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USER GUIDE

VI Diagnosis Toolkit User Guide

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14. ABSTRACT

The VI Diagnosis Toolkit for Assessing Vapor Intrusion Pathways and Mitigating Impacts in Neighborhoods Overlying Dissolved Chlorinated Solvent Plumes (Johnson et al., 2020) is a set of tools that can be used selectively or in total in a sequence to assess volatile organic contaminant (VOC) vapor intrusion (VI) impacts at one or more buildings overlying regional-scale chlorinated solvent-impacted dissolved groundwater plumes.

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1.0 OVERVIEW

The *VI Diagnosis Toolkit for Assessing Vapor Intrusion Pathways and Mitigating Impacts in Neighborhoods Overlying Dissolved Chlorinated Solvent Plumes* (Johnson et al., 2020) is a set of tools that can be used selectively or in total in a sequence to assess volatile organic contaminant (VOC) vapor intrusion (VI) impacts at one or more buildings overlying regional-scale chlorinated solvent-impacted dissolved groundwater plumes.

The tools and uses discussed below can complement conventional regulatory guidance for assessing and mitigating the VI pathway, and their use can lead to quicker, more confident, and more cost-effective neighborhood-scale VI pathway assessments.

The primary components of the VI Diagnosis Toolkit and their uses include:

- **External VI source strength screening** helps to identify buildings most likely to be impacted by VI at levels warranting building-specific testing.
- **Indoor air source screening** is conducted to locate and remove indoor air sources that might confound building-specific VI pathway assessment.
- **Controlled pressurization method (CPM) testing** is a building-specific diagnostic test that can be used to quickly (in a few days or less) measure the worst-case indoor air impact caused by VI that could occur under natural conditions; it can also be used to identify the presence of undetermined indoor air sources and diagnose active VI pathways. Results from CPM testing can be used to determine if mitigation or long-term monitoring are warranted.
- **Passive sampling** is a better approach than short-term grab samples for determining long-term average indoor air concentrations under natural VI conditions or during mitigation system operation in buildings that warrant longer-term monitoring.
- **Comprehensive VI conceptual model development and refinement** is an evergreen process that makes use of all regional and building-specific data as it is collected to ensure that appropriate monitoring, investigation, and mitigation strategies are being selected.

This document provides a brief introduction for practitioners on the use of the VI Diagnosis Toolkit components and links to more detailed information and example uses. As stated above, these tools can be used selectively or in total in a sequence to assess VOC VI impacts at one or more buildings overlying regional-scale chlorinated solvent-impacted dissolved groundwater plumes, and it is up to the practitioner and regulatory agencies to decide their relevance to specific situations.

2.0 BACKGROUND

Most federal, state, and local regulatory guidance for assessing and mitigating the VI pathway reflects USEPA's *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* (USEPA, 2015). The paradigm outlined by that guidance included: 1) a preliminary and mostly qualitative analysis that looks for site conditions that suggest VI might occur (e.g., the presence of vapor-forming chemicals in close proximity to buildings); 2) a multi-step and more detailed quantitative screening analysis that involves site-specific data collection and their comparison to screening levels to identify buildings requiring mitigation or continued monitoring; and 3) selection and design of mitigation systems, as needed. With respect to (2), regulatory guidance (e.g., USEPA, 2015; NJDEP, 2013) typically recommends consideration of "multiple lines of evidence" in decision-making, with typical lines-of-evidence being groundwater, soil gas, sub-slab soil gas, and indoor air concentrations. Of those, measured short-term indoor air concentrations are weighted most heavily, and decision-making is rarely completed without it, even though there is uncertainty as to whether or not that data is representative of maximum and/or long-term average indoor concentrations—or whether the data have been confounded by indoor sources—as the number of samples is typically small, indoor concentrations can vary with time, and a number of household products can emit the chemicals being measured. When conducting VI pathway assessments in neighborhoods where it is impractical to assess all buildings, the EPA recommends following a "worst first" investigational approach.

