This document references Chapters and Sections from the ITRC Vapor Intrusion Technical and Regulatory Guidance, and Fact Sheets and Technology Information Sheets from the ITRC Vapor Intrusion Toolkit, published January 2026. These resources can be accessed at: **https://itrcweb.org/vapor-intrusion-toolkit**.

MULTIPLE LINES OF EVIDENCE FACT SHEET

Questions related to vapor intrusion (VI) and VI management decisions should ultimately be based upon multiple lines of evidence (MLE) rather than upon a single line of evidence (LOE). This is especially important given that regulator-defined screening levels are often close to background levels for many compounds and that spatial and temporal variability and sampling bias are often present. This fact sheet provides definitions and explains how to apply an MLE approach to make decisions about a building or site.

Definitions

What is a line of evidence? For a VI project, an LOE is a piece of information that is used to help create an understanding of the site (or building) and answer a question or questions related to VI at the building or a management decision related to VI. An LOE may also incorporate information gained as part of a site/building's VI risk assessment. An LOE could be a piece of data (e.g., a groundwater concentration at a well or indoor air data in a building) or the result of an assessment (e.g., the result of a building survey, the results of evaluating time series data, or the results from evaluating data from a flux chamber). Any piece of information that improves understanding of the potential pathway, the risk to receptor from VI, and management of the site can be thought of as an LOE.

What does a multiple lines of evidence approach mean? MLE, also known as "using an MLE approach," is, at its core, applying the scientific method to answer a question. This type of approach is used in many types of science and in everyday life as well as for VI projects. Think about the types of information used to decide what restaurant you want to go to (e.g., how far is it, does it have the desired cuisine, is it crowded); that is an example of using the MLE approach. The MLE approach is gathering more than one LOE to evaluate and weigh different types of data and information to answer, in this case, a VI question or support a VI management decision.

Introduction

When evaluating data at various stages of the VI project life cycle, the practitioner is typically presented with one or more questions they are trying to answer. Information gathered about the site or building and data gathered from the site or building help formulate and support answers to those questions. The data or site information used to support answers to relevant questions are the MLE as defined above. This fact sheet defines the roles of LOE and MLE as they relate to VI and the VI project life cycle.

The relationship between the subsurface (e.g., geology, utilities, groundwater, soil, soil vapor, etc.), the air (e.g., weather, indoor air, outdoor air), the built environment, and the VI pathway is complex. Management decisions related to VI typically warrant consideration from more than just a single fact, procedure, or data point. MLE is a data evaluation tool that helps the practitioner evaluate and weigh different types of data, different data interpretation methods (e.g., results of modeling, spatial associations, chemical ratio analysis, etc.), and site information to make site management decisions. Note that various methods for evaluating data are described more fully in **Chapter 8: Data Evaluation and Vapor Intrusion Risk Assessment** as well as several fact sheets noted in the **MLE in Screening and Data Evaluation for a Building** section of this fact sheet.

Commonly, MLE are used to develop answers to the following questions:

- Whether VI is likely to be occurring

- Whether VI is likely to occur in the future
- Whether background indoor air sources are present and responsible for vapor-forming chemicals (VFCs) in indoor air versus the VI pathway

MLE can be used at all stages in the project life cycle such as during preliminary screening, during investigation planning, during a risk evaluation, and during mitigation performance assessment (see the **Examples of MLE Use** section of this fact sheet). When applying MLE at a site or building, regulatory frameworks of individual states should be considered. Some states may limit use of a specific LOE or may provide guidance on the weight given to one LOE over another.

MLE and Uncertainty

Uncertainty can be thought of as an additional consideration on top of each LOE used to answer the targeted question. Uncertainty can arise from a variety of factors including spatial or temporal variability (see **Section 7.8.2: Common Vapor Intrusion Investigation Limitations**). The higher the certainty in an LOE, the potentially greater impact (and possibly greater weight) that LOE may have on a site management decision. The data from each LOE, the certainty of that information, and the number of LOEs (especially the number of LOEs that point to the same conclusion) will need to be considered and will influence the certainty in the decision-making process. Regardless of the number of LOEs used, there will likely be some amount of uncertainty and not all LOEs will always point to the same answer for every question. Thus, decisions should be made in consultation with regulatory agencies and/or other stakeholders and based on what professional judgment deems to be reasonable and logical for the specific site.

Lines of Evidence and the Conceptual Site Model

Some LOEs are the same as components of the conceptual site model (CSM) such as site history / land use, building use/conditions, and subsurface soil conditions, etc. The difference is the way in which those components are being used and the questions you are trying to answer. Site information is used in the VI CSM to create a written and/or visual representation of source, pathways, and receptors likely to be affected by VI. Site information is used as LOEs when supporting an answer to a site critical question such as, Is VI occurring at the targeted building? or Are background indoor air sources influencing indoor air at the targeted building? Components of the CSM that may also act as an LOE are likely information that, through evaluation of the site, stand out as key or important pieces of information. For example, building characteristics are a component of the CSM and tend to be more important as an LOE for a site than the CSM component nonaqueous-phase liquid when trying to answer a question regarding preferential pathways.

Components of the CSM may also act in conjunction with LOEs as they may increase or decrease certainty when evaluating MLE. For example, site history, a component of the CSM as described in **Chapter 4: Conceptual Site Model**, could be used to increase certainty in the VI evaluation if the site history is known and detailed. If there are large knowledge gaps and the site history is generally unknown, it may decrease certainty in the VI evaluation. More information on the development of a CSM can be found in **Chapter 4: Conceptual Site Model**.

MLE and Community Engagement

Practitioners need to communicate in plain language to the people in the community regarding VI assessment and recommended actions based on data and other information. Similarly, decisions following stakeholder input need to be communicated. See **Chapter 3: Community Engagement** for more information on why and how to engage with stakeholders and those who own, live, work, or otherwise occupy buildings potentially impacted by VI.

Community stakeholders may be reassured to know that MLE were used for site or building management decisions. Communications should stress the variety of environmental media that may have been sampled and the variety of site-specific evaluations completed.

Examples of MLE Use

The MLE approach is used either formally or informally in many stages of a VI project. Below are ways in which gathering LOEs can be helpful in each VI project stage.

- **Screening** (Chapter 5: Site Screening)—When conducting a preliminary screen or a site screening, MLE can help build the evidence used to decide whether the building can be screened out or in for further VI assessment.
- **CSM** (Chapter 4: Conceptual Site Model)—The components of the CSM may be considered LOEs and can help to determine whether VI is occurring or is likely to occur now or in the future. LOEs may help determine whether you have gaps in your CSM that need to be filled before further evaluation can proceed.
- **Site investigation planning, and sampling** (Chapter 7: Sampling and Analysis)—When planning an investigation, MLE are used to help determine where, when, and how many samples to collect or other evaluations to perform to further develop the site CSM or further evaluate the VI pathway. For example, you may use building size, condition, use, foundation type, and site history as the LOEs to determine where to collect sub-slab soil vapor samples. MLE and the site CSM will help determine what VFCs you are sampling for, what media needs to be sampled, and the reason for your sampling (e.g., for site characterization, plume delineation, and/or risk assessment).
- **Data evaluation and VI risk assessment** (Chapter 8: Data Evaluation and Vapor Intrusion Risk Assessment)—MLE are used most commonly at this stage of a VI project. LOEs will be the pieces of information that are used to determine whether VI is or is likely to occur now or in the future. MLE can also be used in other ways such as to provide evidence that a site may have a VI preferential pathway (VIPP) (see the **Vapor Intrusion Preferential Pathways Fact Sheet**), to compile evidence that there is a background indoor air source influencing or causing impacts to indoor air (see the **Background Sources to Indoor Air Fact Sheet**), or to provide the evidence needed to develop and use site-specific attenuation factors (AFs) (see the **Attenuation Factors Fact Sheet** and the **MLE in Vapor Intrusion Risk Assessment** section in this fact sheet.). MLE also provide documentation used to show that a building does not have a VI concern now or in the future and no additional assessment or investigation is needed (see the **VI Completion/Closeout** bullet below). For risk evaluation, MLE may be used in conjunction with the output of the risk evaluation to determine what, if anything, needs to be done to manage VI risk. MLE and risk evaluation are discussed in more detail below (**MLE in Vapor Intrusion Risk Assessment**).
- **VI Mitigation** (Chapter 10: Vapor Intrusion Mitigation)—If VI is determined to be present at a building (or potentially present in the future), MLE can be used in several ways. MLE may support the position to mitigate or not. If mitigation is chosen, MLE can be used to support the decision for a particular type of mitigation. For example, a passive mitigation system may be chosen over an active mitigation system for a targeted building using the LOEs that groundwater impacts are limited, no shallow soil source is present, soil vapor impacts are limited, the site is zoned commercial, and a new building will be installed allowing for control over how and what is installed under the building. MLE can also be used to support a VI mitigation system (VIMS) that is functioning as designed. For example, the LOEs that a system is operating to design objectives would be that a visual inspection shows the system in good working condition, flow rates were recorded similar to commissioning conditions, vacuum

across the floor met the minimum differential pressure for the design, and indoor air concentrations were below a set threshold.

- **VI Completion/Closeout** (Chapter 11: Vapor Intrusion Component Determination, Exit Points, and Closure and Vapor Intrusion Mitigation System Curtailment and Shutdown Fact Sheet)—MLE can be used to support the conclusion that a site/building can be considered completed or closed out for the potential for VI. If VI or the potential for VI was found at a site/building, and a VIMS had been implemented, MLE can also be used to support the decision that a VIMS is no longer needed to mitigate the VI pathway, a VIMS can be scaled back, or that a VIMS can be shut down and decommissioned or transitioned to other purposes.

In addition to the above, MLE may also be helpful to regulators and practitioners when evaluating information across several sites or buildings when looking to help define information that will help create rankings for sites. This may help prioritize sites or buildings for further evaluation when there are limited resources (sometimes referred to as triage).

What are Typical Lines of Evidence?

Table 3 at the end of this fact sheet lists LOEs that may be useful in answering VI-related questions about a site or making site management decisions. The table is not listed in any particular order; however, some information that tends to be understood first as part of the VI CSM development are listed at the top of the table. Because each site is different and the questions to be answered are different, it is important to consider which LOEs will be most helpful for the site in question, keeping in mind that this may not always be the same list for each site and may include LOEs from one or more categories in the table. The table includes a short description of the LOEs, how they are helpful in a VI assessment, and where to locate more information in the ITRC VI guidance document.

The objective of the table is to highlight LOEs that are typically used for VI projects; however, not all LOEs will be used at each site. It is common for practitioners to select a subset of LOEs that are most applicable to site-specific conditions and ones that help to answer the questions being asked and/or to fit into a state's regulatory framework. Site-specific conditions, the site CSM, and the question being asked will help to determine the relative importance of each LOE. The use of many LOEs may not be required if only a few, or even one LOE, provides clear evidence to answer the targeted question or support management decisions. Often a list of LOEs is similar to lists developed to discuss the advantages and disadvantages of various sampling and analytical techniques. Chapter 7: Sampling and Analysis (Section 7.8 Advantages and Disadvantages of Various Investigation Strategies) provides a list of advantages and disadvantages of various investigative strategies. Other publications also exist that describe the use of MLE and list various LOEs or investigation technologies (e.g., USDOD 2019).

MLE in the Project Life Cycle

As noted in this fact sheet, MLE can be used in many ways throughout a VI project life cycle. It is the process of supporting interpretations made about a site or building or supporting VI management decisions proposed for a site or building. Additional detail is provided in this section on three of the traditionally most common ways that MLE are used which are (1) to make interpretations about whether VI is or is not occurring at a building, (2) to evaluate whether there are background indoor air sources, and (3) to evaluate the presence/importance of a VIPP. This is not an exhaustive list, and the MLE approach is also important when considering other questions during the data evaluation process.

