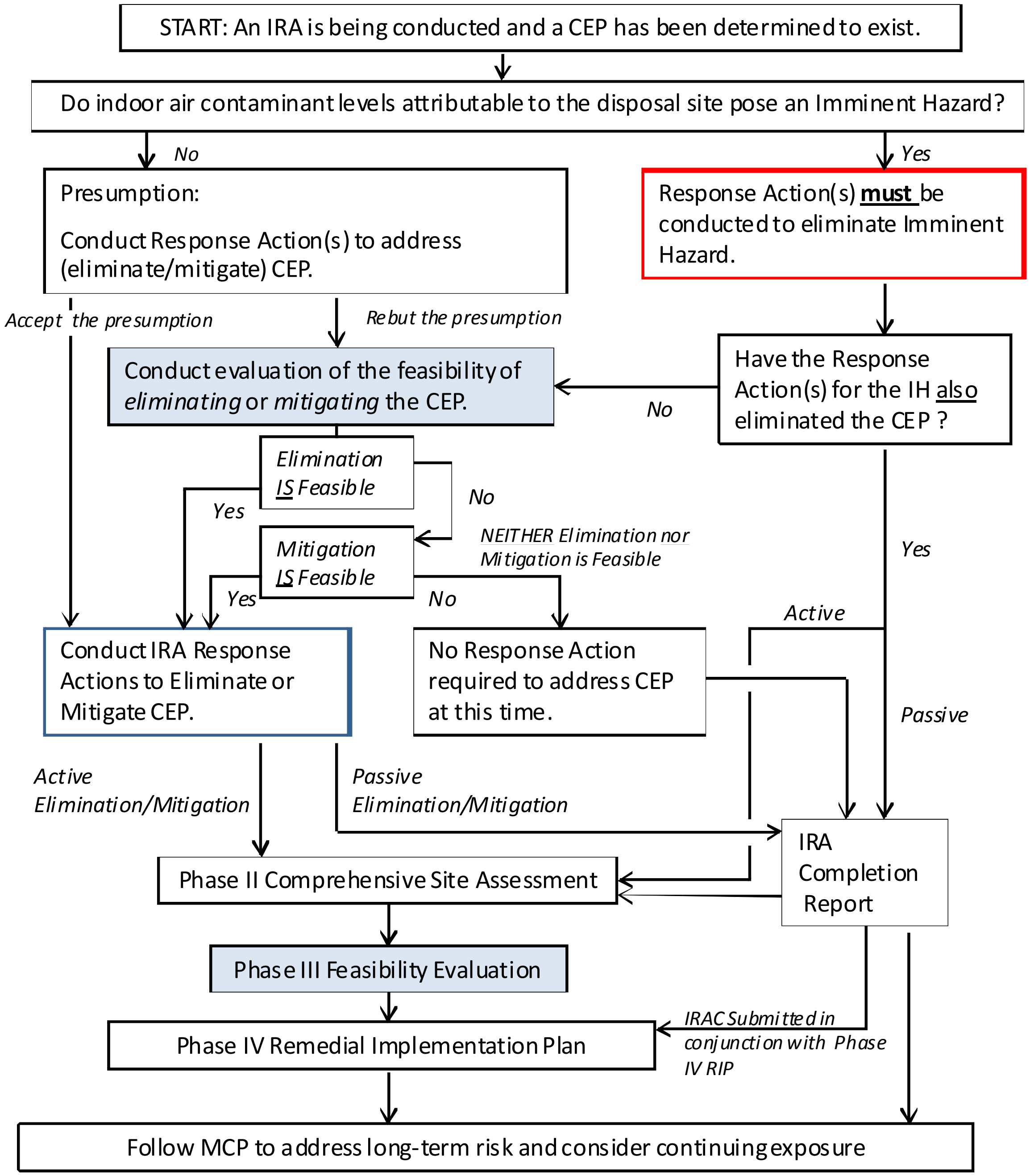
At owner-occupied residences with a CEP that does not pose a Significant Risk based on information collected to-date, MassDEP considers response actions to eliminate or mitigate CEP conditions to be infeasible if the owner-occupant will not agree to address CEP conditions. Documentation of the PRP/LSP's efforts to conduct measures to address CEP conditions at the residence should be provided in the CEP Feasibility Evaluation (see Section 4.3.2.4).

4.3.2.3 Rebutting the MCP Presumption for CEP Elimination/Mitigation

Where there is no Imminent Hazard, the PRP may rebut the presumption of the need for response actions 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 addresses actions to be taken as part of an IRA. If the subsequent Phase II Assessment concludes that Comprehensive Remedial Actions are required to achieve a Response Action Outcome (conditions pose a Significant Risk), a comprehensive Phase III evaluation of remedial alternatives must also be performed.

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 (See Figure 4-2).

Figure 4-2: Addressing Critical Exposure Pathways from Vapor Intrusion



For example, if building or site conditions pose special challenges to the installation of a typical active SSD system, a feasibility evaluation may be performed to weigh the costs and benefits of eliminating the CEP conditions. The CEP feasibility evaluation for such a system should anticipate operation and maintenance costs for a period of 2 to 5 years (the time typically taken to complete a Phase II Comprehensive Site Assessment and a Response Action Outcome Statement), , as well as the benefits from risk reduction accrued over the same period of time. The following factors are recommended for consideration in CEP feasibility evaluations:

- *Risk-reduction benefits of eliminating/mitigating CEP*

  Even though data may be limited when a CEP is initially identified, it is important to evaluate the risk-reduction benefits associated with the elimination/mitigation of the CEP considering the following:

  - Where the available data suggest levels that may pose a significant risk of harm to human health, the benefits associated with implementing response actions to address the CEP and the significant risk are compelling. Any feasibility-based rebuttal should include an evaluation of how and when the condition of Significant Risk will otherwise be addressed (e.g., through other remedial measures underway, such as source control, groundwater treatment, etc.). Note that a Permanent Solution cannot be reached if the CEP conditions pose a Significant Risk.
  - Where the available data suggest that concentrations do not pose a significant risk, the feasibility evaluation should compare the incremental benefit of further risk reduction with the cost considerations below.
  - Where the available data is limited, there may be substantial uncertainty in the risk estimates due to the quality/quantity of the data. If data and risk conclusions from the data are uncertain, there is benefit to eliminating or mitigating CEP to reduce uncertainty and risks that may not be well characterized. This benefit may be greater in situations where site-related OHM have a higher toxicity and persistence (relative to other OHM). The number and location of samples collected from groundwater, sub-slab soil gas, indoor air and ambient air should be considered, as well as whether seasonal and worst-case conditions have been evaluated.

- *The expected costs of eliminating/mitigating CEP*

  Site-specific issues may affect the costs of implementing measures to eliminate or mitigate CEP. Consider whether there are factors associated with the building and its setting that significantly affect the available remedial options and cost of CEP elimination. Examples of situations to be considered for this evaluation include those that result in the need for: (1) reconstruction of basement walls or pouring of new slabs; (2) installation of raised floors for SSD system installation due to the presence of a high groundwater table; or (3) an excessive number of extraction points and fans due to poor sub-slab communication within 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 of CEP mitigation should be addressed in a manner similar to CEP elimination.

4.3.2.4 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 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, 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 no action being taken as an IRA (in cases where it is not feasible to eliminate or mitigate the CEP), or it may result in Response Actions to eliminate and/or mitigate CEP. An IRA Completion Report would be submitted in cases where addressing CEP is determined to be infeasible and no further assessment is being performed as an IRA (see Section 4.5.1.1).

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.

4.4 Numerical Ranking System and the Indoor Air Pathway

The Numerical Ranking and resulting Tier Classification of a site conducted after the completion of a Phase I Initial Site Investigation will be affected by the presence of a potential, likely, or confirmed indoor air exposure pathway. The exposure pathway designation criteria for air are outlined in 310 CMR 40.1512(4). The guidance in this section assumes that at the time of Tier Classification, site investigations are ongoing and the presence or absence of a vapor intrusion pathway has not yet been confirmed through a full multiple Lines of Evidence investigation. The suggested scoring levels in the following paragraphs would not apply if a full investigation (including data from groundwater, soil gas, indoor air, and outdoor air, and an evaluation of preferential pathways) has demonstrated that there is no indoor air exposure pathway.

"*Likely or Confirmed Exposure Pathway*" scores 200 points under Section IID when "OHM has been identified in indoor air in an occupied building, above background concentrations, when the OHM is likely attributable to a non-permitted release at the disposal site." MassDEP recommends comparing indoor air OHM concentrations to the appropriate residential or commercial/industrial TVs (Appendix I). If current indoor air concentrations are above the applicable TVs, the air pathway should be scored as a Likely or Confirmed Exposure Pathway unless the levels are associated with on-going commercial or industrial processes.

"*Potential Exposure Pathway*" scores 100 points under Section IID when "a reasonable likelihood exists that the indoor air quality of an occupied building will be impacted by OHM likely attributable to the disposal site". For the purpose of NRS scoring, MassDEP recommends scoring the air pathway as a Potential Exposure Pathway when the criteria for "Likely or Confirmed Exposure Pathway" are not met, but any of the following conditions exist: (1) sub-slab soil gas OHM concentrations exceed the soil gas screening values (Appendix II); (2) LNAPL or DNAPL (without an overlying clean groundwater lens) is present within 30 feet of an occupied building; or (3) groundwater OHM concentrations exceed GW-2 Standards and the building of concern may be impacted due to its construction (earthen floor, fieldstone foundations, cracks or sumps).

"*Evidence of Contamination*" (Assumes No Exposure Pathway) scores 15 points under Section IID when "a release, or potential release, of OHM to air has been identified." MassDEP recommends that the presence of OHM in groundwater at levels exceeding the GW-2 standard be considered a potential release of OHM to air, if there are no data indicating that the criteria for "Potential Exposure Pathway" or "Likely or Confirmed Exposure Pathway are met. Also, in cases where an SSD system has been installed or other measures have been taken and indoor air quality has been mitigated to acceptable levels, "Evidence of Contamination" would be the appropriate score for the Indoor Air Pathway. Although the SSD system is addressing the current release to indoor air, the criteria for "None or Not Applicable" are not met, and there is the potential for a recurring release should the SSD system or other measures be disabled or become ineffective.

Pursuant to 310 CMR 40.0530(1), when new or additional data is obtained which is reasonably likely to result in a finding that would cause reclassification of a disposal site, the site shall be re-evaluated using the Numerical Ranking System and the Inclusionary Criteria. If there was no indoor air data confirming the indoor air pathway when the site was tier classified originally, the change from "Potential Exposure Pathway" to "Likely or

Confirmed Exposure Pathway" adds 100 points, which can change a classification from Tier II to Tier I. Similarly, if indoor air contaminants previously assumed to be attributable to the disposal site are determined to be from an indoor source unrelated to the release, the resulting reclassification of a disposal site could change from Tier I to Tier II.

4.5 MCP Closure at Sites with Vapor Intrusion Pathways

This section of the guidance addresses aspects related to MCP closure for disposal sites with vapor intrusion pathways, including:

1. MCP endpoints available for closure of IRAs with CEP conditions;

2. Considerations for RAO submittals;

3. The distinction between various RAO Classes when closing sites with vapor intrusion pathways; and

4. Examples of MCP closure considerations for various vapor intrusion scenarios.

4.5.1 Immediate Response Action Completion (IRAC) Criteria and Possible Outcomes

The requirements for closure of IRAs are specified at 310 CMR 40.0427(1). 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: (1) that the site is stabilized; (2) Imminent Hazards are addressed without continued operation and maintenance of active remedial systems, pending completion of any necessary Comprehensive Response Actions; and (3) CEP(s) have been eliminated, prevented or mitigated without continued operation and maintenance of active remedial systems, pending the completion of a risk assessment and a Phase III feasibility study. The requirements related to the timing and content of Immediate Response Action Completion (IRAC) Reports are listed in 310 CMR 40.0427 (3) and (4) Note that the submittal of an IRAC Report does not necessarily mean that a CEP no longer exists, but rather that the CEP conditions, if present, are no longer being addressed as an IRA. The following sections describe possible points at which IRAs implemented to address CEP conditions may be closed.

4.5.1.1 It Is Not Feasible to Eliminate or Mitigate CEP

When vapor intrusion does not pose an Imminent Hazard, 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 4.3.2. 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 4-2). Long-term risk from the CEP condition would need to be part of the site-wide evaluation in the Phase III feasibility evaluation.