MLE in Screening and Data Evaluation for a Building

Determining whether VI is likely occurring at a target building is one of the most common ways to incorporate MLE into a VI project. MLE are used initially in the site screening process for a site, and MLE for this process are discussed in **Chapter 5: Site Screening**. If a site/building needs additional evaluation beyond screening, MLE are incorporated into this more comprehensive evaluation. Multiple questions could be asked to evaluate the VI pathway for a building, including determining whether VI is occurring, determining whether VI is likely to occur in the future, determining whether VI is occurring above an acceptable risk threshold, or determining whether anything needs to be done to mitigate the VI pathway. Each question may need to be evaluated separately and may use different LOEs.

MLE includes interpretation of data and CSM components that, taken together, support an evaluation of VI. There are several methods for interpretating data that may include, among others, evaluating concentration data (e.g., soil vapor, indoor air, outdoor air data, etc.) and evaluating other building data (e.g., data from a heating, ventilation, and air conditioning [HVAC] evaluation, results from a chemical inventory, vapor pathway identification, etc.).

Some simple examples of how MLE may be used in a VI evaluation, or in a risk interpretation if a risk assessment is done, could include the following:

- VFCs are present in groundwater and/or soil vapor so a VI evaluation is performed. The soil vapor concentrations are found to be low (e.g., below an applicable screening level), and the VFCs are not present in indoor air. These data may present LOEs indicating that, although the chemical is present in soil vapor, VI is not likely occurring.
- VFCs are present in soil vapor and indoor air so a VI evaluation is performed. Constituent ratios are reviewed between VFCs found in soil vapor and VFCs found in indoor air, and the results are not similar (for example, trichloroethylene or trichloroethene [TCE] is higher in concentration than tetrachloroethene (PCE, also called perchloroethene and tetrachloroethylene) in the soil vapor but in indoor air PCE concentrations are much higher than TCE concentrations). This LOE (constituent ratios) may point to VFCs in indoor air due to a background source and not VI. This LOE may be augmented by other LOEs such as AFs by chemical and data from a building survey and chemical inventory.

Methods for data collection and then evaluation and interpretation are detailed throughout this guidance document. More information can be found in the following chapters and fact sheets:

- **Chapter 7: Sampling and Analysis**
- **Chapter 8: Data Evaluation and Vapor Intrusion Risk Assessment**
- **Chapter 8: Data Evaluation and Vapor Intrusion Risk Assessment, Section 8.2.2.3: Use Multiple Lines of Evidence**
- **Approaches for Vapor-Forming Chemical Source Determination Fact Sheet**
- **Attenuation Factors Fact Sheet**
- **Background Sources to Indoor Air Fact Sheet**
- **Building Characteristics Fact Sheet**
- **Flux Chamber and Other Flux Measurement Devices Fact Sheet**
- **General Concepts of Mass-Flux-Based Screening Fact Sheet**

- High-Volume Sampling Fact Sheet
- Pressure Monitoring and Building Pressure Control Fact Sheet
- Real-Time Monitoring Fact Sheet
- Screening Levels Fact Sheet
- Tracers for Determination of Attenuation Factors and Ventilation Rates Fact Sheet

Example Scenario #1 presented below illustrates the use of the MLE approach in determining whether VI is occurring at a building based on available site and building data and information.

MLE to Evaluate Indoor Air due to Background Sources

MLE are commonly used to help understand the potential for VI as well as the potential that other sources (i.e., background sources) are present and causing impacts to indoor air that are not the result of VI. Multiple sources of chemicals may be affecting the overall quality of the indoor air but may not be associated with the investigated chemical release, confounding the interpretation of indoor air sample results and the evaluation of VI. Sources in outdoor air may be influencing or impacting indoor air. Background sources may be from building materials, heating/cooling energy sources, residual volatile components of stored items, household activities (cooking/cleaning), consumer products used in the building, or background contaminants from outdoor air. Source determination of measured chemicals in indoor air can become a relatively complex and difficult task. For more information on indoor air impacted by background sources and data evaluation regarding background source sampling and data evaluation approaches please see the Background Sources to Indoor Air Fact Sheet as well as Chapter 7: Sampling and Analysis, Section 7.8.2.3 Background Sources, the Approaches to Vapor-Forming Chemical Source Determination Fact Sheet, and Chapter 8: Data Evaluation and Vapor Intrusion Risk Assessment, and Section 8.2.2 Key Data Evaluation Steps.

When volatile chemicals with multiple potential sources are measured in indoor air, it may be helpful to gather MLE to support a site management decision either to include or exclude certain chemicals from further evaluation. In addition, MLE could be used to exclude certain chemicals from the risk assessment, if being performed, as the risk assessment may be only applicable to exposure to those VFCs that are a result of VI. See Section 8.5.2 and Section 8.6 of Chapter 8: Data Evaluation and Vapor Intrusion Risk Assessment for additional information on assessing risk with the presence of background indoor air sources.

If it can be demonstrated through the MLE approach that an indoor air concentration, and in particular an indoor air concentration above a threshold, is not derived from a subsurface source, no VI management may be warranted because the indoor air concentrations are due to background source(s). The more evidence gathered to support such a conclusion, the stronger the justification for the resulting decision. In some cases, this may include chemical testing to confirm the indoor source. Site-specific decisions should be made as to the number and types of information employed.

Example Scenario #2 below illustrates the use of the MLE approach in determining whether VFCs detected in indoor air are due to background sources. This example has been simplified to highlight a targeted MLE approach; therefore, not all site data or VI CSM components available are shown.

MLE to Evaluate the Presence of Vapor Intrusion Preferential Pathways

Preferential pathways, as a general term, are mentioned in many state guidance documents. What is considered a preferential pathway and the relative importance of its contribution to VI, however, can vary.

(Eklund et al. 2024). The **Vapor Intrusion Preferential Pathways Fact Sheet** includes various terms used to describe and differentiate among VIPPs, other normal vapor transport pathways, and vapor entry points. An example scenario on how MLE are used to help evaluate the presence of a VIPP is included in the **Vapor Intrusion Preferential Pathways Fact Sheet**.

MLE in Vapor Intrusion Risk Assessment

The process of evaluating data at a given site to understand the VI pathway and the potential risks associated with VI may in some states be completed informally and not as a prescriptive or formal risk assessment. In some states and at the federal level, however, the data evaluation process is driven by or heavily influenced by a more formal VI risk assessment. In these cases, the risk assessment process is used to understand relevant receptor exposures, current known media concentrations (e.g., groundwater, soil vapor, indoor air, etc.), and VFC toxicity to make an assessment of potential VI risk.

In the process of evaluating the VI pathway and assessing risk, MLE would most often be incorporated in the initial steps of a risk assessment (e.g., to identify which VFCs to select as chemicals of potential concern, or COPCs) and/or after the risk calculations have been completed to interpret the results of the risk assessment. One nuance to the evaluation of MLE for risk assessment is that it is most often chemical specific. So rather than answering a question such as, Is the VI pathway complete?" (such as presented in example Scenario #1, below), the MLE evaluation as part of the risk assessment could be used to answer the question, Is this specific chemical likely to be present due to the VI? Data evaluation and VI risk assessment are discussed in further detail in **Chapter 8: Data Evaluation and Vapor Intrusion Risk Assessment**.

The MLE approach is most often applied at two points in the VI risk assessment process: (1) COPC selection and (2) VI risk interpretation.

COPC selection refers to the selection of chemicals to be carried through for quantitative risk evaluation. COPC screening is most often performed by comparing maximum detected concentrations to available screening levels, where chemicals detected below the screening level would not be retained as COPCs. LOEs that may typically be considered in COPC selection for risk assessment include but are not limited to the following:

- Presence of and concentrations in groundwater and/or soil
- Presence of and concentrations in soil vapor, outdoor air, and/or indoor air
- Comparison of media concentrations to applicable screening levels
- Chemical concentration ratios for soil vapor to indoor air (i.e., AFs or constituent ratios)
- Comparison of AFs by chemical
- Building surveys and chemical inventories

Some examples of how MLE could be applied to exclude VFCs from being COPCs include but are not limited to the following:

- VFC is not detected in soil and/or groundwater.
- VFC is not detected in soil vapor.
- VFC is detected in the medium at a concentration below an applicable VI-based screening level.

- The ratio of two chemicals in indoor air appears inconsistent with the ratio of the same two chemicals in soil vapor, indicating a potential indoor air source rather than VI. Additional information on AF calculations can be found in the **Attenuation Factors Fact Sheet** and **Background Sources to Indoor Air Fact Sheet**.

COPC screening in a risk assessment is generally designed to be conservative, to avoid eliminating chemicals as COPC that are site-related for VI. This approach can therefore lead to the potential for chemicals to be carried through the risk assessment and calculation process because they technically meet the COPC selection criteria, but, in the end, are not due to VI. As such, another point where MLE can be used in the risk process is at the outcome of the risk assessment when the risk assessment is interpreted to provide context to the results and evaluate whether the risks observed may be due to the VI pathway. This is done using the result of the risk assessment in the context of other site data (e.g., information from the VI CSM, source information, vapor pathway identification, etc.). Using MLE at the risk interpretation stage of the project is similar to using MLE during screening and data evaluation for a building, which is discussed above.

What Does an MLE Approach Look Like?

The following section helps to convey the concept of the MLE approach by stepping through what an MLE approach may look like when applied to the evaluation of the VI pathway for a building. When applied in a real-world setting, this process may not occur in such a deliberate, stepwise fashion as outlined below and instead may be more fluid. The steps below, however, have been included to illustrate the thought process and may be one way in which MLE can be applied to draw conclusions about a site or building to make a VI management decision.

Step 1: Choose a question you would like to answer.

- The question will be highly dependent on the current stage of the VI project. Examples are provided below:
    - If a project is in the data evaluation stage, typical questions to ask, among others, would be, Do my data suggest that VI is likely occurring? Do my data suggest that VI is likely to occur in the future? or Is an indoor air exceedance due to an indoor air background source?
    - If a risk assessment is being conducted a common question may be, Should this VFC be included as a COPC in the risk evaluation?
    - If the project is in the VI mitigation stage, common questions to ask may be, Is my system operating as designed? or Did the solution meet the objectives?
- The questions are easiest to formulate if they are yes/no questions versus open-ended questions. For example, Is VI likely occurring? is a clearer question on which to apply MLE than, What is the data telling me about my site? Yes/no questions are not a requirement of using the MLE approach. Any question where multiple pieces of data are used to support an answer would apply. Some examples of questions that are not yes/no but could work with the MLE approach include the following: What is the indoor air source? Where are VFCs entering the building? or What are the options for this building to reduce VFC concentrations in indoor air to below risk thresholds?

Step 2: Pull applicable data, site information, and data interpretation as LOEs to support the answer to your question.

- Data often includes some form of concentration data from one or more media. It is not typically necessary to investigate all media or collect concentration data from all media to gather sufficient LOEs for a VI project.

- Data interpretation listed in Step 2 refers to LOEs that are evaluations performed on data (e.g., spatial analysis of data, ratio analysis of data, etc.) or can refer to other types of information gathered, like interpreting the results of the building's chemical inventory or the results from building pressure control tests.
- Focus only on the LOEs needed.
- A list of LOEs can be found in Table 1 at the end of Step 3 in the MLE Approach for Scenario #1. The table contains descriptions of each listed LOE and also links to other sections of this document where more details (e.g., how to sample for it, or how to interpret the data) can be found.

Step 3: Take each LOE and determine whether it supports an answer to the target question or whether the data are inconclusive. The answers may be, for example, yes, no, supporting, or neutral.

- It is helpful to not only note how the data supports the answer to the target question but also list why this conclusion was made.
- For this fact sheet, the following terms are used to apply to each LOE as it relates to the target question:
    - **Yes/No**—Standard answers that indicate the answer to the question is either yes or no.
    - **Supporting/Not Supporting**—This term is used to indicate that the specific LOE provides indirect support (or not) of the question being asked but cannot be used to provide a clear yes/no. An LOE that is deemed "supporting" may mean that an additional data interpretation method may be needed as an LOE to make a determination. A good example of this is the LOE of sub-slab vapor concentrations. The existence of concentrations of VFCs in sub-slab vapor may be a supporting LOE to determine that there is VI or there is likely a VI pathway to a building, but it would take the additional assessment of comparing those sub-slab vapor concentrations to a screening level (i.e., another LOE) to provide more information.
    - **Neutral**—This term is used in this fact sheet to indicate an LOE that may help inform other LOEs, be used in combination with other LOEs, or may help develop your VI CSM but does not directly answer the targeted question. For example, outdoor air concentrations may be a neutral LOE. These data help inform about the environment around the targeted building or may be used in combination with indoor air or other data to make a determination but do not provide definitive information on their own.

Step 4: Evaluate the uncertainty of each LOE and the relative degree of uncertainty.

- It is important to note certainty/uncertainty on the data or on the evaluation results and whether some of the LOEs affect the certainty of other LOEs. More weight may be given to an LOE with higher certainty.
- There could be some uncertainty associated with the MLE process, regardless of the number of LOEs considered.
- This step is meant to be general and qualitative. It may not be possible to quantify an exact level of uncertainty. Data uncertainty being low or high can be influenced by the VI CSM. For example, if the VI CSM developed indicates that the off-site groundwater plume is stable or decreasing, this would increase your certainty in, for example, the groundwater data and the interpretation that groundwater concentrations are not going to increase significantly under the target building.
- Uncertainty can also be decreased if more than one LOE supports the same conclusion.
- Uncertainty and weight of each LOE may go hand in hand, and Step 4 may often be combined with Step 5 below.

Step 5: Evaluate the weighted importance of each LOE.

- This process can be subjective and may be dependent on state guidance or site-specific conditions. In some states, the more standard the data, (e.g., soil vapor and indoor air data compared to screening levels), the more relative weight they may carry. For example, in some states (e.g., Wisconsin, Minnesota, Michigan) more weight is applied to sub-slab vapor data than to indoor air data.
- The importance or weight of a particular LOE may also depend on the question that you are looking to answer. For example, if looking to understand background indoor air sources, then the concentrations of VFCs in groundwater may not carry as much weight as the evaluation of sub-slab vapor concentrations compared to indoor air concentrations.

Step 6: Summarize results of the MLE and evaluate.

- Using the above steps, an answer to the targeted question can be formed based on the findings from each LOE and professional judgment. It should be noted that not all LOEs will point to the same answer, and some LOEs may indicate opposite answers. This is where uncertainty, weight, professional judgment, site VI CSM, and state-specific guidance will be used to help interpret the data and form site management decisions.

Example Scenario #1: MLE in Screening and Data Evaluation for a Building

The following scenario includes data collected as part of the Environmental Security Technology Certification Program (ESTCP) Project ER-201119 (Beckley et al. 2013). This example has been simplified to highlight a targeted MLE approach; therefore, not all data or VI CSM components available from the project or from the example building were used in this example scenario.

Example Building Summary – This scenario uses the Joint Base Lewis-McChord Logistics Center (one building) located on the Lewis-McChord Joint Base near Tacoma, WA. General site/building information (Beckley et al. 2013) includes the following:

- Shallow stratigraphy consists of alternating glacial and nonglacial sediments.
- Depth to water is approximately 20–30 feet (ft) below ground surface.
- Chlorinated VFCs are present in shallow groundwater as a result of historical releases from former disposal areas located upgradient of the example building.
- The following indicator VFCs are used: TCE, cis-1,2-DCE, PCE, 1,1,1-TCA, and vinyl chloride.
- TCE is the target chemical.
- Near the example building, TCE concentrations in groundwater in the shallow aquifer range from 55 to 110 micrograms per liter.

Graphical representations of relevant building data for the example scenario are provided in **Figure 1** through **Figure 3**.

Example Site Data

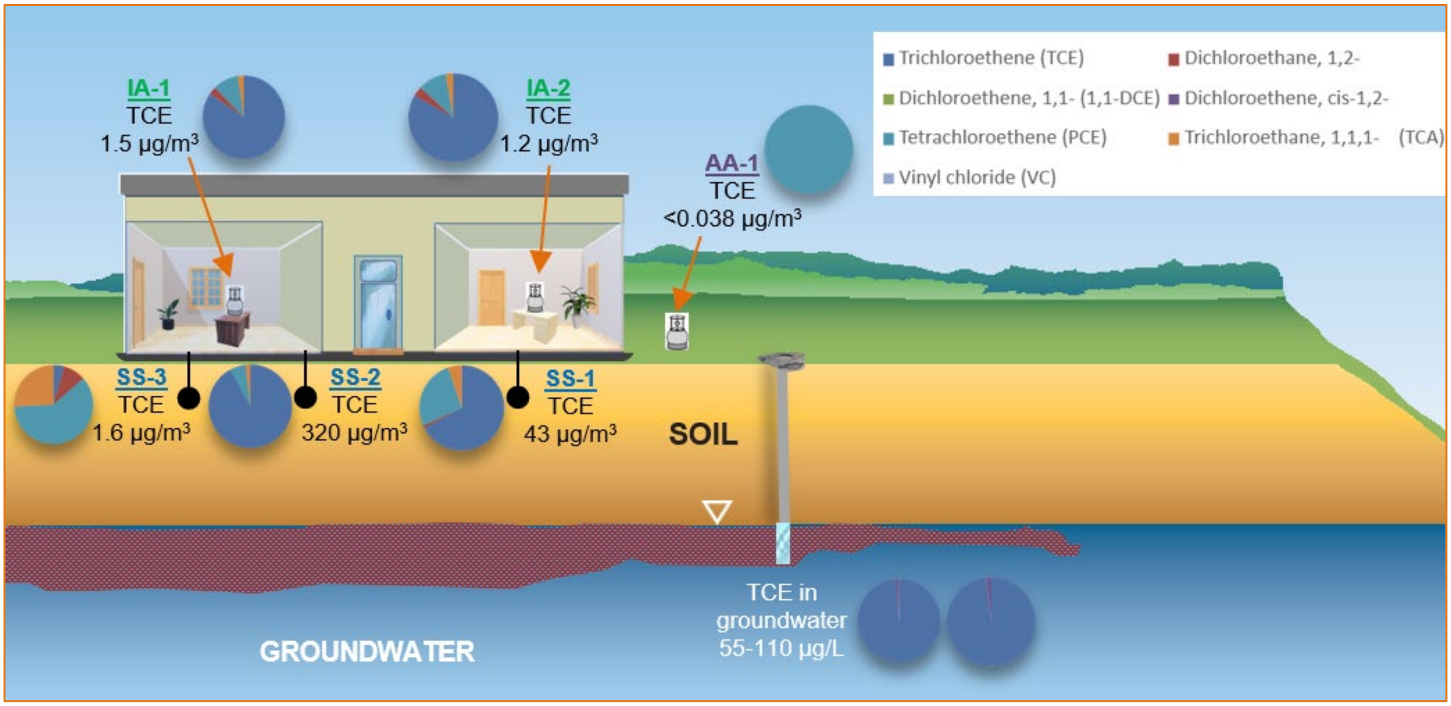

Figure 1. Example Scenario #1 building / site data.

Source: Used with permission from Laura Trozzolo, Catherine Regan and Lila Beckley. Adapted from ESTCP Project ER-201119, (Beckley et al. 2013, Figure B.1.1).

			BUILDING 9669					
Sample Location ID:	**LC-18**	**LC-48**	**1-SS-1**	**1-SS-2**	**1-SS-3**	**1-IA-1**	**1-IA-2**	**1-AA-1**
Description:	**South of Building 9669**	**West of Building 9674**	**Sub-slab, front, near battery recycling**	**Sub-slab, middle, near 1-IA-1**	**Sub-slab, back of building**	**Indoor air, center of warehouse**	**Indoor air, shelf in product storage area**	**Outdoors**
Matrix: Sample Type:	**GW**	**GW**	**SS**	**SS**	**SS**	**IA**	**IA**	**AA**
Sample Collection Date:	**6/21/2012**	**6/21/2012**	**7/24/2012**	**7/24/2012**	**7/24/2012**	**7/24/2012**	**7/24/2012**	**7/24/2012**
Analytical Method (units):	**8260 (ug/L)**	**8260 (ug/L)**	**TO-15 SIM (ug/m3)**	**TO-15 SIM (ug/m3)**	**TO-15 SIM (ug/m3)**	**TO-15 SIM (ug/m3)**	**TO-15 SIM (ug/m3)**	**TO-15 SIM (ug/m3)**
Key Analyte for VI Evaluation								
Trichloroethene (TCE)	**55**	**110**	**43**	**320**	**1.5**	**1.5**	**1.2**	<0.038
Dichloroethane, 1,2-	-	-	**0.65**	<0.55	**3.2**	**0.053**	**0.05**	<0.038
Dichloroethene, 1,1- (1,1-DCE)	-	-	<0.13	<0.55	<0.91	<0.037	<0.036	<0.038
Dichloroethene, cis-1,2-	**0.73**	**2.1**	<0.13	<0.55	<0.91	<0.037	<0.036	<0.038
Tetrachloroethene (PCE)	<0.5	<0.5	**17**	**22**	**21**	**0.18**	**0.15**	**0.052**
Trichloroethane, 1,1,1- (TCA)	<0.5	<0.5	**3.4**	**6.2**	**9**	**0.042**	**0.039**	<0.038
Vinyl chloride (VC)	<0.5	<0.5	<0.13	<0.55	<0.91	<0.037	<0.036	<0.038

Figure 2. Example Scenario #1 tabulation of selected data.

Source: Adapted from ESTCP Project ER-201119 (Beckley et al. 2013, Table C.1.1).