4.5.1.2 CEP Has Been Eliminated

When the CEP condition has been eliminated using passive measures (Section 3.4.2), an IRAC Report may be submitted to document the completion of the IRA activities related to eliminating the CEP. This 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 (Figures 4-2 and 4-3). If the CEP condition has been eliminated using an active system, a Phase II Comprehensive Site Assessment must be performed. In these cases, the IRAC Report would be submitted in conjunction with the Phase IV Remedial Implementation Plan (See Figure 4-2.)

At sites with vapor intrusion impacts from groundwater and/or soil contamination, the conclusion that CEP has been eliminated should be supported by indoor air data as outlined in Table 3-1.

4.5.1.3 CEP Elimination Is Not Feasible and CEP Mitigation Is Performed

If the CEP feasibility study concluded that CEP elimination was not feasible, but CEP mitigation was feasible, mitigation activities would have been implemented and monitored with consideration to the sampling regimen outlined in Table 3-1. If monitoring indicates that indoor air contaminant levels are above the No Significant Risk level without continued operation of the mitigation system, the CEP mitigation would need to continue as part of the Comprehensive Response Actions for the site (see Section 4.5.1.4 below). If the full site assessment indicates that Comprehensive Response Actions are not necessary because site conditions pose No Significant Risk, an IRAC Report could be submitted and the site could proceed to closure with an RAO, once the other RAO performance standards are met (source control and the evaluation of the feasibility to reach/approach background).

4.5.1.4 CEP Mitigation is Incorporated into Comprehensive Response Actions

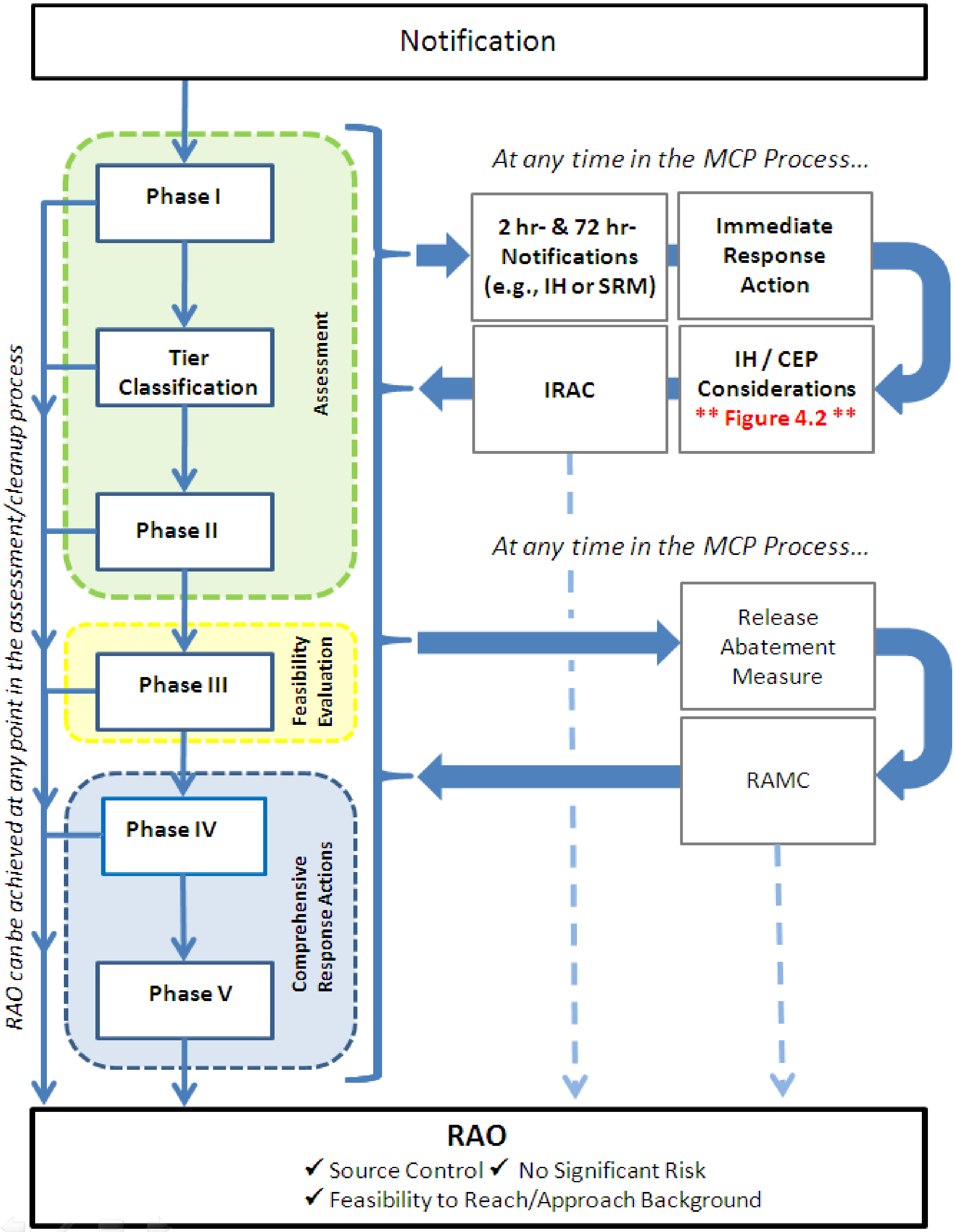
The CEP conditions and response action would generally be incorporated into the Comprehensive Response Actions for the site, including a Phase II Assessment and a Phase III evaluation of remedial action alternatives. At that point, with the submittal of a Phase IV Remedy Implementation Plan, the IRA addressing CEP could be closed with an IRAC Report. The timing of the IRAC Report submittal would be site-specific, but cannot be 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.

> *Example Vapor Intrusion Scenario*
>
> An active SSD system was installed as an IRA to mitigate the CEP conditions caused by vapor intrusion into a residence from a contaminated groundwater plume. The system operated while assessment was performed to identify and characterize the contaminant source. The Phase III Feasibility Evaluation documents the recommended Comprehensive Remedial Action of: (1) in-situ chemical oxidation in soil at the source area beneath a vapor degreaser at an upgradient industrial facility; and (2) continued operation of the active SSD system. The source has not yet been eliminated or controlled, so the performance standards for an RAO have not been met. An IRAC is submitted and the SSD system is operated as part of the Comprehensive Response Actions.

4.5.1.5 CEP Elimination/Mitigation Is Concluded with a Partial RAO

In MassDEP's experience, there is a potential for significant variability in groundwater, soil gas and indoor air contaminant concentrations at sites where vapor intrusion is a pathway of concern. This variability makes it difficult to support partial RAOs for individual buildings with CEP conditions that are the result of a groundwater contaminant plume. However, in cases where the contaminant source has been eliminated or controlled, a partial RAO for an individual building may be supported when indoor air concentrations of site-related OHM, in the absence of any active remediation, are shown to pose No Significant Risk, 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 provided in Table 3-1.

Figure 4-3: Management of Vapor Intrusion Sites Under the MCP



4.5.2 General Considerations for MCP Closure of Vapor Intrusion Response Actions at RAO

Requirements to achieve and document an RAO are provided in 310 CMR 40.1000. The general requirements for RAO submittal are the same at any site. This section discusses considerations specific to sites where a vapor intrusion pathway has been identified.

At the point where an RAO is obtained for the entire disposal site, numerous activities have been completed, including the following:

- Delineation of the extent of contamination in all affected media;
- Performance of the risk characterization documenting whether a level of No Significant Risk exists or has been achieved;
- Conclusion as to whether response actions are required; and
- *If remedial actions are necessary*, evaluation of the feasibility of implementing the response actions and of achieving or approaching background conditions.

The specific requirements for a Class A, Class B or a Class C RAO vary and should be considered depending upon the RAO sought.

4.5.2.1 RAO Prior to Tier Classification at Sites with Vapor Intrusion Mitigation

Sites with a vapor intrusion pathway are generally too complex to achieve Permanent Solution RAOs prior to Tier Classification (i.e., within one year from notification). This is especially true in cases where vapor intrusion is dependent on seasonal fluctuations in soil vapor concentrations and/or groundwater elevations. Indoor air characterization requires seasonal sampling, including during worst case winter conditions (see Section 22.2.1), which likely precludes achieving a Response Action Outcome within one year.

However, there may be vapor intrusion sites with small, discrete OHM sources where it is possible to support a Class A RAO prior to Tier Classification. At some vapor intrusion sites, a Class C RAO (Temporary Solution) can be achieved within one year by prompt source removal and the installation of an active SSD system at buildings affected by vapor intrusion.

Example Vapor Intrusion Scenario

A sudden release of fuel oil from an aboveground storage tank results in contamination of surface and subsurface soil. Indoor air impacts are documented at the time of the release. Following removal of accessible contaminated soil and in-situ treatment of remaining subsurface soil contamination, three rounds of indoor air sampling, including one performed during the winter, indicate that indoor air contamination has been reduced to concentrations that pose No Significant Risk. A Class A RAO Statement is submitted prior to the one-year deadline for Tier Classification.

4.5.2.2 RAO Following Tier Classification at Sites with Vapor Intrusion Mitigation

Considerations for Phase III Feasibility Evaluations

Phase III Feasibility evaluations for addressing vapor intrusion pathways should be conducted following the same statutory and regulatory context as feasibility evaluations for other exposure pathways. Section 3A of Chapter 21E defines Permanent Solutions as including measures that reduce contaminant concentrations to background, where feasible. Guidance about feasibility evaluations is also provided in MassDEP Policy #WSC-04-160, *Conducting Feasibility Evaluations under the MCP*. For all Class A RAOs other than Class A-1, the results of the feasibility evaluation conducted pursuant to 310 CMR 40.0860 must demonstrate that approaching or achieving background is not feasible.

For sites where CEP elimination/mitigation was determined to be feasible (see Section 4.3.2) and was initiated as an IRA, a subsequent feasibility evaluation that looks at Comprehensive Remedial Action alternatives comes during the Phase III evaluation. Where remedial actions have been or are being conducted at the disposal site to achieve a Permanent Solution, the feasibility evaluation addresses both the feasibility of remedial alternatives to achieve a Permanent Solution as well as the feasibility of reducing contaminant concentrations to background. The feasibility evaluation may recommend continuation of the CEP mitigation as part of Comprehensive Response Actions (see below) or, conclude that continued vapor intrusion mitigation is no longer feasible (See Figure 4-3).

For sites with a vapor intrusion pathway but no Imminent Hazard or CEP conditions, the Phase III feasibility evaluation would address this pathway along with all other conditions at the site.

In some circumstances, the necessary and appropriate actions initially taken to address Imminent Hazard 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, sealing of cracks in walls and foundations, placing seals in sumps, and any operational changes to heating, ventilation, and air conditioning (HVAC) systems in buildings. 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 Class A RAO. Note that operational changes to building ventilation needed to maintain a condition of No Significant Risk cannot be relied upon as a necessary part of a Permanent Solution.

Example Vapor Intrusion Scenario

In response to IH levels of VOC contamination in indoor air at a commercial building, a sub-slab depressurization system was installed. 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 should be viewed as a temporary measure and is not an acceptable long-term solution to achieve a Class A RAO. It should be revisited in evaluating response action alternatives during Phase III.

<u>Transitioning Preliminary Response Actions to Comprehensive Response Actions</u>

IRAs are required at vapor intrusion sites to address an Imminent Hazard, CEP or SRM condition. At industrial or commercial sites, a Release Abatement Measure (RAM) may be performed to address vapor intrusion (See Figure 4-3). If the IRA or RAM is not completed prior to the implementation of Comprehensive Response Actions, the IRA/RAM response action may be part of Comprehensive Response Actions recommended following a Phase II Assessment and a Phase III evaluation of remedial action alternatives (310 CMR 40.0429(3)). At this point, with the submittal of a Phase IV Remedy Implementation Plan (310 CMR 40.0864), the IRA or RAM would be closed with an IRA or RAM Completion Statement and the continued operation of the vapor intrusion mitigation would move forward as part of Comprehensive Response Actions.

<u>Addressing Vapor Intrusion through Comprehensive Response Actions</u>

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 Action Alternative and/or Phase V Operation, Maintenance and/or Monitoring activities. Several MCP submittal requirements apply in cases where the Comprehensive Response Actions requires operation, maintenance, and/or monitoring activities. The installation of remedial response actions may be documented in the Remedy Implementation Plan and/or an Operation, Maintenance and/or Monitoring Plan. Phase IV Status Reports may be 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, the following outcomes are possible: (a) submittal of a Class A or Class C RAO; (b) continuation of remedial actions as operation and maintenance of the Comprehensive Response Action under Phase V, including Remedy Operation Status (ROS); or (c) submission of a Class C RAO necessitating post-Class C RAO operation, maintenance and/or monitoring of the remedial action.

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 source elimination or control, the elimination of substantial hazards, 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 an RAO and the requirement to extend Tier I permits or Tier II Classifications while ROS is maintained.

4.5.3 Class A RAOs - Permanent Solutions

Class A RAOs apply to disposal sites where a Permanent Solution has been achieved and where response actions have been conducted to: (a) achieve a level of No Significant Risk; (b) eliminate or control any source of OHM; and (c) where feasible, reduce to the extent possible the level of OHM concentrations in the environment to background. Class A RAOs do not apply to disposal sites where a condition of No Significant Risk already exists, and therefore no response actions are required.

There are four different types of Class A RAO:

- Class A-1 RAOs apply to sites where a Permanent Solution has been achieved and the level of OHM in the environment has been reduced to background;
- Class A-2 RAOs apply to sites where a Permanent Solution has been achieved, but the level of OHM has not been reduced to background;
- Class A-3 RAOs apply to sites where a Permanent Solution has been achieved; the level of OHM has not been reduced to background; and an Activity and Use Limitation (AUL) is required to maintain a level of No Significant Risk; and
- Class A-4 RAOs apply to sites that meet the criteria for a Class A-3 RAO, *and* soil beneath an engineered barrier or at a depth greater than 15 feet contain OHM at concentrations that exceed the applicable Upper Concentration Limit.

Sites are not eligible for a Class A RAO if Active Operation and Maintenance of remedial actions is required. As defined in 310 CMR 40.0006(12), Active Operation and Maintenance of a remedial action means "activities related to: (a) operating and maintaining an Active Remedial System or (b) conducting an Active Remedial Monitoring Program." An Active Remedial System "means a remedial action that relies upon the continual or periodic use of an on-site or in-situ mechanical or electro-mechanical device." An Active Remedial Monitoring Program is "a remedial action that employs a systematically designed and monitored program of sampling and analyzing environmental media (e.g. application of Remedial Additives, Monitored Natural

Attenuation, reactive walls); an Active Remedial Monitoring Program does not employ an Active Remedial System."

Active Operation and Maintenance includes the operation of active sub-slab depressurization systems, and those sub-slab venting (SSV) systems that include moving parts, i.e. systems that rely on the use of a mechanical or electro-mechanical device. Turbine ventilators used as an added component to passive SSV systems would not constitute an "Active Remedial System" if they are not required to achieve No Significant Risk.

Ongoing operation of an active SSD system (where it is not necessary for maintaining No Significant Risk) *outside the MCP process* (see Section 4.6), following the submittal of a Class A RAO would not prevent a party from achieving site closure relative to the requirement at 310 CMR 40.1035(3)(b), which precludes Class A Response Action Outcomes where Active Operation and Maintenance of a remedial action is required.

> *Example Vapor Intrusion Scenario*
>
> Following a Phase III Feasibility evaluation, the contamination source is removed through soil excavation and an active SSD system is installed to address vapor contaminant levels above No Significant Risk at a commercial property. The SSD system is installed as outlined in a Phase IV Remedy Implementation Plan, and operates for three years under Remedy Operation Status. 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 No Significant Risk level for commercial use over the last two years of operation. A Class A-3 RAO is submitted, with Activity and Use Limitation (AUL) conditions to prohibit residential, school or daycare use of the property.

To support an RAO at a disposal site with vapor intrusion pathways, a sufficient level of certainty should exist that site conditions are stable and will not worsen, and that contaminant levels in indoor air affected by the disposal site will remain at a level at or below No Significant Risk or diminish over time.

The Response Action Outcome Performance Standards for sites with vapor intrusion are the same as at any other MCP site. The documentation supporting the RAO must include the following:

1. a demonstration that all uncontrolled sources have been eliminated or controlled (310 CMR 40.1056(2)(b));

2. information supporting the conclusion that a level of No Significant Risk exists (310 CMR 40.1056(2)(c)); and

3. information documenting the extent to which levels of OHM have been reduced to background, and for all Class A RAOs other than Class A-1, the results of the feasibility evaluation conducted pursuant to 310 CMR 40.0860 demonstrating that the achievement of background is not feasible.

   M.G.L. chapter 21E Section 3A (g) states: *“Where feasible, a permanent solution shall include a measure or measures designed to reduce to the extent possible the level of oil or hazardous material in the environment to the level that would exist in the absence of the site of concern.”*

MassDEP recommends considering the following issues when supporting a conclusion that contaminant sources at a vapor intrusion site have been eliminated or controlled and a Permanent Solution has been achieved.

- Are the concentrations of contaminants of concern (COCs) in groundwater, soil gas and indoor air stable or decreasing?
- Is the sampling supporting the conclusion in 1. above and the RAO adequate, as discussed in Section 2.2?;

  The variability and uncertainty associated with vapor intrusion sites add a level of complexity to documenting that the RAO requirements have been met. The variability associated with vapor intrusion often results in the need for a denser sampling plan over a longer period of time than at sites without a vapor intrusion pathway.

- Has groundwater monitoring detected NAPL or conditions indicative of NAPL at the site during the past two years?

  The Department recommends evaluating groundwater contaminant concentrations with respect to the EPA’s comparison to 1% of the contaminant’s pure phase solubility as indicative of the presence of DNAPL (EPA 1992 and 1994).

- Are contaminant concentrations in soil gas high enough to cause an increase in indoor air contaminant concentrations if building conditions change? and
- Has the contaminated media (soil and groundwater) that resulted in the increasing contaminant concentrations in soil gas or indoor air been eliminated or controlled?

The burden of proof to demonstrate that the MCP source control/elimination performance standard has been met is significantly greater at sites with elevated levels of contaminated soil, groundwater or NAPL remaining than at those sites with negligible residual contamination, as such elevated concentrations may be a strong indication of an uncontrolled source.

In cases where the achievement of a Permanent Solution is dependent on the maintenance of a vapor barrier or SSD 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 or system as a pathway elimination measure. An AUL in such cases must specify that the integrity of the barrier/system be maintained and that it is periodically monitored to demonstrate effectiveness. Contingencies should be provided in the AUL for the repair of the barrier/system and re-evaluation of its effectiveness in the event of any future renovation/activity that has or has the potential to compromise the system.

An AUL can also be implemented as part of a Permanent Solution to limit the use of an existing building to commercial/industrial use where NSR has not been demonstrated for residential use, but can be supported for shorter exposure durations under commercial/industrial use of the building. 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.

The implementation and adherence to the AUL for existing buildings where it is an element of the Permanent Solution necessary for the maintenance of a condition of NSR is required by 310 CMR 40.1012(2)(b).

4.5.4 Class B RAOs – No Remedial Action Required

Class B Response Action Outcomes apply to disposal sites "where it is determined as a result of assessment actions that a level of No Significant Risk exists under 310 CMR 40.0900 and, therefore, no remedial actions are necessary" (310 CMR 40.1045(1)). Class B Response Action Outcomes do not apply to a disposal site where one or more remedial actions have been conducted.

Sites with confirmed vapor intrusion pathways in existing buildings cannot qualify for a Class B RAO if any response actions have been conducted to address the vapor intrusion. Vapor intrusion remedial actions which would preclude a Class B RAO include the installation of passive or active systems for sub-slab depressurization/venting, building modifications (such as sump covering or foundation repairs) or HVAC system modifications. A Class B RAO may be appropriate for a disposal site where maintaining a condition of No Significant Risk is dependent *only* on the implementation of an Activity and Use Limitation to restrict future building construction or certain property uses.

> *Example Vapor Intrusion Scenario*
>
> A commercial building has low but detectable levels of OHM documented in indoor air. A condition of No Significant Risk exists within the building, based on

its continued commercial use. If an AUL is used to prohibit future building use as a school, residence, or daycare facility, this site could quality for a Class B RAO.

4.5.5 Class C RAOs – Temporary Solutions

Class C RAOs apply to disposal sites where a Temporary Solution has been achieved by elimination of any Substantial Hazards and, to the extent feasible, elimination, control or mitigation of an OHM source as identified at 310 CMR 40.1003(5). A Substantial Hazard is a hazard that would pose a significant risk of harm to health, safety, public welfare, or the environment if it continued to be present for several years (310 CMR 40.0956). The MCP distinguishes between a Class C-1 RAO, where response actions to achieve a Permanent Solution are not currently feasible, and a Class C-2 RAO, where such actions are feasible and are to be implemented.

At sites with vapor intrusion pathways, a Class C-1 RAO may be submitted where implementation of a Permanent Solution is not currently feasible, but where a condition of No Substantial Hazard is being maintained through active operation and maintenance of SSD systems. The MCP requires periodic five-year reviews of Class C-1 remedies to evaluate the continued effectiveness of the Temporary Solution and address the feasibility of additional steps to reach a Permanent Solution (310 CMR 40.1051(3)(b)).

310 CMR 40.1056(2)(i) states that documentation in support of an RAO must include a description of any operation, maintenance, and/or monitoring that will be required to confirm and/or maintain those conditions at the disposal site upon which the RAO is based. The MCP (310 CMR 40.0897) outlines Post-Class C operation, maintenance and/or monitoring activities and documentation. The scope of these activities will be based on the remedial action being undertaken. Post-Class C RAO operation, maintenance and/or monitoring activities must be documented in a Post-Class C RAO Status Report, as described in 310 CMR 40.0898(2). At a minimum, a Post-Class C 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-Class C RAO Status Report and every six months thereafter, in accordance with 310 CMR 40.0898(3).

Example Vapor Intrusion Scenario

Following a Phase III evaluation, the vapor intrusion pathway in a school is mitigated through the continued operation of an SSD system, which was initially installed to address CEP. Monitoring conducted after system shut-downs during school vacations indicates that the SSD system must be operated to maintain a condition of No Significant Risk. Contaminated soil from the source area was excavated to the extent feasible and Substantial Hazards have been eliminated. A Class C-1 RAO is filed, while additional cost-effective, innovative source reduction options to address the groundwater contaminant plume and additional soil removal/remediation are evaluated.

4.6 Post-Closure Voluntary Continuation of Vapor Intrusion Mitigation

In cases where the operation of a mitigation system is no longer required as an MCP response action, MassDEP recognizes that an owner may want to continue effective actions to reduce exposure to remaining low levels of contamination. Without the ongoing MCP oversight and submittal costs, the electricity and maintenance costs for active SSD systems are typically very affordable. The responsibility for system operation and maintenance costs would be the subject of discussion and agreement between the affected parties and the Responsible Parties/Eligible Persons (if different parties).

An additional benefit to continued operation of an SSD system is the mitigation of the natural contaminant radon where it is present[3]. Any radon testing and mitigation performed at a property would be completely outside of the MCP process. Given the health risks associated with radon exposure, an SSD system in place and operating where there is natural radon intrusion could provide great health benefits.

4.7 Future Use Considerations for Vapor Intrusion Sites Evaluated Under the MCP

At disposal sites with *existing* buildings, assessment can be conducted to identify whether vapor intrusion is occurring, and at what levels, as described in Section 2.2. Any remedial actions and mitigation of the vapor intrusion pathway are based on assessment of the actual site conditions, and the success of these measures can be assessed through direct measurements as part of the response action process leading to a RAO.

However, achieving closure that is protective relative to vapor intrusion at sites with VOCs in the soil or groundwater that do not have buildings at the time the RAO is submitted is more difficult since the actual building conditions cannot be directly measured.

Remedial measures that maximize reduction of the source of the VOC contamination and reduce groundwater concentrations and downgradient migration provide the greatest certainty in terms of reducing the potential for likely or long term impacts to future buildings.

In some cases, VOC contamination remains in groundwater and soil after source removal and other remedial measures. Such contamination may not pose a risk in the

[3] 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* (http://www.epa.gov/radon/pubs/citguide.html).

absence of site buildings (i.e., the groundwater is not a drinking water source and concentrations do not pose an ecological risk), but may pose a risk of vapor intrusion into buildings that may be constructed on the site in the future.

If Method 1 is used to close a site, the potential for vapor intrusion into future buildings may not be explicitly addressed: the MCP Method 1 GW-2 Standards do not apply in the absence of an occupied building or plan for a building, and the Method 1 Soil Standards are not protective of vapor intrusion specifically. Sites closed using Method 3 may not even evaluate vapor intrusion as the groundwater would not be categorized as GW-2 (“a potential source of vapors of OHM to indoor air”). As such at sites where there is residual VOC contamination in soil or groundwater, the potential for vapor intrusion from soils or groundwater should be considered in the placement of the building and preparation of the building site.