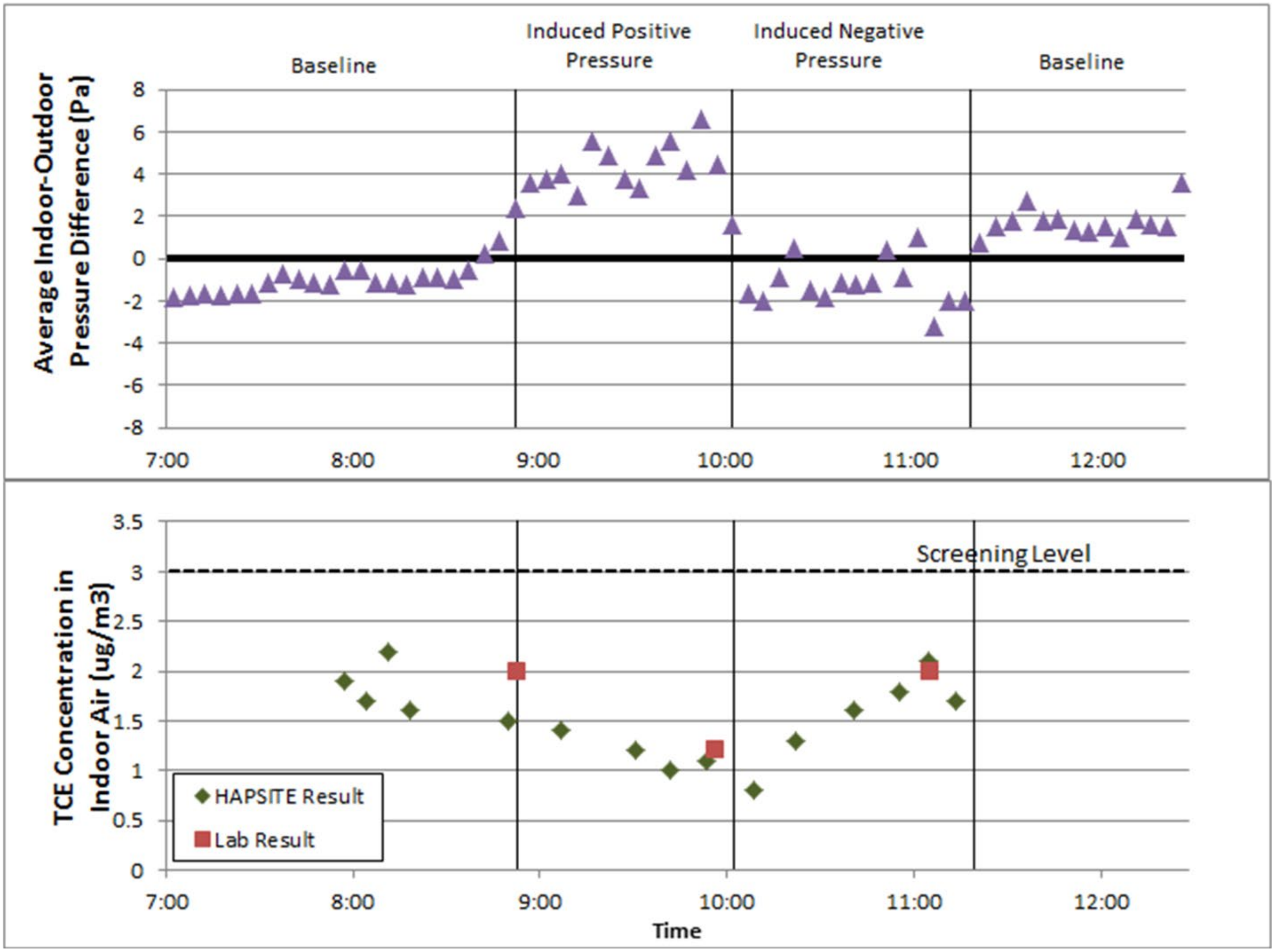

Figure 3. Building pressure control test evaluation.

Source: Adapted from ESTCP Project ER-201119 (Beckley et al. 2013, Figure B.1.3).

MLE Approach

Step 1: Define a target question: Are data consistent with VI likely occurring at this building?

Step 2: Pull together applicable data and data evaluations as the MLE. For this example, the following key LOEs are used:

- Groundwater concentrations
- Sub-slab vapor concentrations
- Indoor air concentrations
- Outdoor air concentrations

- Media concentrations compared to applicable screening levels (U.S. Environmental Protection Agency [USEPA] vapor intrusion screening levels used for this example)
- Indoor air to outdoor air ratios
- Indoor air to sub-slab vapor AF analysis
- Indoor air to sub-slab vapor constituent ratios
- Groundwater to sub-slab vapor ratios
- Building pressure control evaluation

Step 3: Use each LOE, as shown in Table 1, to support an answer to the target question: Are data consistent with VI likely occurring at this building? See Step 3 in the section, What Does an MLE Approach Look Like, for an explanation of the terms yes/no, supporting, and neutral.

Table 1. MLE analysis table for Scenario #1.

Line of Evidence	Are Data Consistent with VI Likely Occurring at This Building?	Further Evaluation
Groundwater concentrations	**Supporting**	This may be considered a screening assessment. Impacts of TCE found in groundwater; therefore, VFCs are present at the site/under or near the building. Although not a definitive LOE on its own that VI is occurring, additional evaluation is warranted to understand potential pathway completeness to indoor air.
Sub-slab vapor concentrations	**Supporting**	This may be considered a screening assessment. Impacts of TCE found in sub-slab vapor; therefore, VFCs are present at the site/under the building. Although not a definitive LOE on its own that VI is occurring, additional evaluation is warranted to understand potential pathway completeness to indoor air.
Indoor air concentrations	**Supporting**	Impacts of TCE found in indoor air; therefore, VFCs are present. Although not a definitive LOE on its own that VI is occurring, additional evaluation is warranted to understand potential pathway completion as well as background indoor air sources at the building.
Outdoor air concentrations	**Neutral**	Impacts of TCE not found in outdoor air data. Indoor air does not appear to be influenced by outdoor air. These data are useful in background indoor air data interpretation but cannot be used directly to evaluate VI.
Concentration data (groundwater and sub-slab vapor) compared to applicable screening levels	**Yes**	Based on the screening levels used, the groundwater and sub-slab vapor concentrations in at least one sample in each medium exceed the screening levels. Additional evaluation is warranted to assess potential pathway completeness to indoor air.
Concentration data (indoor air) compared to applicable screening levels	**No**	Based on the USEPA screening levels, indoor air data are above reporting limits but are below the screening levels.
Indoor air concentration to outdoor air concentration ratios	**Neutral**	Indoor air concentrations are greater than outdoor air concentrations. This may be an indication of VI but also may also indicate a potential indoor source.

Line of Evidence	Are Data Consistent with VI Likely Occurring at This Building?	Further Evaluation
Indoor air to sub-slab vapor concentration attenuation factor (AF) analysis	**Yes**	At two colocated indoor air / sub-slab vapor points (IA-1/SS-2 and IA-2/SS-1), the calculated AF for TCE was 0.03 and 0.004, respectively. This building-specific AF range is equal to or lower than the empirically derived AF of 0.03 typically included in state/federal guidance documents. For context, it is often empirically observed that large industrial buildings experience greater attenuation (Eklund et al. 2022) closer to the AF of 0.004. The example observed range is therefore similar to empirical data sets. It should be noted that, for some buildings, sub-slab vapor concentrations may exhibit larger spatial variability than indoor air concentrations (due to indoor air mixing). It is important to understand uncertainty around colocated locations relative to the vapor source, which may be captured by calculating building-specific AFs (Lahvis et al. 2025). AF calculations are discussed in the **Attenuation Factors Fact Sheet** and **Section 5.4.1.1: Applications of Concentration-Based Screening**.
Indoor air to sub-slab vapor constituent ratios	**Yes**	Looking at the pie charts presented in **Figure 1**, TCE, PCE, and 1,1,1-TCA are the highest concentration VFCs in sub-slab vapor and are also detected in indoor air, with similar concentration ratios.
Groundwater to sub-slab vapor constituent ratios	**Neutral**	Looking at the pie charts presented in **Figure 1**, cis-1,2-DCE in groundwater, is ~2% of the concentration of TCE, but cis-1,2-DCE is not detected in sub-slab vapor or indoor air. PCE, 1,1,1-TCA were also not detected in groundwater. This may be because of the low concentration in the groundwater source so these data cannot rule in or out the VI pathway.
Building pressure control evaluation	**Yes**	When a targeted portion of the building was pressurized (in relation to the sub-slab area), VI was "turned off" and the indoor air concentration of TCE decreased. When VI was enhanced by decreasing the pressure in the building (in relation to the sub-slab area), concentrations of TCE in the indoor air increased.

Note: Refer to Step 3 in the section, What Does an MLE Approach Look Like, for an explanation of yes/no, supporting, and neutral terminology.
AF = attenuation factor, LOE = line of evidence, TCE = trichloroethylene or trichloroethene, USEPA = U.S. Environmental Protection Agency, VFC = vapor-forming chemical, VI = vapor intrusion.

Step 4: Evaluate data for uncertainty.

- An evaluation of the certainty/uncertainty of the LOE may be dependent on state-specific guidance and the site VI CSM. In the example scenario above, the data collected at this building are consistent with the site VI CSM, and thus the data used for the LOE has lower uncertainty.
- Uncertainty can also be decreased by collecting data over more than one sampling event and evaluating whether the LOEs are consistent with additional collected data. Uncertainty can also be decreased by more than one LOE supporting the same conclusion. In this scenario, for example, data describing variability in the seasonality of indoor air data or data changes with fluctuations in water table were not collected. Having data that supports the same conclusion but collected under various different conditions may help to decrease uncertainty.

Step 5: Evaluate the weight of LOE either individually or collectively.

- In this example, the weight or level of importance of each LOE is similar to uncertainty in that the more LOEs that align with the same conclusion and align with the site VI CSM, the larger weight they carry. It may also be important to note that, in some states, the more standard the data (e.g., soil vapor and indoor air data compared to screening levels) the more relative weight they may carry.

Step 6: Summarize the MLE Results.

- In Scenario #1, the results of the LOEs and the additional information provided in **Table 1** are processed by the practitioner using the MLE approach. The overall finding is that the MLE support the conclusion that VI is likely occurring at this building; however, the indoor air concentrations as shown do not exceed the applicable screening levels, so they do not present a potential risk under current conditions. A path forward from this point would depend on the specifics of the site, site objectives, and regulatory environment. Options may include no additional VI evaluation, continued indoor air sampling, collecting other LOEs to further refine the evaluation, or (to decrease uncertainty) making other site management decisions based on current or future use of the building / future risk scenario. These next steps may warrant another MLE approach to make an assessment based on the next question being asked.
- In this example, VIPPs were not evaluated. Based on a site's or a building's CSM, it may be necessary to collect additional data and perform an additional MLE approach to understand the role of VIPPs.

Example Scenario #2: Use of MLE in the Evaluation of Background Indoor Air Sources

The following example scenario includes data collected as part of ESTCP Project ER-201119 (Beckley et al. 2013). For simplicity, not all data from the project or from the example building is used in this example scenario.

Example building summary—This scenario uses a building at the Selfridge Air National Guard Base near Detroit, Michigan. General site/building information (Beckley et al. 2013) includes the following information:

- Building is currently used as a maintenance facility.
- Shallow stratigraphy consists of glacial lake sediments (e.g., clays and silts) overlying a sedimentary bedrock. In the vicinity of the target building, shallow soils are predominantly sand and gravel fill.
- Depth to water is approximately 2–6 ft below ground surface.
- Releases from two underground storage tanks (leaded gasoline and diesel) were noted near the example building. Tanks have since been removed.
- Petroleum hydrocarbons are present in shallow groundwater as a result of underground storage tank releases.
- VFCs for this scenario are benzene, toluene, ethylbenzene, xylenes, and polycyclic aromatic hydrocarbon compounds.
- Benzene is the target chemical.

Graphical representations of relevant data for the example scenario are provided in **Figure 4** through **Figure 8**.

Example Site Data

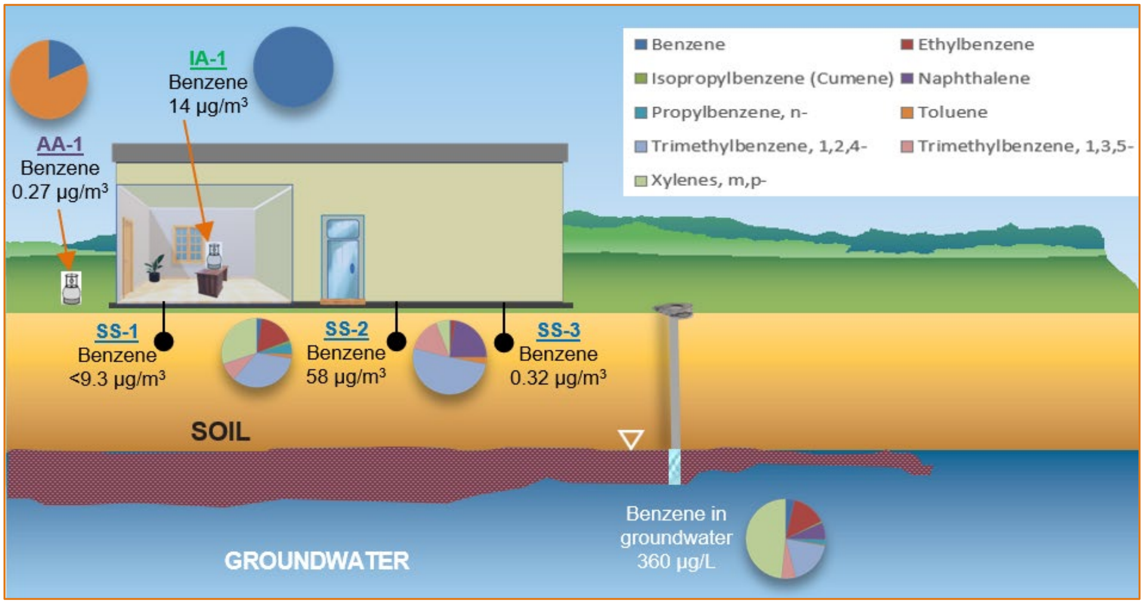

Figure 4. Example Scenario #2 building/site data.

Source: Used with permission from Laura Trozzolo, Catherine Regan and Lila Beckley. Adapted from ESTCP Project ER-201119, (Beckley et al. 2013, Figure B.3.1).

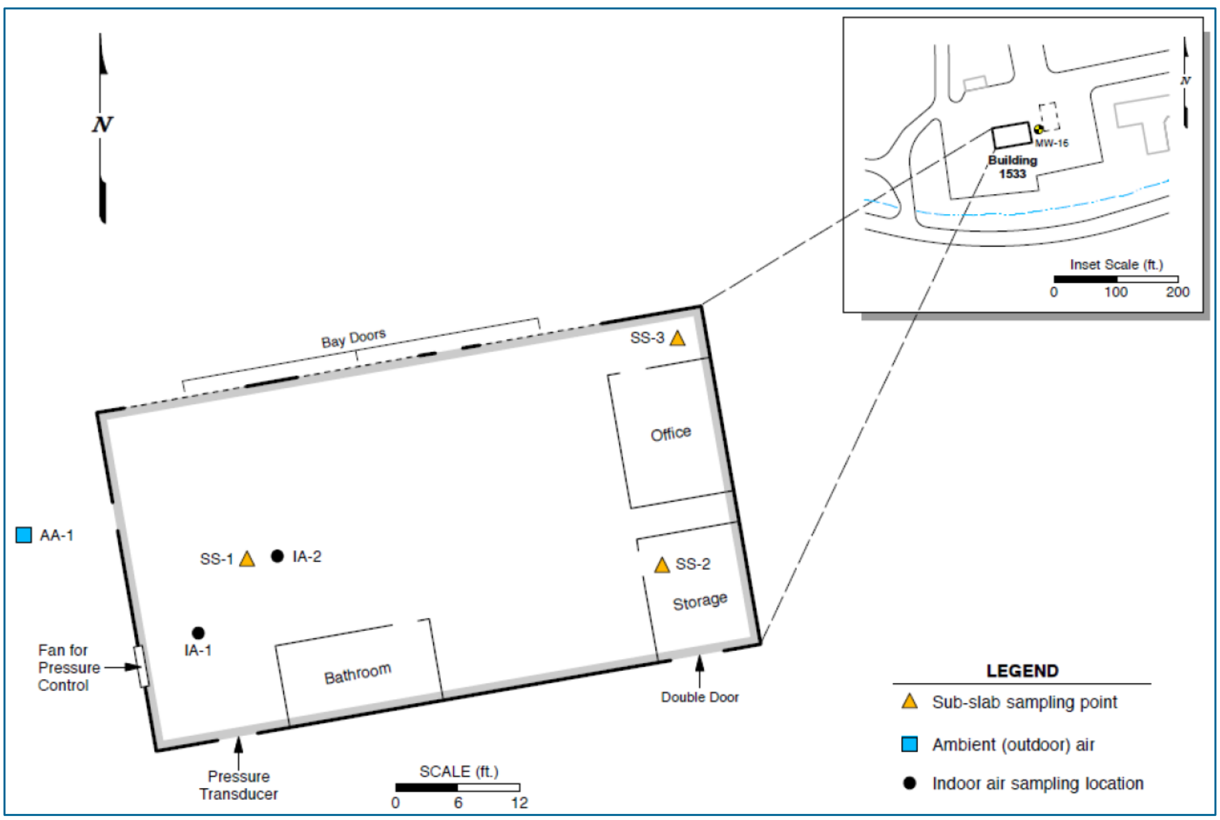

Figure 5. Sampling location spatial layout.

Source: ESTCP Project ER-201119 (Beckley et al. 2013, Figure C.2.2).

	BUILDING 1533					
Sample Location ID:	MW-16	SS-1	SS-2	SS-3	IA-1	AA-1
Description:	Between building and fmr UST	Sub-slab, west bay of building	Sub-slab, inside storeroom	Sub-slab, outside office door	Indoor Air, southwest side of building	Outdoors, west of building
Matrix:	GW	SS	SS	SS	IA	AA
Sample Collection Date/Time:	9/18/2012	9/18/2012	9/18/2012	9/18/2012	9/18/2012	9/18/2012
Analytical Method (units):	8260C (ug/L)	TO-15 (ug/m3)	TO-15 (ug/m3)	TO-15 (ug/m3)	TO-15 (ug/m3)	TO-15 (ug/m3)
Key Analyte for VI Evaluation						
Benzene	**360**	<9.3	**58**	**0.32**	**14**	**0.27**
Ethylbenzene	**1400**	<46	**430**	**0.92**	<57	<0.73
Isopropylbenzene (Cumene)	**68**	<46	**34**	<0.69	<57	<0.73
Naphthalene	**680**	<46	<32	**11**	<57	<0.73
Propylbenzene, n-	**210**	<46	**130**	<0.69	<57	<0.73
Toluene	**41**	<46	**52**	**1.5**	<57	**1.2**
Trimethylbenzene, 1,2,4-	**1800**	<46	**860**	**25**	<57	<0.73
Trimethylbenzene, 1,3,5-	**570**	<46	**220**	**7.4**	<57	<0.73
Xylenes, m,p-	**4800**	<46	**770**	**3**	<57	<0.73

Figure 6. Example Scenario #2 tabulation of selected data.

Source: Adapted from ESTCP Project ER-201119 (Beckley et al. 2013, Table C.2.1).

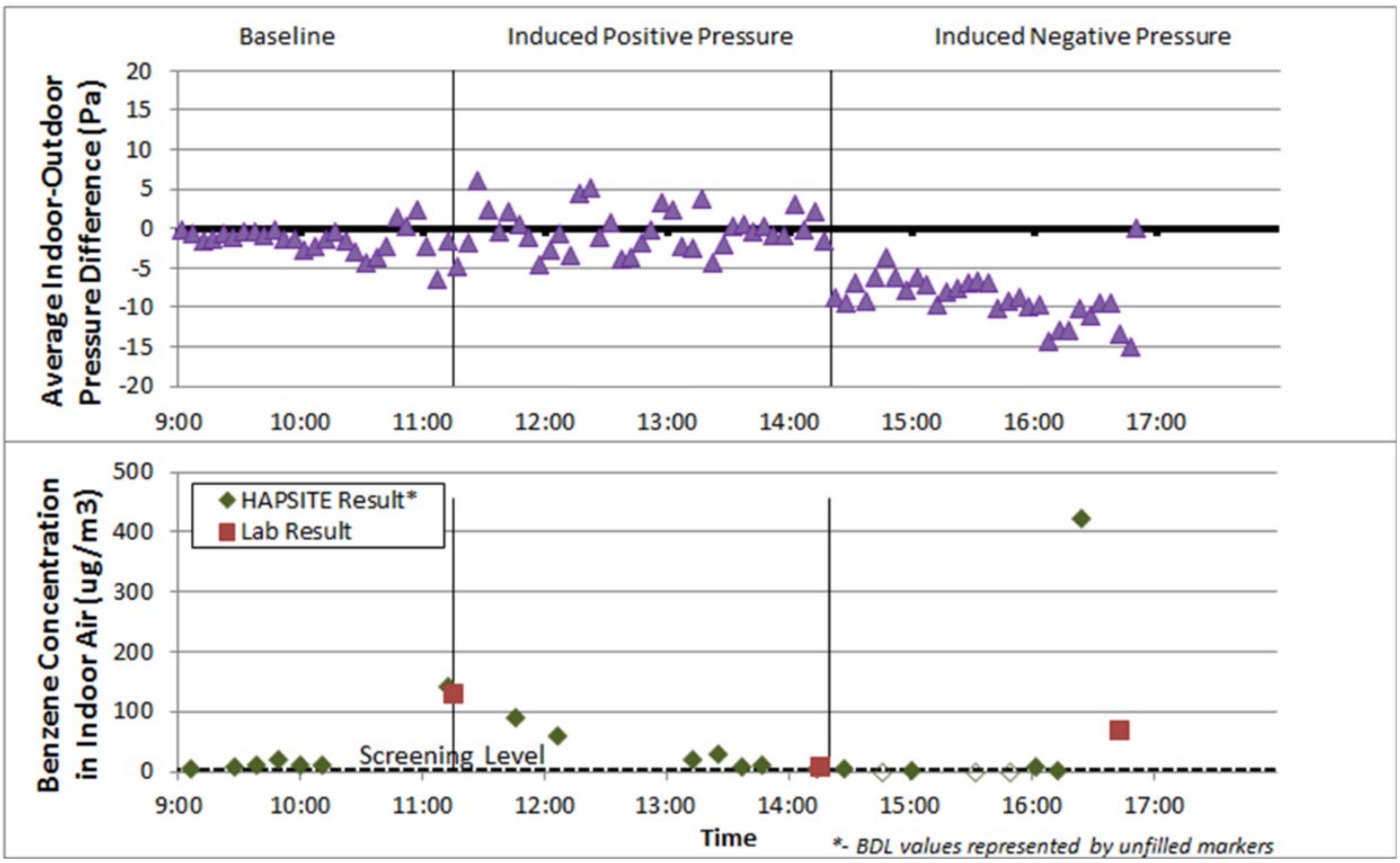

Figure 7. Building pressure control test evaluation.

Source: Adapted from ESTCP Project ER-201119 (Beckley et al. 2013, Figure B.3.3).