Parties conducting cleanups who have identified a potential risk of vapor intrusion from construction of a building that may occur or is occurring after an RAO was submitted have employed different approaches under the MCP to address this concern. These approaches include:

1. Use of an Activity and Use Limitation (AUL) to specify measures for the construction of a future building that is protective against vapor intrusion;
2. New notification of a reportable condition that are inconsistent with the site conditions that were the basis of the previous RAO (e.g. a new building with potential receptors), thus triggering response actions to address the changed conditions; and
3. The use of modeling to evaluate the potential for vapor intrusion into future buildings.

Considerations for the use of these approaches are discussed below.

4.7.1 Voluntary Use of an AUL to Protect Future Buildings

Use of an AUL to ensure that the potential for vapor intrusion is addressed as part of any future building construction typically specifies measures to be taken at the time of building construction (e.g., installation of a SSD system with a vapor barrier) or limits construction to locations outside of areas with groundwater VOC contamination. Another approach specifies that an LSP must evaluate the potential for vapor intrusion prior to the construction of a building. In either case, an AUL provides future developers/owners/occupants clear notice as to the risks and obligations associated with activities at the site.

Implementation of an AUL as part of a Response Action Outcome to address vapor intrusion potential at a future building at a disposal site where groundwater is not currently categorized as GW-2 (because there are no existing or planned buildings) is not a requirement of the MCP.

Section 4.7.4 references engineering and other measures to incorporate into an AUL related to the construction of future buildings on the basis of groundwater concentrations at the disposal site at the time of the RAO. Appendix V provides additional recommendations for drafting AULs that specify measures to protect against vapor intrusion in future buildings. MassDEP supports the use of AULs to address the potential for vapor intrusion in future buildings and the approach presented in Section 4.7.4 and Appendix V, but this approach is considered optional. Where an AUL is used, however, it must be implemented in conformance with the MCP, including the provisions of 310 CMR 40.1070 through 40.1099.

4.7.2 Notification Required for New Buildings

Notification has been used in cases where the previous Response Action Outcome did not categorize groundwater as GW-2 (based on the absence of existing or planned buildings) and did not consider potential vapor intrusion exposures. In recognition that the previous assessment, cleanup and RAO did not address the potential for future buildings, new notification has been provided to MassDEP followed by additional response actions conducted to address this potential pathway. Since the previous RAO did not address potential exposure to future building occupants, the notification exemption at 310 CMR 40.0317(17) would not be valid for groundwater concentrations that indicate the potential for vapor intrusion.

Reliance upon subsequent MassDEP notification to insure appropriate evaluation of potential vapor intrusion concerns is, at best, an uncertain approach. Future developers/owners/occupants may face unanticipated exposures and associated costs if construction proceeds without a full knowledge of site conditions.

4.7.3 Use of Modeling for Future Buildings

Another approach that has been taken as part of RAOs where buildings do not currently exist is to use modeling to evaluate the potential for vapor intrusion into future buildings. As described previously in Section 2, the Method 1 GW-2 Standards incorporate the use of the J & E model using generic assumptions to screen out the potential for vapor intrusion into buildings based on groundwater concentrations. MassDEP supports parties using the Method 2 Standards, as well as the J & E model and its same generic input parameters to screen out the potential for vapor intrusion. The agency does not support, however, use of site-specific modeling inputs. Such site-specific modeling has not been found to be sufficiently predictive of indoor air concentrations and should not, under most circumstances, be relied upon as the sole determinant of potential exposure. This is especially the case with future buildings where the site-specific modeling results cannot be validated through direct measurements under actual conditions. Reliance upon modeling with site-specific inputs alone to evaluate exposures associated with future buildings provides future developers/owners/occupants no real assurance that the site conditions are protective.

4.7.4 Engineering Approach to Address Future Buildings

If buildings are constructed in areas where the VOC contamination remaining in the groundwater or soil poses potential for vapor intrusion into future buildings, engineering measures can be incorporated into the building plans or construction to be protective of the potential for vapor intrusion. Figure 4-4 and the associated text below presents a conceptual approach that MassDEP considers appropriate and adequate to ensure continued protective closure at a disposal site where a building is constructed after an RAO. This conceptual approach is based on VOC contaminant levels in groundwater. As discussed previously, the potential for vapor intrusion from soil VOCs should also be a considered when evaluating the location of future buildings or incorporation of engineering measures to protect against vapor intrusion. Assessment and removal of VOC contaminated soil beneath and near any proposed structure as part of construction planning and activities is recommended where such contamination is of concern.

The approach divides the levels of groundwater contamination and corresponding engineering and monitoring measures to maintain closure into three categories. In applying these categories, parties should use conservative groundwater concentrations representative of conditions at the time of the RAO. These categories are described below:

Category A:
For disposal sites with groundwater concentrations below GW-2 Standards (i.e. “Low” concentrations), no additional assessment or special construction considerations or engineering measures would apply to future buildings. The potential for vapor intrusion into future buildings can be ruled out.

Category B:
For disposal sites with groundwater concentrations *less than* 10 times the GW-2 Standards (“Elevated Levels”), any future construction should include the installation of a vapor barrier and active SSD system that meet performance standards which provide a high level of confidence in the effectiveness of the system in protecting building occupants from potential vapor intrusion. For these sites, no confirmatory indoor air sampling would be necessary to assess the effectiveness of the vapor barrier and SSD system operations, provided the system meets its installation, operation, and performance standards.

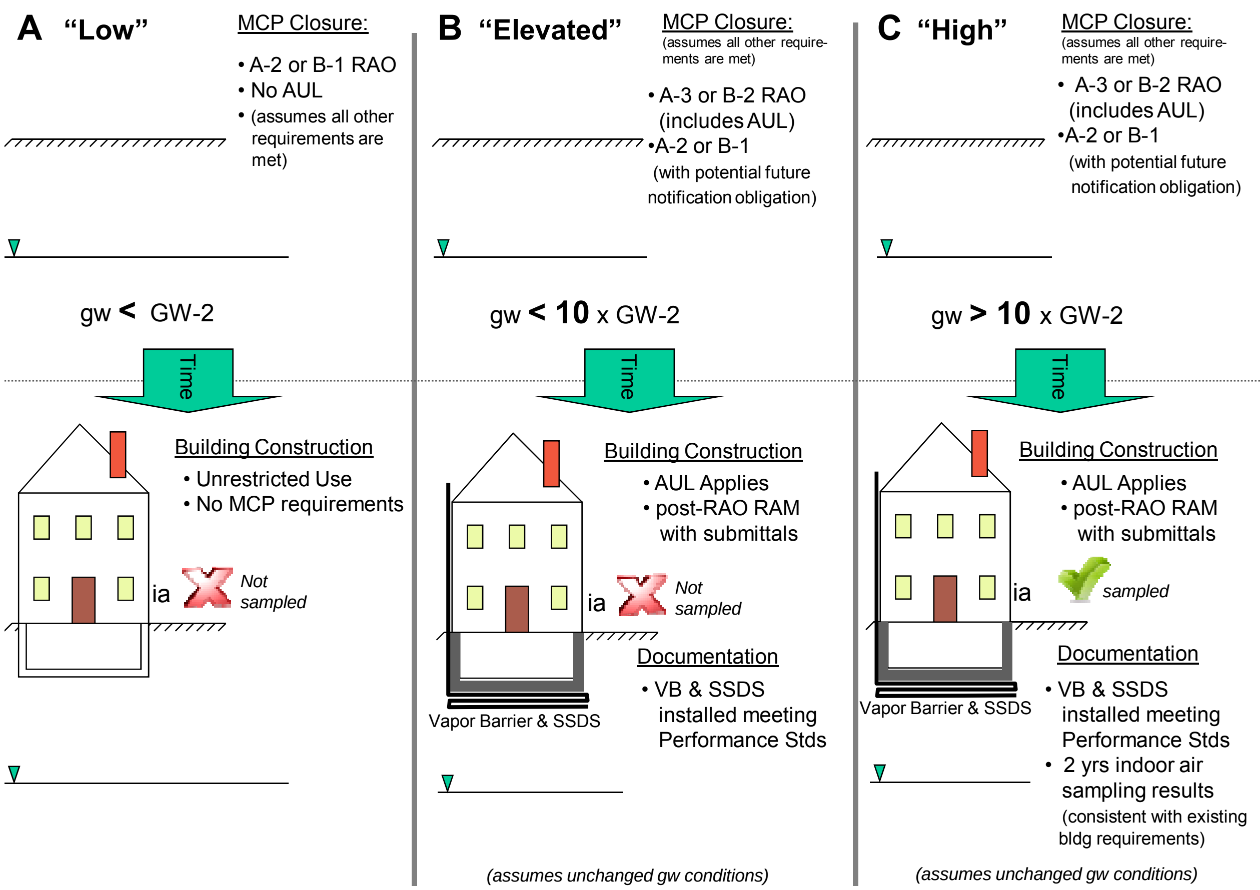
Parties have the option of forgoing operation of SSD systems based on actual post-construction indoor air testing following the sampling regimen outlined in Section 3.5.2 that demonstrates the absence of vapor intrusion.

Category C:
For disposal sites with groundwater concentration *greater than* 10 times the GW-2 Standards (“High” Levels), future buildings would be constructed with a vapor barrier and active SSD system that meet performance standards which provide a high level of confidence in the effectiveness of the system in protecting building occupants from potential vapor intrusion (same barriers and SSD systems used in the case of Category B sites). Upon completion of construction, indoor air should be sampled (when the system is temporarily shut down) over a period of two years to determine whether vapor intrusion is occurring. The recommendation to test the indoor air after construction is based on the increased potential for vapor intrusion, absent the operation of the SSD system, given the higher levels of VOCs in the groundwater in this category. Based on the results of the indoor air testing:

- If the indoor air testing demonstrates that the operation of the SSD system is not necessary to ensure a level of No Significant Risk, then no additional response actions are necessary. The property owner would have the option of operating the system, but such operation would not be considered a response action under the MCP.

- If the indoor air testing indicates vapor intrusion is occurring, Notification to MassDEP would be required due to concentrations in groundwater above applicable Reportable Concentrations and site conditions inconsistent with those that were the basis of the RAO. Additional assessment and likely subsequent response actions, including the activation of the SSD system, may be necessary under the MCP.

Figure 4-4: Protection Occupants of Future Buildings in Areas with VOCs in Groundwater



4.7.4.1 Process for Documenting Building Construction after an RAO

As Figure 4-4 indicates, there are different options under the current MCP for handling the process of conducting additional response actions and providing documentation related to the future building construction. Response actions should be conducted, as applicable, after a new notification, or as part of implementing terms specified in an AUL recorded at the time that the RAO was submitted (i.e., prior to the building construction). In the case of Category B sites, the AUL should specify the installation and maintenance of the vapor barrier and SSD system; in the case of Category C sites, the AUL should specify the installation and maintenance of the vapor barrier and SSD system and the subsequent indoor air testing.

Consistent with other post-RAO Response Actions in AUL areas, supporting documentation must be submitted to MassDEP according to the provisions at 31 CMR 40.1067. This documentation should include as-built information on the design and location of the vapor barrier and SSD system, and any indoor air testing results.