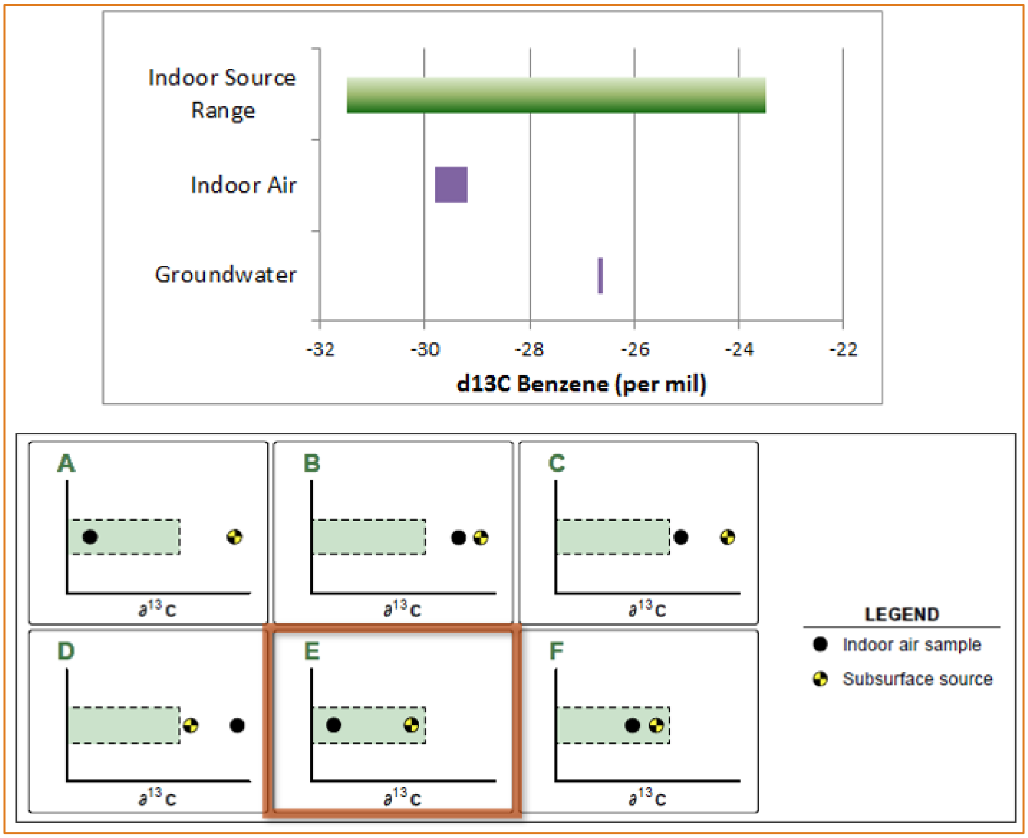

Figure 8. Compound-specific isotope analysis.

Source: Adapted from ESTCP Project ER-201119 (Beckley et al. 2013, Figure B.3.2).

MLE Approach

Step 1: Define a target question: Are data consistent with background sources causing benzene impacts to indoor air?

Step 2: Pull together applicable data and data evaluations as the LOEs. For this example, the following key LOEs are used:

- Groundwater data
- Sub-slab vapor data
- Indoor air data
- Outdoor air data
- Building survey and chemical inventory results
- Media data compared to applicable screening levels
- Indoor air to outdoor air ratios
- Indoor air to sub-slab vapor AF analysis
- Indoor air to sub-slab vapor constituent ratios

- Groundwater to sub-slab vapor constituent ratios
- Sub-slab vapor and indoor air spatial analysis
- Pressure control testing results
- Compound-Specific Isotope Analysis (CSIA)

Step 3: Use each LOE to support an answer to the target question, as shown in Table 2. See Step 3 in the section, What Does an MLE Approach Look Like, for an explanation of the terms yes/no, supporting, and neutral.

Table 2. Analysis table for Scenario #2.

Line of Evidence	Are Data Consistent with Background Sources Causing Benzene Impacts to Indoor Air?	Comment
Groundwater data	**No**	Impacts of benzene found in groundwater, so VFCs are present and may be influencing indoor air via VI. This is not a definitive LOE on its own; additional evaluation is warranted to evaluate whether there is a background indoor air source.
Sub-slab vapor data	**No**	Impacts of benzene found in soil vapor, so VFCs are present and may be influencing indoor air via VI. This is not a definitive LOE on its own; additional evaluation is warranted to evaluate whether there is a background indoor air source.
Indoor air data	**Neutral**	Impacts of benzene found in indoor air, so VFCs are present. Could indicate VI or a background indoor air source. Not a definitive LOE on its own, additional evaluation is warranted.
Outdoor air data	**Neutral**	Impacts of benzene found in outdoor air data. These data will be useful in data interpretation methods.
Building survey and chemical inventory results	**Yes**	Building survey indicated auto maintenance activities are actively being conducted in the building. Products and equipment containing petroleum were noted and present. These products could not be removed prior to sampling. It should be noted that even if products had been removed, their previous use and presence in the building may still influence indoor air concentrations.
Concentration data (groundwater and sub-slab vapor) compared to applicable screening levels	**No**	Based on USEPA screening levels, the groundwater and sub-slab vapor benzene concentrations in at least one sample in each medium exceed the screening levels. This indicates impacts in groundwater and sub-slab vapor could potentially be the cause of impacts in indoor air via VI, but additional evaluation is warranted.
Concentration data (indoor air) compared to applicable screening levels	**Neutral**	Based on USEPA screening levels, indoor air data exceeds the screening level. Products that contain benzene can also cause indoor air concentrations that exceed screening levels. The exceedances of screening levels may be either from VI or from an indoor air source. Additional evaluation is warranted.
Indoor air concentration to outdoor air concentration ratios	**Neutral**	Indoor air benzene concentrations are higher than outdoor air. This may be an indication of either VI or a background indoor source.

Line of Evidence	Are Data Consistent with Background Sources Causing Benzene Impacts to Indoor Air?	Comment
Indoor air to sub-slab vapor concentration attenuation factor (AF) analysis	**Yes**	Known indoor air concentration over the maximum sub-slab vapor concentration produces a site-specific AF of 0.24, which is higher than the empirically derived AF of 0.03 typically included in state guidance documents. This relatively little attenuation of soil vapor to indoor air (i.e., the AF is closer to 1) is more consistent with a background indoor air source than with VI. These data, however, do not rule out the possibility of indoor air contributions from both VI and background sources.
Indoor air to sub-slab vapor constituent ratios	**Yes**	Looking at the pie charts presented in **Figure 4**, indoor air constituent ratios do not match sub-slab vapor ratios. This is an indication that indoor air concentrations are not from the same source as the sub-slab vapor concentrations. This example has elevated reporting limits for the indoor air data, and this may affect the ability to evaluate the constituent ratios in more detail.
Groundwater to sub-slab vapor constituent ratios	**Supporting**	Looking at the pie charts presented in **Figure 4**, some sub-slab vapor ratios appear similar to the constituents observed in groundwater (for example SS-2 and SS-3 are similar in make up to MW-16). This indicates that sub-slab vapor is likely present due to groundwater.
Sub-slab vapor and indoor air spatial analysis	**Yes**	Sub-slab vapor was collected under three areas of the building with the highest sub-slab vapor, and SS-2 was collected under the storage area. The location of the elevated indoor air concentrations of benzene is located on the opposite side of the building from SS-2 and was actually colocated with the lowest sub-slab vapor concentration of benzene.
Building pressure control testing results	**Yes**	Building pressure control testing did not document an increase in indoor air benzene concentrations when a negative pressure was induced inside the building (i.e., the building was mechanically manipulated to enhance upward advective flow into the building), nor did it document a decrease in indoor air benzene concentrations when a positive pressure was induced inside the building (i.e., the building was mechanically manipulated to enhance downward advective flow into the sub-slab). Benzene concentrations remained relatively constant, indicative of a background indoor air source.
Compound-specific isotope analysis (CSIA)	**Yes**	This test is not as common as other LOEs but was performed at this building. Results of the CSIA compared isotope analysis of the groundwater to isotope analysis of indoor air. The results demonstrated that the isotope fingerprint for the groundwater is generally a different isotope fingerprint than the isotope fingerprint from indoor air. As noted in a previous LOE, groundwater appears to be the source for sub-slab vapors. CSIA data indicates the primary source of VFCs in indoor air are from compounds within the building and not a subsurface source.

Note: Refer to Step 3 in the section, What Does an MLE Approach Look Like, for an explanation of yes/no, supporting, and neutral terminology.
AF = attenuation factor, CSIA = compound-specific isotope analysis, LOE = line of evidence, USEPA = U.S. Environmental Protection Agency, VFC = vapor-forming chemical, VI = vapor intrusion.

Steps 4 and 5: Evaluate data for uncertainty and weight of evidence.

- An evaluation of uncertainty will be dependent on state-specific guidance and the site/building CSM. In this example scenario, the data interpreted within the MLE are generally consistent with the site CSM. When multiple pieces of data align with each other and/or multiple pieces of data align with the understanding of the VI CSM, then that may increase the practitioner's confidence in the MLE or, in other words, lower the uncertainty in the MLE approach results.

- In this example scenario, an example of higher uncertainty would be the constituent ratios. The reporting limits for several VFCs in indoor air were elevated. This made it difficult to see whether these compounds were really not present in indoor air or were simply detected below the reporting limit.
- Although not all LOEs align to support a background indoor air source for benzene, more weight could be applied to more significant LOEs for this VI CSM. Some of the more significant LOEs for this example scenario include the observation that automobile maintenance was actively being conducted during the VI assessment, and that indoor air concentrations of benzene were higher than benzene concentrations in the colocated sub-slab vapor. Supplemental data also supported these LOEs, which included the results of the building pressure control testing and the results of the CSIA sampling; both indicated a background indoor air source.

Step 6: Summarize the MLE Results.

- In the above example scenario, the results of the LOEs and the additional information provided in **Table 2** are processed by the practitioner. The overall finding is that the MLE support the conclusion that the primary sources of benzene are inside the building and not present due to VI. Although indoor air concentrations are higher than the screening levels, they are likely due to background indoor air sources.
- Although sub-slab vapor screening levels are slightly exceeded for benzene, no additional evaluation is warranted, and no mitigation is warranted under current site conditions.
- Future building use conditions may warrant further assessment, and this additional assessment may be another MLE approach with a different target question.

Summary

Using LOE and the MLE approach is a technique that practitioners and regulators use every day, often without even realizing it. Although laid out as a series of steps in this fact sheet, the concept can be used in a variety of ways. The central idea to the MLE approach for VI assessment is to provide an interpretation of the potential for VI at a building or to provide an answer to a target question that is supported by data/information observed, collected, and/or evaluated. An MLE approach can be used at various different points within a VI project life cycle and may need to be used repeatedly as different questions warrant the use of different LOEs for interpretation. It is important to understand the regulatory framework for the geographic area, which may influence the LOEs selected and the relative importance of each LOE.

Table 3. Example lines of evidence.

Line of Evidence (LOE)	Description	How Are They Helpful?	Where in the Guidance Can More Information Be Found?
Site history / land use	Information on site history and land use, including chemical use and potential release mechanisms that may lead to VI exposures. Knowing the proximity of a historical VFC release point within a building may be a predictor of potential higher indoor air concentrations (Lutes et al. 2021)—for example, finding high concentrations in indoor air and then finding out that this area was the location of the vapor degreaser. That site history would be an LOE in support of VI.	Detailed vs. insufficient information reduces or increases uncertainty with VI exposure estimates.	Section 4.2 Components of a Conceptual Site Model; Section 4.2.2 Historical, Current, and Future Site Use; Section 5.2.1 Preliminary Vapor Intrusion Exposure Assessment
Site characterization (source nature and extent)	Information on the nature and extent of contamination, contaminant fate and transport, and exposure pathways.	Complete vs. incomplete or limited site characterization may reduce or overestimate VI exposure estimates.	Section 4.2 Components of a Conceptual Site Model, Section 4.2.6 Nature and Extent of Contamination, Chapter 5: Site Screening
Subsurface soil conditions	Impact of site geology and hydrogeology (soil type, moisture content, porosity, and extent of fracturing) on the distribution and fate and transport of vapors in the subsurface.	To support the evaluation of soil vapor profiles, air permeability estimates, and anticipated or impeded soil vapor migration routes (e.g., clean water lens).	Section 2.2.8 Clean Water Lenses, Section 4.2.13 Geology and Hydrogeology, Section 7.6.2 Soil, Table 7-6
Vapor-forming chemicals (VFCs)	Subsurface source of chemicals with sufficient volatility (Henry's Law Constant > 1E-05 atm-m^3/mol or vapor pressure > 1 mm Hg) in soil vapor or groundwater underneath or near a building.	To identify COPCs to support a complete VI pathway and limit data evaluation and analytical parameters.	Section 2.1.3.1 Sources of Vapor-Forming Chemicals in Soil Vapor, Chapter 5: Site Screening

Line of Evidence (LOE)	Description	How Are They Helpful?	Where in the Guidance Can More Information Be Found?
VFC environmental persistence	Ability of a VFC to either persist in the environment, biodegrade, or chemically react (e.g., chemicals such as acrolein or 1,3-butadiene).	To support a complete VI pathway, evaluate the amount of attenuation between a VFC source and building, and assess whether additional investigation or vapor mitigation is warranted.	Section 4.2.5 Sources of Vapor, Section 5.3.2 Distance-Based Screening, Appendix F: Distance-Based Screening at Petroleum Vapor Intrusion Sites
Nonaqueous-phase liquid (NAPL)	NAPL composition, environmental persistence, and proximity to current or future building.	To support VI CSM, amount of attenuation occurring, and identify which buildings are within the lateral inclusion zone and vertical separation distance.	Section 2.1.3 Vapor Transport, Section 4.2.9 Nonaqueous-Phase Liquids, Section 7.6.3 Nonaqueous-Phase Liquid, Table 7-6, Section 5.3.2 Distance-Based Screening, Appendix F: Distance-Based Screening at Petroleum Vapor Intrusion Sites
VI preferential pathways (VIPPs)	Presence or absence of conduit VIPPs such as sewer lines or vertical VIPPs such as elevator pits/shafts that may transport VFCs toward buildings and then into indoor air more than under normal conditions.	Identification of such pathways may provide an explanation for indoor air results. Conduits may result in indoor air concentrations higher than would be expected from normal or typical conditions at a building.	Vapor Intrusion Preferential Pathways Fact Sheet, Section 5.3.1 Precluding Factor Assessment, Appendix E: Application of Precluding Factors

Line of Evidence (LOE)	Description	How Are They Helpful?	Where in the Guidance Can More Information Be Found?
Media Concentrations (see media-specific LOE below)	Concentration of VFCs in media (groundwater, soil vapor, sub-slab vapor, crawl space air, indoor air, and outdoor air).	Media concentration measurements may be used to evaluate spatial and/or temporal variability if the data set is appropriate for that purpose. Other possible uses are outlined below.	
Groundwater concentrations	Concentration of dissolved-phase VFCs at or near the top of the water table.	Compare the proximity of current and/or future buildings to lateral and vertical screening distances from groundwater concentrations to determine whether VI is screened in or out. If screened in based on distance, then compare measured groundwater values to screening levels to determine whether VI is screened in or out. Data also may be useful for evaluating groundwater plume stability.	Screening Levels Fact Sheet, Section 7.6.1 Groundwater, Table 7-6; Section 5.4.1 Concentration-Based Screening
Soil vapor concentrations	Concentration of VFCs in soil vapor under, near-slab (<10 ft), or exterior (> 10 ft) to building. Data from two or more depths can be used for vertical profiling.	Measured concentrations can be compared to screening levels to determine whether VI is screened in or out, assuming samples are collected between the vapor source and the building. Data can be used to determine soil vapor attenuation over distance if samples are collected at multiple depths.	Screening Levels Fact Sheet, Section 7.4 Sampling Methods, Section 7.10 Analytical Methods, Table 7-6, Section 5.4.1 Concentration-Based Screening
Sub-slab vapor concentrations	Concentration of VFCs collected from directly beneath a building slab.	Compare measured values to screening levels to determine whether VI is a potential issue. If concentrations are similar to indoor air concentrations, serves as potential evidence of background sources. Data can be combined with barometric pressure and differential pressure data to establish presence of concentration gradients. Data can be evaluated temporally or spatially (detailed in Spatial Variability and Temporal Variability below). Data also can be used in evaluating performance of VIMS.	Screening Levels Fact Sheet, Section 7.4 Sampling Methods, Section 7.10 Analytical Methods, Table 7-6, Section 5.4.1 Concentration-Based Screening

Line of Evidence (LOE)	Description	How Are They Helpful?	Where in the Guidance Can More Information Be Found?
Crawl-space air concentrations	Concentration of VFCs collected from within the crawl space at a building with pier-and-beam construction.	Compare measured values to indoor air screening levels to determine whether VI is a potential issue. No attenuation is the typical assumption.	Screening Levels Fact Sheet, Section 7.3.2 Crawl-Space Sampling Points, Section 7.10 Analytical Methods, Table 7-6, Section 5.4.1 Concentration-Based Screening
Indoor air concentrations	Concentration of VFCs collected within a building at breathing zone level (3–5 ft above building slab or floor).	Direct measurement of potential exposure from all sources. Measurement results can be compared with indoor air standards (if available) or screening levels to determine whether potential exposures are acceptable. Contribution from VI can be determined by accounting for contributions from indoor and outdoor background sources. Data can be evaluated temporally or spatially (detailed in Spatial Variability and Temporal Variability below). Data also can be used in evaluating performance of VIMS.	Screening Levels Fact Sheet, Section 7.3.1 Indoor and Outdoor Air Sampling Points, Section 7.10 Analytical Methods, Table 7-6, Section 5.4.1 Concentration-Based Screening
Outdoor air concentrations	Concentration of VFCs in outdoor air.	To evaluate whether sources of background outdoor air concentrations may be contributing to indoor air concentrations. Samples are collected concurrently with indoor air at representative upwind locations away from wind obstructions such as trees and buildings or obvious sources of VFCs. For commercial buildings, samples can also be collected near HVAC air intakes.	Section 7.3.1 Indoor and Outdoor Air Sampling Points, Section 7.10 Analytical Methods, Table 7-6, Background Sources to Indoor Air Fact Sheet, Section 5.4.1 Concentration-Based Screening
System exhaust concentrations and mass-flow rate	Measurements of gas concentration and gas flow rate from VIMS.	Results can be used in deciding whether a VIMS needs to remain operating or can be curtailed or shut down. Results over time may be most useful.	Vapor Intrusion Mitigation System Post-Installation Verification Fact Sheet; Vapor Intrusion Mitigation System Operation, Maintenance, and Monitoring Fact Sheet; Vapor Intrusion Mitigation System Curtailment and Shutdown Fact Sheet

Line of Evidence (LOE)	Description	How Are They Helpful?	Where in the Guidance Can More Information Be Found?
Fixed Gas Concentrations (see specific fix gases below)	Concentration of fixed gases (O_2, CO_2, and CH_4) in soil vapor. Measurements can be made in the field or at an off-site analytical laboratory. Data from two or more depths can be used for vertical profiling.	Data can be used to better understand the fate and transport of VFCs in the subsurface.	
Oxygen	Concentration of O_2 in soil vapor under, near-slab (<10 ft), or exterior (> 10 ft) to building. Or concentration of O_2 collected from directly beneath a building slab.	Oxygen data indicates whether the subsurface at a given location and depth is aerobic (with oxygen) or anaerobic (without oxygen). Chemicals such as benzene, ethylbenzene, and other petroleum hydrocarbons, and other VFCs such as vinyl chloride, may undergo aerobic biodegradation, and conditions conducive to aerobic biodegradation can be documented by the presence of O_2 in soil vapor measurements.	Section 7.2.1 Handheld Logging Instruments, Section 7.10.1 Choosing an Appropriate Analytical Method; Section 5.4.1 Concentration-Based Screening
Carbon dioxide	Concentration of CO_2 in soil vapor under, near-slab (<10 ft), or exterior (> 10 ft) to building. Or concentration of CO_2 collected from directly beneath a building slab.	Carbon dioxide is produced from both aerobic and anaerobic biodegradation. Degradation of VFCs (in particular, petroleum hydrocarbons) and methane will produce CO_2. The amount of CO_2 present provides a rough indication of the amount of degradation that has occurred.	Section 7.2.1 Handheld Logging Instruments
Methane	Concentration of CH_4 in soil vapor under, near-slab (<10 ft), or exterior (> 10 ft) to building. Or concentration of CH_4 collected from directly beneath a building slab.	Methane can be produced when there is insufficient O_2 and petroleum hydrocarbons are broken down anaerobically. The presence of methane may indicate anaerobically conditions are present. This most commonly occurs for wet, organic-rich soils but may also occur in the presence of high petroleum hydrocarbon concentrations or large source area.	Section 7.2.1 Handheld Logging Instruments, Section 7.10.1 Choosing an Appropriate Analytical Method; Section 5.2.3 Evaluation of Emergency or Rapid Response
Nitrogen	Concentration of nitrogen in soil vapor under, near-slab (<10 ft), or exterior (> 10 ft) to building. Or concentration of nitrogen collected from directly beneath a building slab.	Concentrations measured in soil vapor can help as a quality control measure to understand whether the collected sample is over or under pressurized, there is an issue with laboratory analysis, and whether you have gas-phased advection.	Section 7.10.1 Choosing an Appropriate Analytical Method

Line of Evidence (LOE)	Description	How Are They Helpful?	Where in the Guidance Can More Information Be Found?
Building Evaluations (see specific building LOE below)	Document information from the design, construction, and operation of the building that may affect VI. Characterize conditions within building envelope to evaluate susceptibility to vapor entry from a vapor source near or underneath building.		
Chemical inventory	Identify and document potential indoor air emission sources, such as from chemicals stored and/or used in the building or materials stored/used in the building.	Measured indoor air concentrations can be compared with the chemical inventory to attempt to identify potential background impacts. In some cases, COPCs can be removed from the building at least 24 hours prior to the start of indoor air sampling; however, this may not always eliminate the presence of those chemicals in the indoor air. It is often difficult to find and remove indoor air background sources (Bingham et al. 2023; Doucette et al. 2010).	Section 7.3.1 Indoor and Outdoor Air Sampling Points, Section 8.2.1.2 Adequate Data, Section 8.2.2.3 Use Multiple Lines of Evidence, Table 8-1, Section 5.2.1 Preliminary Vapor Intrusion Exposure Assessment, Building Characteristics Fact Sheet, Appendix B: Example Documents
Building design, construction, condition	Evaluate information on foundation and slab type, age, and integrity; basement details; and presence of key vapor entry points.	Helps in picking specific sampling locations to help provide an adequate data set for evaluating VI. For example, soil vapor sampling locations may need to be added if a building is made up of numerous separate foundations. Data can also be used in interpreting indoor air measurement results. Higher rates of VI may occur if elevators are present or the surface area of cracks or expansion joints is greater than usual.	Section 4.2.15 Building Characteristics, Section 8.2.2.3 Use Multiple Lines of Evidence, Table 8-1, Chapter 5: Site Screening, Building Characteristics Fact Sheet, Appendix B: Example Documents
Building material evaluation	Evaluation of the materials used or stored in a building or the materials used to construct the building.	This evaluation could include furniture, soft surfaces, dry wall, materials stored in warehouses, etc. Some materials can absorb VFCs, or VFCs may be used in the manufacturing process of that material and these VFCs may later off-gas. It may help interpret indoor air measurement results and may be used to identify backgrounds sources.	Background Sources to Indoor Air Fact Sheet