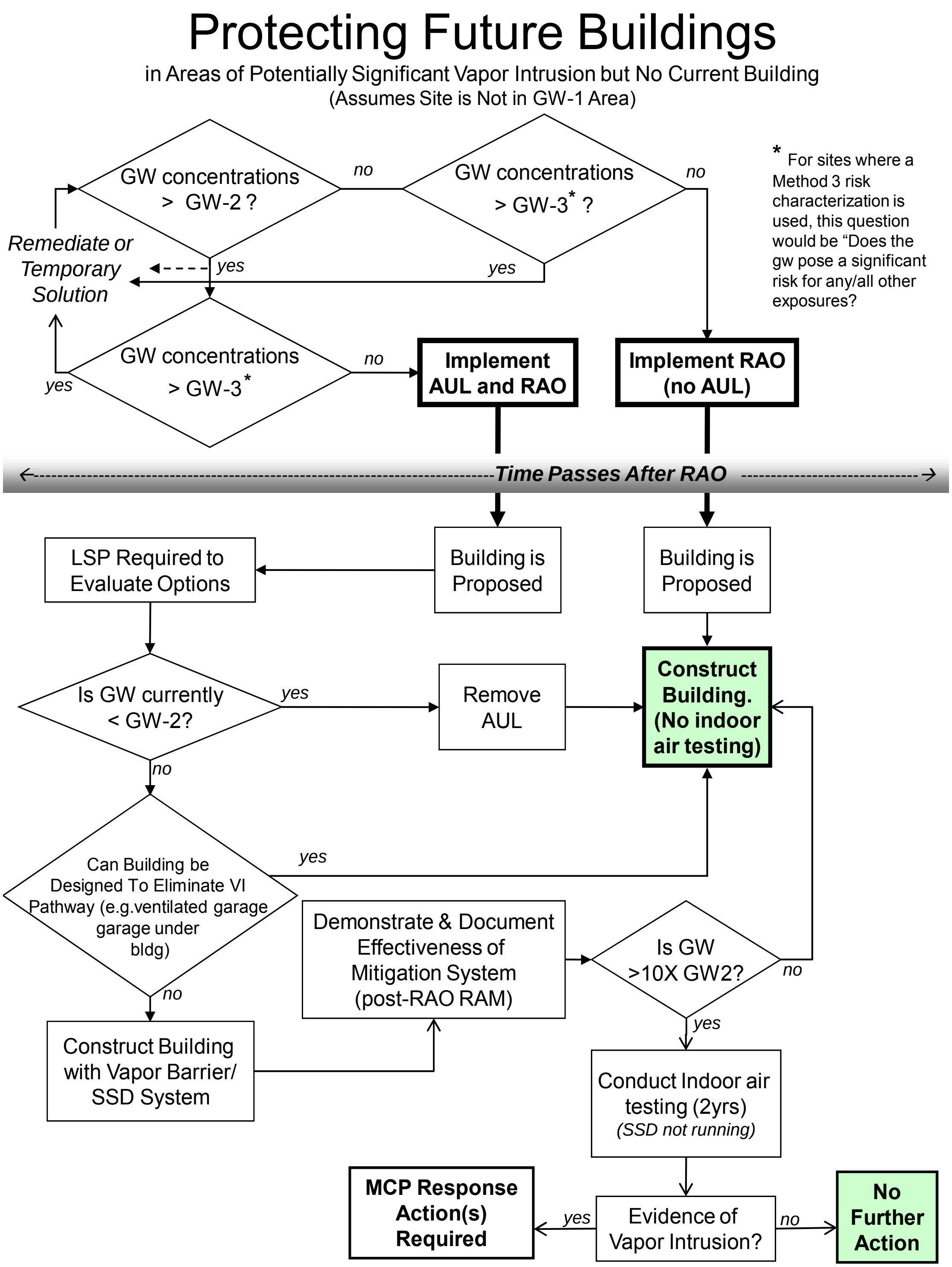
4.7.4.2 Other Scenarios for Future Building Construction

There are other future building scenarios that could preclude the need for further evaluation of the vapor intrusion pathway. For example, future building construction that employs an open air or ventilated parking garage on the ground level or an open air structure on the ground level, or restricts construction to the portions of a parcel unaffected by and upgradient of groundwater contamination, could be exceptions that preclude the need for vapor barriers and SSD systems. Figure 4-5 illustrates how these options could be applied at a site with residual levels of VOCs in groundwater that could act as a source of vapor intrusion if a building were constructed sometime in the future.

4.7.4.3 Additional Guidance on AULs for Future Building Construction

Appendix V provides additional guidance on information to include in an AUL Opinion and Form (including the lists of Inconsistent/Consistent Uses and Obligations and Conditions) consistent with the approach described in this section (Section 4.7) with respect to future construction where the potential for vapor intrusion exists.

Figure 4-5: Protecting Future Buildings



5. Communication and Public Involvement and Vapor Intrusion Sites

5.1 Introduction

The purpose of public involvement activities at MCP sites 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. This is 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 where building inhabitants and users 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. 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.

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 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.

MassDEP encourages early, clear and frequent communication with property owners and other concerned individuals about 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 through 5.4 summarize specific public notification requirements that may be triggered under the public involvement provisions 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 for this purpose of providing these notifications. These requirements and related forms are described below.

5.2.1 Notice of Environmental Sampling (Form BWSC 123)

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 BWSC 123. 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 5.5.

5.2.2 Notice Related to Immediate Response Actions (Form BWSC 124)

When conducting a remedial action as part of an Immediate Response Action to address an Imminent Hazard or Critical Exposure Pathway, 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 BWSC 124. 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. Note, 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 tenants of residential, commercial or industrial space where a remedial action is being conducted as part of an IRA to address an Imminent Hazard or Critical Exposure Pathway. 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).

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 Imminent Hazard or Critical Exposure Pathway; submittal of a completion statement for an IRA for an Imminent Hazard; and implementation of field work involving the use of respirators or Level A, B or C protective clothing.

Once the IRA is completed, written notice that includes a copy of the IRA Completion Statement to Affected Individuals is again required using Form BWSC 124.

Information on optional communication related to notice related to IRA remedial actions is provided in Section 5.5.

5.2.3 Notification of Owners of Property within the Boundaries of a Disposal Site (Form BWSC 122)

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 would include 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 BWSC 122.

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 Response Action Outcome 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 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 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, Response Action Outcome Statements (RAOs) and Downgradient Property Status (DPS) Opinions; and
- Recording/registering, amendment, release or termination of a Notice of an Activity and Use Limitation (AUL).

5.3.2. Public Involvement Opportunities During Preliminary Response Actions

The provisions at 310 CMR 40.1403(9) outline a process for local officials and residents to become involved with disposal sites in their community during Preliminary Response Actions (IRAs and RAMs). A fact sheet "*Opportunities for Public Involvement in Preliminary Response Actions*" is available on MassDEP's website (http://www.mass.gov/dep/cleanup/laws/fs_v1n1.htm). 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 the fact sheet "*Tips on PIPs: Understanding and Using the Public Involvement Processes*" which is available on MassDEP's website (http://www.mass.gov/dep/cleanup/sites/piptip01.htm).

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, difficulties 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, early communication about the investigation may make access easier to obtain. It may be useful to consider general communication about 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 prepared a general fact sheet available on its website at http://www.mass.gov/dep/cleanup/laws/vifs.htm that could 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. The 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. Fact sheets about specific chemicals are available from the Agency for Toxic Substances and Disease Registry (ATSDR) (http://www.atsdr.cdc.gov/toxfaqs/index.asp) and from 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 may 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 to gain access should be documented.

If the initial attempts to gain access are not successful, parties may, consistent with the provisions of the MCP, request MassDEP assistance in gaining access. The MCP (310 CMR 40.0173(1) and (2)) outline the steps a person conducting response actions must follow to request assistance from MassDEP. If the person conducting response actions is unable to obtain access after reasonable efforts, the person conducting response actions should send a notice, by certified mail (return receipt requested) to the 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 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 may be submitted to MassDEP asking MassDEP to assist with access property for the purpose of performing one or more necessary response actions. 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

Revision Notes:
March 7, 2013 - revisions were made to make consistent the rounding methodology used in the tables in Appendices I and II. In Appendix I, these adjustments resulted in slight differences in some of the values in Tables I.2, and I.3.
February 22, 2013- revisions were made to Tables I.1, I.2 and I.3 to reflect revised toxicity values and correct errors.

Appendix I

Indoor Air Threshold Values

for the Evaluation of a Vapor Intrusion Pathway

I.1 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.2 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 50th, 75th and 90th 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.

In general MassDEP selected Threshold Values 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 50th 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 90th percentile is the upper bounds for this screening effort. When screening using the 90th percentile the department is confident that detections above the 90th 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.3 Threshold Values

Residential – TV_r

Table I.1 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.3 provides the risk management values used, and Table I.4 provides the Analytical Reporting Limits used.

MassDEP established the Residential Threshold Values in Table I.1 for each chemical as follows:

- The 90th 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.3) 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 1-8 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 50^{th}, 75^{th} or 90^{th} percentile value), the highest analytical Reporting Limit provided for MassDEP APH and TO-15 (Scan Mode) (Table I.4) 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.2 lists the Commercial/Industrial Threshold Values. The $TV_{c/i}$s are the risk-based concentrations adjusted to the 90^{th} percentile values from MassDEP's list of Typical Indoor Air Concentrations where that value is higher. In the absence of well-documented and applicable commercial TIACs, the residential TIAC values are used to develop both the residential and commercial/industrial Threshold Values. Table I.2 also provides the basis for the $TV_{c/i}$ (e.g., risk-based or 90^{th} percentile value) for each chemical. Table I.3 provides the risk management values used. Table I.4 provides the Analytical Reporting Limits used.

MassDEP established the Commercial/Industrial (non-residential) Threshold Values in Table I.2 for each chemical as follows:

- The 90^{th} 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 90^{th} percentile value was compared to the risk-based concentrations (Table I.3) 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 90^{th} percentile TIAC value, then the 90^{th} 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.4 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 Contaminant of Concern 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 $1x10^{-6}$ / 0.2 target levels. These higher risk-based concentrations are also listed in Table I.3.

Revision Note:
February 22, 2013 -revisions were made to Table I.1 to reflect revised toxicity values and correct errors.

Table I.1 Residential Threshold Values (TV_r)

Chemical	CAS No.	TV_r		Basis for Value
		µg/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	0.020	1.0 x 10^{-6} Cancer Risk
BROMOFORM	75-25-2	2.1	0.20	1.0 x 10^{-6} Cancer Risk
BROMOMETHANE	74-83-9	0.60	0.15	90th%
CARBON TETRACHLORIDE	56-23-5	0.54	0.086	50th%
CHLOROBENZENE	108-90-7	2.3	0.50	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	0.60	0.10	90th%
DICHLOROBENZENE, 1,4- (p-DCB)	106-46-7	0.50	0.083	50th%
DICHLOROETHANE, 1,1-	75-34-3	0.80	0.20	Reporting Limit
DICHLOROETHANE, 1,2-	107-06-2	0.090	0.022	1.0 x 10^{-6} Cancer Risk
DICHLOROETHYLENE, 1,1-	75-35-4	0.80	0.20	Reporting Limit
DICHLOROETHYLENE, CIS-1,2-	156-59-2	0.80	0.20	Reporting Limit
DICHLOROETHYLENE, TRANS-1,2-	156-60-5	0.80	0.20	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	0.0010	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	8.0	1.4	Reporting Limit
NAPHTHALENE	91-20-3	0.60	0.11	Non-cancer Risk: HI=0.2
C5 to C8 ALIPHATICS	NOS	58	NA	50th%
C9 to C12 ALIPHATICS	NOS	68	NA	50th%
C9 to C10 AROMATICS	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	0.040	0.0059	1.0 x 10^{-6} Cancer Risk
TETRACHLOROETHYLENE	127-18-4	1.4	0.21	Reporting Limit
TOLUENE	108-88-3	54	14	90th%
TRICHLOROBENZENE, 1,2,4-	120-82-1	3.4	0.46	90th%
TRICHLOROETHANE, 1,1,1-	71-55-6	3.0	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	0.40	0.075	Non-cancer Risk: HI=0.2
VINYL CHLORIDE	75-01-4	0.27	0.10	1.0 x 10^{-6} Cancer Risk
XYLENES (Mixed Isomers)	1330-20-7	20	4.6	Non-cancer Risk: HI=0.2

***Note**: All data reported to two significant figures, except in cases where the original study or analytical reporting limit was reported with one significant figure.*
NA – Not Available
NOS- Not Otherwise Specified

Revision Notes:
March 7, 2013 - revisions were made to make consistent the rounding methodology used for in the tables in Appendices I and II. These adjustments resulted in slight differences in some of the values in Table I.2.
February 22, 2013 - revisions were made to Table I.2 to reflect revised toxicity values and correct errors.

Table I.2 Commercial/Industrial Threshold Values (TV_c)

Chemical	CAS No.	TV_c		Basis for Value
		ug/m^3	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	1.0	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	0.30	1.0 x 10^{-6} Cancer Risk
CHLOROBENZENE	108-90-7	18	3.8	Non-cancer Risk: HI=0.2
CHLOROFORM	67-66-3	3.0	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	180	29	Non-cancer Risk: HI=0.2
DICHLOROBENZENE, 1,3- (m-DCB)	541-73-1	180	29	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	440	110	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	31	7.8	Non-cancer Risk: HI=0.2
DICHLOROETHYLENE, TRANS-1,2-	156-60-5	62	16	Non-cancer Risk: HI=0.2
DICHLOROMETHANE	75-09-2	530	150	Non-cancer Risk: HI=0.2
DICHLOROPROPANE, 1,2-	78-87-5	0.60	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	0.0050	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%
C5 to C8 ALIPHATICS	NOS	330	NA	90th%
C9 to C12 ALIPHATICS	NOS	220	NA	90th%
C9 to C10 AROMATICS	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	0.20	0.029	1.0 x 10^{-6} Cancer Risk
TETRACHLOROETHYLENE	127-18-4	4.1	0.60	90th%
TOLUENE	108-88-3	4400	1200	Non-cancer Risk: HI=0.2
TRICHLOROBENZENE, 1,2,4-	120-82-1	180	24	Non-cancer Risk: HI=0.2
TRICHLOROETHANE, 1,1,1-	71-55-6	4600	850	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**: All data reported to two significant figures, except in cases where the original study or analytical reporting limit was reported with one significant figure.*
NA – Not Available
NOS- Not Otherwise Specified

Revision Notes:
March 7, 2013 - revisions were made to make consistent the rounding methodology used for in the tables in Appendices I and II. These adjustments resulted in slight differences in some of the values in Table I.3.
February 22, 2013 - revisions were made to Table I.3 to reflect revised toxicity values and correct errors.

Table I.3 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	160	800			710	3500		
BENZENE	71-43-2	6.0	30	0.30	3.0	27	130	1.5	15
BROMODICHLOROMETHANE	75-27-4	14	70	0.13	1.3	62	310	0.65	6.5
BROMOFORM	75-25-2	14	70	2.1	21	62	310	10	100
BROMOMETHANE	74-83-9	1.0	5.0			4.4	22		
CARBON TETRACHLORIDE	56-23-5	20	100	0.39	3.9	88	440	1.9	19
CHLOROBENZENE	108-90-7	4.0	20			18	88		
CHLOROFORM	67-66-3	130	660	0.10	1.0	580	2900	0.50	5.0
DIBROMOCHLOROMETHANE	124-48-1	14	70	0.097	0.97	62	310	0.48	4.8
DICHLOROBENZENE, 1,2- (o-DCB)	95-50-1	40	200			180	880		
DICHLOROBENZENE, 1,3- (m-DCB)	541-73-1	40	200			180	880		
DICHLOROBENZENE, 1,4- (p-DCB)	106-46-7	160	800	0.34	3.4	710	3500	1.7	17
DICHLOROETHANE, 1,1-	75-34-3	100	500			440	2200		
DICHLOROETHANE, 1,2-	107-06-2	11	55	0.090	0.90	49	240	0.44	4.4
DICHLOROETHYLENE, 1,1-	75-35-4	40	200			180	880		
DICHLOROETHYLENE, CIS-1,2-	156-59-2	7.0	35			31	150		
DICHLOROETHYLENE, TRANS-1,2-	156-60-5	14	70			62	310		
DICHLOROMETHANE	75-09-2	120	600	230	2300	530	2700	1100	11000
DICHLOROPROPANE, 1,2-	78-87-5	0.80	4.0	0.12	1.2	3.5	18	0.60	6.0
DICHLOROPROPENE, 1,3-	542-75-6	4.0	20	0.58	5.8	18	88	2.9	29
DIOXANE, 1,4-	123-91-1	24	120	0.57	5.7	110	530	2.8	28
ETHYLBENZENE	100-41-4	200	1000			880	4400		
ETHYLENE DIBROMIDE	106-93-4	1.8	9.0	0.0078	0.08	8.0	40	0.038	0.38
HEXACHLOROBUTADIENE	87-68-3	0.14	0.70	0.11	1.1	0.62	3.1	0.52	5.2
METHYL ETHYL KETONE	78-93-3	1000	5000			4400	22000		
METHYL ISOBUTYL KETONE	108-10-1	600	3000			2700	13000		
METHYL TERT BUTYL ETHER	1634-04-4	600	3000			2700	13000		

Revision Notes:
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February 22, 2013 - revisions were made to Table I.3 to reflect revised toxicity values and correct errors.

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
METHYLNAPHTHALENE, 2-	91-57-6	10	50			44	220		
NAPHTHALENE	91-20-3	0.60	3.0			2.7	13		
C5 to C8 ALIPHATICS	NOS	40	200			180	880		
C9 to C12 ALIPHATICS	NOS	40	200			180	880		
C9 to C10 AROMATICS	NOS	10	50			44	220		
STYRENE	100-42-5	200	1000	4.1	41	880	4400	20	200
TETRACHLOROETHANE, 1,1,2,2-	79-34-5	19	93	0.040	0.40	82	410	0.20	2.0
TETRACHLOROETHYLENE	127-18-4	920	4600	0.23	2.3	4100	20000	1.2	11
TOLUENE	108-88-3	1000	5000			4400	22000		
TRICHLOROBENZENE, 1,2,4-	120-82-1	40	200			180	880		
TRICHLOROETHANE, 1,1,1-	71-55-6	1000	5200			4600	23000		
TRICHLOROETHANE, 1,1,2-	79-00-5	15	74	0.15	1.5	65	330	0.72	7.2
TRICHLOROETHYLENE	79-01-6	0.40	2.0	0.58	5.8	1.8	8.8	2.9	29
VINYL CHLORIDE	75-01-4	20	100	0.27	2.7	88	440	1.3	13
XYLENES (Mixed Isomers)	1330-20-7	20	100			88	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.

Appendix II

Sub-Slab Soil Gas Screening Values

Revision Notes:
March 7, 2013 - revisions were made to make consistent the rounding methodology used in the tables in Appendices I and II. In Appendix II, these adjustments resulted in slight differences in some of the values in Tables II.1 and II.2.
February 22, 2013- revisions were made to Tables II.1, and II.2 to reflect revised toxicity values and correct errors.

Appendix II

Sub-Slab Soil Gas Screening Values

II.1 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 Section 2.2.2 and a generic sub-slab soil gas-to-indoor air dilution factor presented in more detail below.

II.2 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 80^{th} percentile attenuation value was chosen as a reasonably conservative estimate of sub-slab soil gas attenuation. Choosing the 80^{th} 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.3 Use of the Sub-Slab Soil Gas Screening Values

As described in more detail in Section 2.2.3 of the Interim Final Guidance Document, 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.

Revision Notes:
March 7, 2013 - revisions were made to make consistent the rounding methodology used in the tables in Appendices I and II. These adjustments resulted in slight differences in some of the values in Table II.1.
February 22, 2013- revisions were made to Table II.1 to reflect revised toxicity values and correct errors.

Table II.1 Residential Sub-Slab Soil Gas Screening Values

Chemical	CAS	Residential Sub-Slab Soil Gas Screening Value	
		ug/m^3	ppbv
ACETONE	67-64-1	6400	2700
BENZENE	71-43-2	160	50
BROMODICHLOROMETHANE	75-27-4	9.1	1.4
BROMOFORM	75-25-2	150	14
BROMOMETHANE	74-83-9	42	11
CARBON TETRACHLORIDE	56-23-5	38	6.0
CHLOROBENZENE	108-90-7	160	35
CHLOROFORM	67-66-3	130	27
DIBROMOCHLOROMETHANE	124-48-1	6.8	0.80
DICHLOROBENZENE, 1,2- (o-DCB)	95-50-1	50	8.3
DICHLOROBENZENE, 1,3- (m-DCB)	541-73-1	42	7.0
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	8.4	1.8
DICHLOROPROPENE, 1,3-	542-75-6	41	9.0
DIOXANE, 1,4-	123-91-1	40	11
ETHYLBENZENE	100-41-4	520	120
ETHYLENE DIBROMIDE	106-93-4	0.550	0.072
HEXACHLOROBUTADIENE	87-68-3	7.7	0.72
METHYL ETHYL KETONE	78-93-3	840	290
METHYL ISOBUTYL KETONE	108-10-1	150	37
METHYL TERT BUTYL ETHER	1634-04-4	2700	750
METHYLNAPHTHALENE, 2-	91-57-6	560	96
NAPHTHALENE	91-20-3	42	8.0
C5 to C8 ALIPHATICS	NOS	4100	NA
C9 to C12 ALIPHATICS	NOS	4800	NA
C9 to C10 AROMATICS	NOS	700	NA
STYRENE	100-42-5	98	23
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	240	32
TRICHLOROETHANE, 1,1,1-	71-55-6	210	39
TRICHLOROETHANE, 1,1,2-	79-00-5	11	2.0
TRICHLOROETHYLENE	79-01-6	28	5.2
VINYL CHLORIDE	75-01-4	19	7.4
XYLENES (Mixed Isomers)	1330-20-7	1400	320

Note: All data reported to two significant figures.
NA – Not Available
NOS – Not Otherwise Specified

Revision Notes:
March 7, 2013 - revisions were made to make consistent the rounding methodology used in the tables in Appendices I and II. These adjustments resulted in slight differences in some of the values in Table II.2.
February 22, 2013- revisions were made to Table II.2 to reflect revised toxicity values and correct errors.

Table II. 2 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	770	250
BROMODICHLOROMETHANE	75-27-4	46	6.8
BROMOFORM	75-25-2	700	70
BROMOMETHANE	74-83-9	310	77
CARBON TETRACHLORIDE	56-23-5	130	21
CHLOROBENZENE	108-90-7	1300	270
CHLOROFORM	67-66-3	210	43
DIBROMOCHLOROMETHANE	124-48-1	34	3.9
DICHLOROBENZENE, 1,2- (o-DCB)	95-50-1	13000	2000
DICHLOROBENZENE, 1,3- (m-DCB)	541-73-1	13000	2000
DICHLOROBENZENE, 1,4- (p-DCB)	106-46-7	120	20
DICHLOROETHANE, 1,1-	75-34-3	31000	7700
DICHLOROETHANE, 1,2-	107-06-2	31	7.7
DICHLOROETHYLENE, 1,1-	75-35-4	13000	3200
DICHLOROETHYLENE, CIS-1,2-	156-59-2	2200	550
DICHLOROETHYLENE, TRANS-1,2-	156-60-5	4300	1100
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	55
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	46000
METHYL TERT BUTYL ETHER	1634-04-4	190000	52000
METHYLNAPHTHALENE, 2-	91-57-6	2400	410
NAPHTHALENE	91-20-3	190	36
C5 to C8 ALIPHATICS	NOS	23000	NA
C9 to C12 ALIPHATICS	NOS	15000	NA
C9 to C10 AROMATICS	NOS	3100	NA
STYRENE	100-42-5	1400	330
TETRACHLOROETHANE, 1,1,2,2-	79-34-5	14	2.0
TETRACHLOROETHYLENE	127-18-4	290	42
TOLUENE	108-88-3	310000	84000
TRICHLOROBENZENE, 1,2,4-	120-82-1	13000	1700
TRICHLOROETHANE, 1,1,1-	71-55-6	320000	60000
TRICHLOROETHANE, 1,1,2-	79-00-5	50	9.1
TRICHLOROETHYLENE	79-01-6	130	23
VINYL CHLORIDE	75-01-4	91	36
XYLENES (Mixed Isomers)	1330-20-7	6200	1400

Note: All data reported to two significant figures.
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-1 Introduction

Section 2.0 of the Massachusetts Department of Environmental Protection (MassDEP) DRAFT Interim Final Vapor Intrusion Guidance presents the concept of developing the Lines of Evidence to determine if the vapor intrusion pathway is complete and outlines how to characterize risk when vapor intrusion pathway is complete and the indoor air is impacted by volatile organic compounds (VOCs) released from a site. This Appendix provides a more detailed discussion of air sampling and analysis as part of vapor intrusion investigations and risk characterizations. 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-2 Sample Collection

III-2.1 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-2.2 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-2.3 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-3 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-3 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-2.4 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 Imminent Hazard evaluation should be collected in a timely way as soon as the potential Imminent Hazard 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, ventilation 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-3 Procedure for the Collection of Sub-Slab Soil Gas Samples

Installation of Sub-Slab 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.