Line of Evidence (LOE)	Description	How Are They Helpful?	Where in the Guidance Can More Information Be Found?
Building ventilation evaluation	Document building features that may influence ventilation, including any HVAC systems, heaters, exhaust fans, open exterior doors or windows, and internal walls and other barriers to free air flow. The number of air changes per hour can be measured via tracer gas tests.	Information can be used in selecting specific sampling locations to help provide an adequate data set for evaluating VI. For example, indoor air samples may need to be added if areas of the building are serviced by significantly different HVAC systems. Data can also be used in interpreting indoor air measurement results. Building ventilation measurement data or estimates can be compared with typical air change data for the type of building being tested.	Section 4.2.15 Building Characteristics, Section 8.2.2.3 Use Multiple Lines of Evidence, Table 8-1, Building Characteristics Fact Sheet, Section 2.1.3 Vapor Transport, Appendix B: Example Documents
Data Interpretation (see specific LOE below)	Detailed study of nature of contamination using data evaluation and interpretation tools.		
Data comparisons	Compare measured indoor or outdoor air results to data from other sources.	Comparison to indoor air data collected from similar buildings outside the area of suspected VI that serve as controls, comparison to outdoor air data collected near the buildings of interest, or comparison to previously reported indoor air results for buildings not known to have VI. Indicator compounds may also be a useful data comparison tool. These compounds may be site specific and may help identify a vapor source or indicate VI is occurring even though they are not the site's COPC.	Section 5.4.1 Concentration-Based Screening
Comparison across multiple media or sample types	Compare measurement data for groundwater, soil vapor, indoor air, crawl-space air, and/or outdoor air.	Can be used to determine whether results are consistent or not across various media. This may include reviewing the concentration gradients, concentration profiles for different COPCs, or reviewing concentrations over different depths.	Multiple Lines of Evidence Fact Sheet: Example Scenarios #1 and #2, Section 8.2.2.3 Use Multiple Lines of Evidence, Table 8-1, Section 5.4.1 Concentration-Based Screening, Section 7.6 Other Media Sampling Methods, Table 7-6

Line of Evidence (LOE)	Description	How Are They Helpful?	Where in the Guidance Can More Information Be Found?
Constituent ratios	Using compound ratios (e.g., DCE/TCE) and comparing ratios in soil vapor to ratios in indoor air.	Significant differences in ratios between soil vapor and indoor air may indicate contributions from unaccounted indoor or outdoor air sources. Comparing ratios of VFCs and their breakdown products (e.g., PCE/TCE/cis-DCE) in soil vapor to ratios of VFC and its breakdown products in indoor air may also be helpful in understanding potential vapor migration.	Approaches for Vapor-Forming Chemical Source Determination Fact Sheet
Site-specific attenuation factors (AFs)	The calculated ratio of the indoor air to sub-slab vapor concentrations for a given VFC.	Best estimate of relative rate of current VI. Comparison of values for different VFCs can help in identifying chemicals with likely background sources. AFs can also be used to back-calculate media-specific screening levels.	Approaches for Vapor-Forming Chemical Source Determination Fact Sheet: Attenuation Factors, Section 8.5.3 Attenuation Factors
Fingerprinting/ Forensic (see specific LOE below)	More sophisticated analytical techniques to produce chemical fingerprints of potential sources.		
Hydrocarbon fingerprinting	Distinguishing between different types of hydrocarbons (e.g., diesel, gasoline, jet fuels) using comprehensive analysis of the samples, including total chromatographic patterns.	To produce chemical fingerprints that are source specific.	Approaches for Vapor-Forming Chemical Source Determination Fact Sheet
Compound-specific isotope analysis (CSIA)	Using isotope ratios (e.g., Cl-37 to Cl-35, C-13 to C-12, H-2 to H-1) in determining what sources of VFCs may be present.	To produce chemical fingerprints that are source specific. CSIA can be used to distinguish between chlorinated solvent manufacturers and identify multiple sources in commingled groundwater plumes and can be used as a tool to distinguish between chlorinated solvents from use within the building versus chlorinated solvents found in impacts under the building. CSIA also may be useful in differentiating between old and new sources of methane.	Approaches for Vapor-Forming Chemical Source Determination Fact Sheet
Spatial variability	Using spatial analysis tools to determine the relationship among samples collected in different locations.	By showing how the distribution of impacts in soil vapor aligns with the distribution of impacts in groundwater and/or indoor air. A random distribution of indoor air impacts is more likely associated with background levels. Spatial variability may help identify hot spots among various floors or rooms in a building. Spatial variability may also help identify concentration gradients vertically in exterior soil vapor or sub-slab vapor.	Section 2.2.5 Spatial and Temporal Variability, Section 7.8.2.1 Spatial Variability

Line of Evidence (LOE)	Description	How Are They Helpful?	Where in the Guidance Can More Information Be Found?
Temporal variability	Using temporal analysis tools to determine the relationship among samples collected at different times.	Evaluating temporal variability may help increase confidence in data evaluation and decision-making. Temporal variability can be evaluated in subsurface and indoor air concentrations from multiple sampling events and correlated with other LOEs such as heterogeneous geology, wind effects, temporal variation in building and atmospheric pressure, buildings impacted by VIPPs, investigative methods to control for temporal variability (e.g., passive samplers, BPC, continuous monitoring, and high volume sampling), and site-specific AFs. Evaluation of temporal variability may also be performed by collecting data in different seasons or when the building is experiencing different pressure gradients. Pressure gradients can be natural (e.g., barometric pressure dynamics, temperature changes, etc.) as well as anthropogenic (e.g., ventilation, HVAC, fans, window and door positions, etc.). Manipulating the pressure or timing the sampling event with depressurized building conditions could support collecting data under conditions that may be more conducive to VI, but this condition may be building or site-specific.	Section 2.2.5 Spatial and Temporal Variability, Section 2.1.3.3 Advective Transport, Section 7.8.2.2 Temporal Variability, Approaches for Vapor-Forming Chemical Source Determination Fact Sheet, Real-Time Monitoring Fact Sheet, Attenuation Factors Fact Sheet, High-Volume Sampling Fact Sheet
Building pressure control test evaluation	Manipulation and correlation of building pressure with on-site or other analysis of indoor air concentrations.	Can be used to help determine whether VFCs detected in indoor air are present due to VI or not. If VI is the source, the indoor air concentration will exhibit large changes for relatively large positive pressure gradients versus relatively large negative pressure gradients. If the indoor air concentration exhibits little or no change as a function of pressure gradients, VI may not be the source of the VFCs detected in indoor air.	Pressure Monitoring and Building Pressure Control Fact Sheet
Mass-flux determination	Measure or calculate mass flux. May include building pressure control as a component of the approach.	Can be used to more directly measure vapor intrusion compared with concentration-only measurements.	General Concepts of Mass-Flux-Based Screening Fact Sheet, Section 5.4.2 Mass-Flux-Based Screening

Line of Evidence (LOE)	Description	How Are They Helpful?	Where in the Guidance Can More Information Be Found?
Differential pressure measurements	Use of digital micromanometer or other manometer to measure pressure differential across the building slab, between indoors and outdoors of building, or between two separate spaces within the same building.	The differential pressure measurement results can indicate whether the building is operating under positive pressure relative to the sub-slab or, if the differential pressure across the slab is negative, the rate of VI may be correlated with the size of the pressure gradient. Data also can be used in evaluating the performance of a VIMS.	Pressure Monitoring and Building Pressure Control Fact Sheet, Design and Implementation Considerations for Vapor Intrusion Mitigation Approaches Fact Sheet, General Concepts of Mass-Flux-Based Screening Fact Sheet, Section 5.4.2 Mass-Flux-Based Screening
Marker chemicals	VFCs that are either naturally occurring (e.g., radon) or a VFC associated with the subsurface impacts but not typically found in indoor air (e.g., 1,1-DCE, H_2S, and others) and may serve as a tool to provide a tracer or a fingerprint.	Sub-slab and indoor air concentrations of marker chemicals (for example 1,1-DCE) can be used to help evaluate whether VFCs in indoor air may be due to VI or background sources. VFC marker compounds like H_2S may be used to help evaluate the presence of a vapor entry point impacted by a sewer conduit VIPP. Marker chemical concentrations in soil vapor and indoor air can be used to calculate an AF for the building of interest. If using radon as a tracer or surrogate, radon attenuation results may vary from those for VFCs due to differences in spatial distribution in the subsurface for radon versus VFCs (Lutes and Holton 2023; Lutes et al. 2023; Schuver and Steck 2015).	Tracers for Determination of Attenuation Factors and Ventilation Rates Fact Sheet, Approaches for Vapor-Forming Chemical Source Determination Fact Sheet, Tracers for Determination of Attenuation Factors and Ventilation Rates Fact Sheet, Vapor Intrusion Preferential Pathways Fact Sheet
Meteorological Data (see specific meteorological LOE below)	Variations in rate of VI or soil vapor concentrations due to weather conditions.		
Temperature	Measurement of outdoor and indoor air temperatures to understand relative differences at various locations outside (ground level, roof) and within a building (all floors, multiple locations).	A temperature differential of 20°F or more between indoor and outdoor air is generally considered to be worst-case conditions for VI. Temperature differences between outdoor and indoor air are indicators of stack effect during heating season, especially if there are combustion gases exhausted from the heating system.	Section 4.2.14 Climate and Weather, Section 7.5 Sampling Locations and Frequency

Line of Evidence (LOE)	Description	How Are They Helpful?	Where in the Guidance Can More Information Be Found?
Precipitation	Measurement of precipitation to correlate with VFC concentration in media samples.	Significant precipitation events may affect rates of soil vapor transport and, to a lesser extent, soil vapor concentrations if infiltrating precipitation increases soil moisture levels. Sampling during or soon after a significant precipitation event may need to be avoided to help obtain representative data.	Section 4.2.14 Climate and Weather, Section 7.8.2.2 Temporal Variability
Wind direction	Measurement of wind direction to correlate with VFC concentrations in outdoor and indoor air samples.	Wind direction can affect how winds interact with a given building. May affect which upwind sources can contribute to indoor air concentrations.	Section 7.5.3 Outdoor Air, Background Sources to Indoor Air Fact Sheet
Barometric pressure	Measurement of barometric pressure to correlate with VFC concentrations in media samples.	Changes in barometric pressure in the days prior to sub-slab vapor or indoor air sampling may affect measured concentrations. The effect of the barometric pressure tends to be less than the effect of temperature gradients.	Pressure Monitoring and Building Pressure Control Fact Sheet
Fate and transport modeling	Predictive mathematical modeling used to assess potential migration into overlying buildings and estimate indoor air concentrations.	To predict or estimate indoor air concentrations for various scenarios of interest. May be used to evaluate current conditions or the effect of modifying various input values. May be used to estimate potential VI for future construction projects.	Chapter 9: Modeling

Note: AF = attenuation factor; atm-m^3/mol = one standard atmosphere per cubic meter per mole; BPC = building pressure control; COPC = contaminant or chemical of potential concern; CSM = conceptual site model; DCE = dichloroethene; ft = feet; Hg = mercury; HVAC = heating, ventilation, and air conditioning; LOE = line of evidence; mm = millimeter; NAPL = nonaqueous-phase liquid; PCE = tetrachloroethene (also called perchloroethene and tetrachloroethylene); TCE = trichloroethylene or trichloroethene; VFC = vapor-forming chemical; VI = vapor intrusion; VIMS = vapor intrusion mitigation system; and VIPP = vapor intrusion preferential pathway.

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