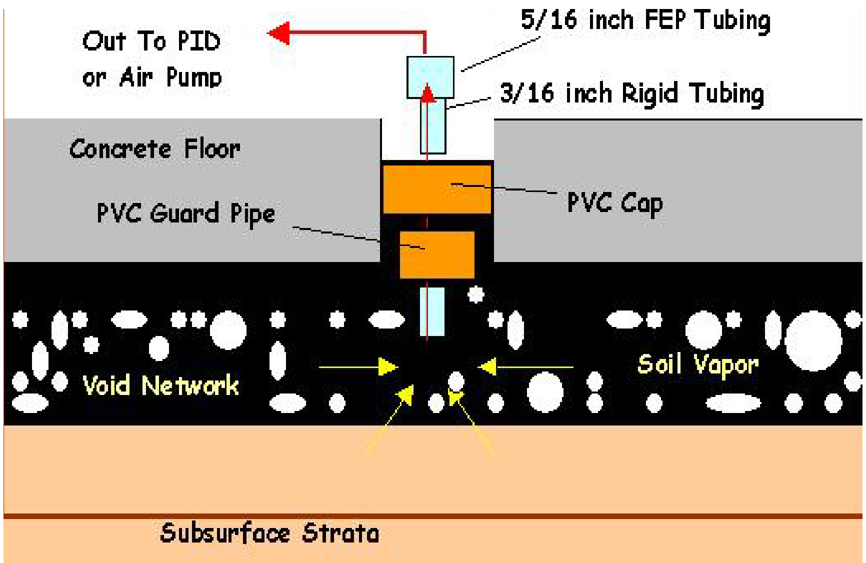

Figure III-1. Example of a Soil Gas Sampling Point

Sample Collection from the Sub-slab Point

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).

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-2.3 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-4 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 and APH 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/dep/cleanup/laws/qaqcdocs.htm.

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-5 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 in MassDEP's "MCP Representativeness and Data Usability Assessments" (MassDEP Policy #WSC-07-350).

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
and
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)[4]:

- 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.

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[4] 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: ( )____________

<u>List of Current Occupants</u>:

INITIALS	AGE	SEX (M/F)

<u>Building Construction Characteristics</u>:

(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	<u>Basement Floor</u>:	<u>Foundation Walls</u>:	<u>Moisture</u>:
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

<u>Heating and Ventilation System(s) Present</u>:

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):_______

<u>Sources of Chemical Contaminants</u>:

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		

<u>Outdoor Sources of Contamination</u>:

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?______________________________
____

<u>Weather Conditions During Sampling</u>:

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

Appendix IV

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

IV.1 Introduction

A sub-slab depressurization (SSD) system is a proven technique to eliminate or mitigate vapor intrusion into impacted structures (See Figure IV-1). 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-1: 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.2 Purpose/Objective of a 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.3 Description of a 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.4 Design and Installation of a 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.4.1 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. (see http://www.dranjer.ca/)

IV.4.2 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.4.3 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.4.4 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.4.5 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.4.6 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.

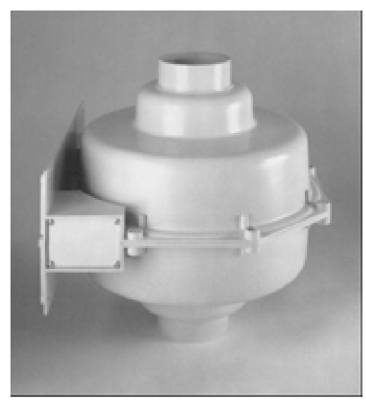

Figure IV-2: SSDS Fan

Generally, one of two types of units will be specified:

- **Low Pressure/High Flow** - The most common application, used at sites with relatively permeable 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-2). 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-3:
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-3). 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-4).

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.4.7 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-5).

Figure IV-4: Fan in Attic

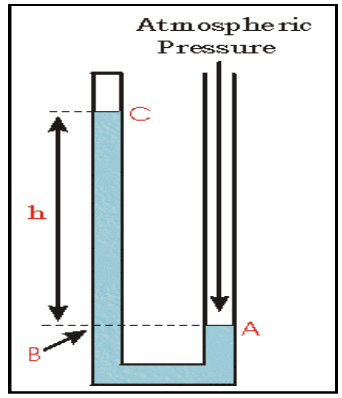

Figure IV-5: Manometer

IV.4.8 Backdrafting

Consideration should be given to the possible occurrence of a flue-gas backdrafting 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. Backdrafting 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 backdrafting 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 backdrafting. Extreme or unusual weather conditions need to be considered in evaluating data.

If a backdrafting 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.

IV4.9 Other Considerations

- The presence of a sump in a basement can provide a significant short-circuiting vehicle to the establishment of a subslab 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.5 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.5.1 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 entire slab. 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.

References

Bonnefous, Y.C., et. Al., *Field Study and Numerical Simulation of Subslab Ventilation Systems*, ES&T, 1992, 26, 1752-1759.

Crawshaw, D.A., and Crawshaw, G.K., "Migration of Elevated VOC Concentrations in Buildings Arising From Contaminated Groundwater", Proceedings of HMC, Hazardous Materials Research Institute, September, 1990.

DiGiulio, Dominic C., and Paul, Cynthia J., *Assessment of Vapor Intrusion in Homes Near the Raymark Superfund Site Using Basement and Sub-Slab Air Samples*, EPA/600/R-05/147, March 2006.

USEPA, "Radon Mitigation Standards", EPA 402-R-93-078, October 1993 (Rev April 1994).

Sub-slab Depressurization System Completion Report	Town: Address:

Section			
Personnel	Contractor Name & Address: Contact: Phone No.:		
	Project Manager Name:		
Dates	Date Project Started:	Date Project Completed:	Date of Completion Report:

Section	
Building Details	Use of Building: ☐ residential ☐ school ☐ daycare ☐ other:
	Foundation: ☐ poured concrete ☐ concrete block ☐ fieldstone ☐ other:
	Basement Type: ☐ full basement ☐ crawlspace ☐ slab-on-grade ☐ other:
	Basement/Lowest Level: ☐ concrete slab ☐ earthen floor/crawlspace ☐ other
	Concrete Slab/Floor Cracks: ☐ no cracks ☐ minimal ☐ moderate ☐ substantial
	Basement Drainage: ☐ no sump/drain ☐ sump with drain ☐ sump with pump ☐ other
Sealing	☐ None ☐ small cracks ☐ large cracks ☐ small area ☐ large area ☐ sump ☐ floor drains
	Materials: ☐ elastomeric sealant ☐ polyethylene sheeting ☐ grout ☐ concrete ☐ other Brand name of sealant(s):

Section			
Diagnostics	Negative Pressure (inches w.c.)		Sub-slab materials:
	Probe ID #	Probe ID #	Estimated Depth of groundwater below slab/floor: ☐ > 6 inches ☐ > 12 inches ☐ other/known:
System	Number Extraction Points:		# Permanent sub-slab probes: ☐ 2 ☐ other:
	Number of Fans:		Feet of PVC pipe used:
	Monitoring: ☐ manometer ☐ gauge ☐ alarm Range (inches w.c.):		
	Fan Make & Model:		

Section				
Startup	Date:	Negative Pressure (inches of W.C.)		
	☐ no problems noted ☐ problems encountered & fixed	Manometer/gauge	Probe #	Probe #
	Backdraft Evaluation	Appliances evaluated: ☐ furnace ☐ water heater ☐ other:		
		Result: ☐ OK; less than 5 Pascal depressurization ☐ other:		
	Acceptable Range Notated on System Manometer/Gauge:			

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:

Appendix V

Use of Activity and Use Limitations (AULs) to Address Future Buildings in Areas of Potential Vapor Intrusion and Existing Buildings Where Maintenance of Barriers/Use Restrictions are Warranted

Appendix V

Use of Activity and Use Limitations (AULs) to Address Future Buildings in Areas of Potential Vapor Intrusion and Existing Buildings Where Maintenance of Barriers/Use Restrictions are Warranted

V.1 Introduction

This Appendix supplements Section 4.7, and applies to those cases where parties are implementing an Activity and Use Limitation (AUL) to condition use or specify activities to protect against vapor intrusion into a structure. It applies to situations in which a party *elects* to implement an AUL to address future building construction (pursuant to 310 CMR 40.1012(3)), and to situations in which a party *must* implement an AUL to condition existing building use and maintenance where the AUL is an element of the Permanent Solution necessary for the maintenance of a condition of NSR (pursuant to 310 CMR 40.1012(1)).

Future Buildings – The approach outlined in Sections 4.7 of the Interim Final Guidance and V.2 of this Appendix for using an AUL to manage future construction to protect against vapor intrusion is provided as an option. Such an AUL can be used to prohibit the construction of future buildings, specify locations acceptable for future construction, or impose requirements on the construction to protect against vapor intrusion. Consistent with that guidance, MassDEP does not consider it warranted to use an AUL to condition future building construction in cases where groundwater contaminant levels are at or below GW-2 concentrations and there is no concern about the potential for VOCs remaining in soil to impact future buildings. Use of an AUL to condition future construction at a location that is not currently a GW-2 area (i.e., does not have an existing or planned building) is not required by the MCP.

If a party elects to implement an AUL to manage future construction, Section V.2 provides suggestions for the content of such AULs.

Existing Buildings – Section V.3 of this Appendix provides additional guidance on the use of an AUL where vapor intrusion has been found in an existing building during the course of response actions. As discussed in Section 2.3.2.2, AULs are required by the MCP in cases where mitigation measures such as vapor barriers or passive sub-slab venting systems are installed and necessary to maintain a Permanent Solution, or to limit the use of an existing building to commercial/industrial use where NSR has not been demonstrated for residential use, but can be supported for shorter exposure durations under commercial/industrial use of the building. AULs may also be useful to restrict use of an operating facility that uses VOCs that are the contaminants of concern at the disposal site when vapor intrusion cannot be ruled out.

V.2 AULs for Future Buildings

In cases where an AUL is implemented as part of a Response Action Outcome (RAO) to set requirements for future building construction, the AUL should specify the site conditions that warrant the AUL and obligations and conditions to be adhered to in the event that future building construction is undertaken at the site. In addition, if new construction of the building includes a vapor barrier and sub-slab depressurization or venting system (consistent with the approach presented in Section 4.7 of the Interim Final Vapor Intrusion Guidance), the presence, specifications and footprint of the vapor barrier and sub-slab depressurization/venting system, as well as any indoor air sampling and response action information must be documented consistent with the procedures for conducting response actions in an AUL area at 310 CMR 40.1067. The sections below describe in more detail the components of an AUL implemented to condition future building construction.

AUL Opinion - The narrative AUL Opinion (Exhibit C of the Notice of Activity and Use Limitation) should include the following, in cases where requirements are specified for future building construction in areas of potential vapor intrusion:

1. a description of the source of the disposal site, response actions taken to address the contamination, nature and extent of the contamination at the property (with respect to concentrations and locations in groundwater and soil, depth to groundwater, and direction of groundwater flow);

2. a description of the consistent and inconsistent uses of the property;

3. a description of the ongoing obligations and conditions that are necessary to maintain a condition of no significant risk; and

4. a readily understandable explanation (i.e., is understandable to someone who does not have specific knowledge of the MCP or contaminant behavior in the environment) of why adherence to the AUL is necessary to maintain a condition of no significant risk.

Where the AUL includes provisions to control vapor intrusion in future buildings, these components should include descriptions relevant to that pathway (i.e. the presence of volatile organic compounds in various site media). The description of the need for an AUL (Item 4. above) should specify the conditions that indicate that the potential for vapor intrusion exists, such as groundwater concentrations above GW-2 Standards or VOCs in soil. This section should contain a clear statement that "The presence of volatile organic compounds in groundwater and/or soil at the property poses the potential for vapor intrusion into buildings constructed at the disposal site. To guard again this potential, specific, building design and construction, and maintenance measures must be followed which include…"

Note, the narrative descriptions of items 2 and 3 above, as provided in the AUL Opinion, must be consistent with information contained in those respective sections of the Notice of Activity and Use Limitation Form 1075. Any discrepancy between the AUL Opinion and the form creates ambiguity as to what conditions govern the AUL and may result in the need to correct the AUL.

The remaining conditions in the AUL Opinion (i.e., the specific building design, construction and maintenance measures) depend on both the type of approach (e.g., no building, building with a specific design or systems to prevent vapor intrusion) the property owner elects to follow for future building construction to prevent vapor intrusion and the concentration of VOCs in groundwater at the property at the time the RAO is submitted. Using the approach outlined in Section 4.7 of the guidance, the conditions included in the AUL would depend on whether the concentration of VOCs are "elevated" or "high" as described in that section.

Consistent and Inconsistent Uses - The AUL Opinion and the AUL form (Form 1075 for the Notice of Activity and Use Limitation) require a listing of uses and activities that are consistent with the AUL Opinion and those that are inconsistent. Consistent uses are those uses or activities that can take place at the property without jeopardizing the maintenance of a condition of No Significant Risk. Conversely, inconsistent uses are uses or activities that have the potential for human exposure to contaminants at the property and would be inconsistent with maintaining a level of no significant risk.

In the case of a property where there is the potential for vapor intrusion into buildings constructed at the property, the consistent and inconsistent uses would be used to specify the protective features to be included in future buildings. More details on appropriate consistent and inconsistent uses are provided under specific future building scenarios in Table V-1.

Obligations and Conditions - The Obligations and Conditions section of the AUL (numbered Section 3 of Form 1075) would contain ongoing requirements for keeping the building features associated with preventing vapor intrusion intact, and any associated monitoring and/or maintenance to evaluate whether the features are effective. More details on appropriate obligations and conditions are provided under specific future building scenarios in Table V-1.

Appropriate AUL Conditions for Various Future Building Scenarios – As discussed in Section 4.7 of the Interim Final Vapor Intrusion Guidance, various management strategies can be used to condition future building construction to be protective of vapor intrusion. The strategies include:

- Limiting future building construction to locations outside of the AUL Area (areas upgradient or cross-gradient of the contamination;
- Limiting future building construction to buildings with an open-air ground level;

- Limiting future building construction to building with a ventilated parking garage on the ground level; or
- Conditioning future building construction to incorporate measures protective of vapor intrusion, including a vapor barrier and sub-slab depressurization (SSD) system, as outlined in Section 4.7 of the guidance and described in more detail below.

<u>Future Building Construction at Properties with "Elevated" concentrations of VOCs without Incorporation of Open-Air Structure or Ventilated Garage (as described in Section 4.7):</u>

In the case of properties with "elevated" concentrations of VOCs, MassDEP recommends property owners place conditions requiring the incorporation of a vapor barrier system and active sub-slab depressurization system into the building construction. In such cases, the AUL would specify these building construction requirements and the ongoing obligation to keep them intact and operational.

AUL Opinion – The AUL Opinion should provide a clear statement that the presence of VOCs in the groundwater of the property poses the potential for vapor intrusion into buildings constructed at the property. The AUL Opinion should also specify that to guard against this potential, all buildings shall be constructed with a vapor barrier system and active SSD system consistent with the minimum specifications [provide a description of the type and or thickness of the barrier and SSD system sufficient to ensure the installation of an effective high quality system].

Consistent and Inconsistent Uses – Consistent uses would include the construction of buildings that include a vapor barrier system and active sub-slab depressurization system that meet the specifications described in the AUL Opinion. Inconsistent Uses would include the construction of buildings that do not include a vapor barrier system and active SSD system that meets specification or activities that damage the integrity or operational effectiveness of the vapor barrier system and active sub-slab depressurization system.

Obligations and Conditions – Obligations and conditions would include keeping the vapor barrier system and active SSD system intact and operating continuously.

<u>Future Building Construction at Properties with "High" concentrations of VOCs without Incorporation of Open-Air Structure or Ventilated Garage (as described in Section 4.7):</u>

In the case of properties with "high" concentrations of VOCs, MassDEP recommends property owners place conditions requiring the incorporation of a vapor barrier system and active SSD system into the building construction. In such cases, the AUL would specify these building construction requirements and the ongoing requirement to keep them intact and operational. In addition, because construction in such cases is occurring at a location where relatively high concentrations of VOCs are present in groundwater, it is advisable to include an obligation to conduct post construction indoor air testing to determine whether vapor intrusion is occurring in the new building. This building should be conducted when the active SSD system is not operating.

AUL Opinion – The AUL Opinion should provide a clear statement that the presence of VOCs in the groundwater of the property poses the potential for vapor intrusion into buildings constructed at the property. MassDEP also recommends that the AUL Opinion also specify that to guard again this potential "(1) all buildings shall be constructed with a vapor barrier system and active SSD system consistent with the minimum specifications [provide a description of the type and or thickness of the barrier and SSD system sufficient to ensure the installation of an effective high quality system]; and (2) following building construction, the indoor air in the building shall be sampled while the active SSD system is shut off and analyzed for site related volatile organic compounds. This work shall be conducted under the supervision of a Licensed Site Professional."

Consistent and Inconsistent Uses – Consistent uses would include the construction of buildings that include a vapor barrier system and active SSD system that meet the specifications in the AUL Opinion. Inconsistent uses would include the construction of buildings that do not include a vapor barrier system and active SSD system that meet specified requirements or activities that damage the integrity or operational effectiveness of the vapor barrier system and active SSD.

Obligations and Conditions – Recommended language for Obligations and Conditions include:

i. Following building construction, the indoor air in the building shall be sampled while the active SSD is shut off and analyzed for site-related VOCs. This work shall be conducted under the supervision of a Licensed Site Professional (LSP). The presence of site-related VOCs in indoor air that are determined to be the result of vapor intrusion requires Notification to the MassDEP and subsequent response actions, as required, under M.G. L. chapter 21 E and the MCP; and
ii. Following the initial indoor air sampling and analysis that does not indicate the presence of site-related VOCs, indoor air shall be sampled and analyzed twice a year for a two year period. This work shall be conducted under the supervision of a LSP. The presence of site-related VOCs in indoor air that are determined to be the result of vapor intrusion requires Notification to the MassDEP and subsequent response actions, as required, under M.G.L. chapter 21 E and the MCP;

iii. The vapor barrier system shall be kept intact. The active SSD system shall be operated continuously, except during the indoor air sampling events specified in ii.

Table V-1 below summarizes the recommended AUL conditions for different future building construction scenarios where the concern is limited to VOCs remaining in groundwater. Similar approaches could be applied where the concern for vapor intrusion is related to VOCs remaining in soils.

V.3 AULs for Existing Buildings

AULs and Permanent Solutions - In cases where the achievement of a Permanent Solution is dependent on the maintenance of a vapor barrier or SSD 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 or system as a pathway elimination measure. An AUL in such cases must specify that the integrity of the barrier/system be maintained and that its effective be periodically monitored. Contingencies should be provided in the AUL for the repair of the barrier/system and re-evaluation of its effectiveness in the event of any future renovation/activity that has or has the potential to compromise the system.

An AUL can also be implemented as part of a Permanent Solution to limit the use of an existing building to commercial/industrial use where NSR has not been demonstrated for residential use, but can be supported for shorter exposure durations under commercial/industrial use of the building. 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.

In contrast to the discussion of AUL use for future building construction as optional, AUL use for existing buildings where it is an element of the Permanent Solution necessary for the maintenance of a condition of NSR, the implementation and adherence to the AUL is required by 310 CMR 40.1012(2)(b).

AULs and Operating Facilities that Use COCs of Concern

At an facility that uses VOCs in its operations (e.g., active dry cleaner, gasoline station) where an assessment of vapor intrusion cannot be successfully concluded given confounding sources in indoor air (and cannot otherwise be ruled out based on soil gas screening levels), an AUL may be an appropriate means of ensuring that the facility is not converted to another use without additional investigation of the potential for vapor intrusion. The AUL could be voluntarily implemented in such a case as part of a Temporary Solution pursuant to 310 CMR 40.1012(3)(g). It should be noted that the AUL would only be appropriate to address the 21E issues at the facility arising from contamination in the environment (i.e., soil or groundwater). Facility discharges that are operating outside of permitted levels or vapor infiltration from the facility to adjacent building tenants must be addressed separately and at the time they are identified.

Table V-1
Summary of AUL Conditions for Different Future Building Construction Scenarios

Example 1: Property Owner Elects to Prohibit Building in the AUL Area	
Concentration of VOCs in groundwater at the Time of RAO:	Elevated or High
AUL Narrative Opinion:	Provide a clear statement that the presence of VOCs in the groundwater in portions of the property poses the potential for vapor intrusion into buildings constructed within those portions. To guard again this potential, the construction of buildings is not allowed within the boundary of the AUL Area described in Exhibit A-1.
Inconsistent Uses/Consistent Uses:	Inconsistent Uses within the AUL Area in this case would include the construction of buildings for human occupancy, including residential use, use as a school or day care, office space, or manufacturing space.
Obligation and Conditions:	Since the AUL in this case restricts any building in the AUL Area, there are no obligations and conditions related to maintaining conditions to be specified.
Example 2: Property Owner Elects to Condition Future Building to Structure with an Open Air Structure on the Bottom Level	
Concentration of VOCs in groundwater at the Time of RAO:	Elevated *or* High
AUL Narrative Opinion:	Provide a clear statement that the presence of VOCs at the property poses the potential for vapor intrusion into buildings constructed at the disposal site. To guard again this potential, all buildings constructed within the AUL area must have an open air design on the bottom level that allows for the free flow of air between the exterior of the building and the bottom level.
Inconsistent Uses/Consistent Uses:	Consistent uses would include the construction of a building with an open air bottom level. Inconsistent Uses include the construction of building with an enclosed bottom level or the renovation of a building to enclose the bottom level.
Obligation and Conditions:	Obligations and conditions would be ensuring that the bottom level of the building remains as a structure open to the ambient air.
Example 3: Property Owner Elects to Condition Future Building to Structure with a Ventilated Parking Garage on the Bottom Level	
Concentration of VOCs in groundwater at the Time of RAO:	Elevated or High
AUL Narrative Opinion:	Provide a clear statement that the presence of VOCs at the property poses the potential for vapor intrusion into buildings constructed at the disposal site. To guard again this potential, all buildings constructed within the AUL area must have a ventilated parking garage on the bottom level that meets building code and ensures the venting of vapors that may be drawn into the garage from the subsurface environment.
Inconsistent Uses/Consistent Uses:	Consistent uses would include the construction of a building with a ventilated parking garage on the bottom level. Inconsistent Uses include the construction of building without parking garage on the bottom level, renovation of a building to convert the garage, or failure to operate the ventilation system as required to properly ventilate the garage.
Obligation and Conditions:	Obligations and conditions would be ensuring that the bottom level of the building remains a garage with a properly.

Table V-1 (continued)
Summary of AUL Conditions for Different Future Building Construction Scenarios

Example 4: Existing Building with a Vapor Barrier and or SSD System that is necessary for maintaining a Permanent Solution	
AUL Narrative Opinion:	Provide a clear statement that the presence of VOCs at the property poses the potential for vapor intrusion into the building. To guard again this potential, a vapor barrier and/or SSD system has been installed to protect against vapor intrusion. The vapor barrier and/or SSD system must be kept intact to ensure that it remains protective.
Inconsistent Uses/Consistent Uses:	Consistent uses would include use of the building that the construction of buildings that include a vapor barrier system and active SSD system that meet the minimum specifications provided in the AUL Opinion. Inconsistent Uses would include the construction of buildings that do not include a vapor barrier system and SSD system that meet minimum specifications or activities that damage the integrity or operational effectiveness of the vapor barrier system and active SSD.
Obligation and Conditions:	Obligations and conditions would include keeping the vapor barrier system and active SSD system intact and operating continuously.
Example 5: Property Owner Builds in an Area of "High" Groundwater Contamination with a Vapor Barrier and SSD System	
Concentration of VOCs in groundwater at the Time of RAO:	High
Concentration of VOCs in groundwater at the Time of RAO:	Provide a clear statement that the presence of VOCs at the property poses the potential for vapor intrusion into buildings constructed at the disposal site. To guard again this potential (1) all buildings shall be constructed with a vapor barrier system and active SSD system consistent with the minimum specifications [provided in the AUL Opinion] to ensure the installation of an effective high quality system; and (2) following building construction, the indoor air in the building shall be sampled while the active SSD system is shut off and analyzed for site related volatile organic compounds. This work shall be conducted under the supervision of a LSP.
Concentration of VOCs in groundwater at the Time of RAO:	Consistent uses would include the construction of buildings that include a vapor barrier system and active SSD system that meet the minimum specifications provided in the AUL Opinion. Inconsistent uses would include the construction of buildings that do not include a vapor barrier system and active SSD system that meet specifications or activities that damage the integrity or operational effectiveness of the vapor barrier system and active SSD system.
Concentration of VOCs in groundwater at the Time of RAO:	i. Following building construction, the indoor air in the building shall be sampled while the active SSD system is shut off and analyzed for site-related volatile organic compounds. This work shall be conducted under the supervision of a LSP. The presence of site-related VOCs in indoor air that are determined to be the result of vapor intrusion shall result in notification of the Massachusetts Department of Environmental Protection and subsequent response actions, as required, under M.G. L. chapter 21 E and the Massachusetts Contingency Plan; ii Following the initial indoor air sampling and analysis that does not indicate the presence of site-related VOCs, indoor air shall be sampled and analyzed twice a year for a two year period. This work shall be conducted under the supervision of a LSP. The presence of site-related VOCs in indoor air that are determined to be the result of vapor intrusion shall result in notification of the Massachusetts Department of Environmental Protection and subsequent response actions, as required, under M.G.L. chapter 21 E and the MCP; and iii The vapor barrier system shall be kept intact. The active SSD system shall be operated continuously, except during the indoor air sampling events specified in ii.