The limitations of this approach, as practiced, are the following:

- Decisions are rarely made without indoor air data and generally, seasonal sampling is required, delaying decision-making.
- The collection of a robust indoor air data set that adequately characterizes long-term indoor air concentrations could take years given the typical frequency of data collection and the most common methods of sample collection (e.g., 24-h samples). Therefore, indoor air sampling might continue indefinitely at some sites.
- The "worst first" buildings might not be identified correctly by the logic outlined in USEPA's 2015 guidance and the most impacted buildings might not even be located over a groundwater plume. Recent studies have shown VI impacts in homes as a result of sewer and other subsurface piping connections, which are not explicitly considered nor easily characterized through conventional VI pathway assessment (Guo et al., 2015; McHugh et al., 2017 and 2018; Riis et al., 2010).
- The presumptive remedy for VI mitigation (sub-slab depressurization) may not be effective for all VI scenarios (e.g., those involving vapor migration to indoor spaces via sewer connections).

The *VI Diagnosis Toolkit* components were developed with these limitations in mind.

3.0 THE VI DIAGNOSIS TOOLKIT COMPONENTS

Table 1 summarizes the VI toolkit components and their use for VI pathway assessment. Below, each is briefly described, and references are given that provide more detail on their development and validation.

External VI source strength screening is used to identify those buildings that warrant more intrusive building-specific assessments, using data collected exterior to the buildings.

The use of groundwater and/or soil gas concentration data for building screening has been part of VI pathway assessments for some time and their use is discussed in many regulatory guidance documents. Typically, the measured concentrations are compared to relevant screening levels derived via modeling or empirical analyses from indoor air concentrations of concern.

More recently it has been discovered that VI impacts can occur via sewer and other subsurface piping connections in areas where vapor migration through the soil would not be expected to be significant, and this could also occur to buildings that do not sit over impacted groundwater (Riis et al., 2010; Guo et al., 2015; McHugh et al., 2017 and 2018). To date, little practical guidance has been available for dealing with this issue, and so it was a focus of project ER-201501 (Johnson et al., 2020).

Therefore, in addition to groundwater and soil gas sampling, regional-scale external data collection might include manhole vapor (e.g., sanitary sewer, storm sewer, and/or land-drain) sampling and collection of videos from sanitary sewers, storm sewers, and/or land-drains. The latter could identify areas of groundwater leakage into utility corridors and lateral connections to structures that create unimpeded conduits for vapor transport. During these investigations, it is important to recognize that utility corridors can transmit both impacted water and vapors beyond groundwater plume boundaries, so extending investigations into areas adjacent to groundwater plume boundaries is necessary.

Using projected indoor air concentrations from modeling and empirical data analyses, and distance screening approaches, external source screening can identify areas and buildings that can be ruled out, or conversely, those that warrant building-specific testing.

Demonstration of neighborhood-scale external VI source screening using groundwater, depth, sewer, land drain, and video data is documented in the ER-201501 final report (Johnson et.al., 2020).

Indoor air source screening using visual inspection, owner surveys, and portable analytical tools is used to locate and remove indoor air sources (e.g., Doucette et al., 2010) that might confound building-specific VI pathway assessment. Visual inspections and surveys might or might not identify significant indoor air sources, and so these can be complemented with use of portable analytical instruments (McHugh et al., 2011; Beckley et al., 2014).

At this time, sufficiently sensitive chemical-specific field instruments are relatively costly and not widely available, (e.g., HAPSITE® portable GC/MS systems; https://www.inficon.com/en/products/hapsite-er-identification-system), so their use might be reserved for situations where indoor air concentrations are already known to exceed the relevant indoor air screening levels.

The advantage of portable gas chromatography mass spectrometry (GC/MS) tools is that they allow practitioners to expeditiously test indoor air concentrations under natural conditions in each room of the structure. Concentrations in any room in excess of relevant screening levels would then trigger more sampling in that room to identify if an indoor source is present in that room. Removal of a suspected source and subsequent room testing could be used to identify if that object or product was the source of the previously measured concentrations.

Building-specific CPM testing can be used to estimate the worst-case VI impact, diagnose contributing VI pathways, and identify indoor air sources (McHugh et al., 2012; Beckley et al., 2014; Guo et al., 2015; Holton et al., 2015; Johnson et al., 2020; Guo et al., 2020). In CPM testing, blowers/fans installed in a doorway(s) or window(s) are set-up to exhaust indoor air to outdoor, which causes the building to be under-pressurized relative to the atmosphere. This CPM test operating condition induces air movement from the subsurface into the test building via openings in the foundation and/or subsurface piping networks with or without direct connections to indoor air. This is similar to what happens intermittently under natural conditions when wind, indoor-outdoor temperature differences, and/or use of appliances that exhaust air from the structure (e.g., HVAC system or dryer exhaust) create an under-pressurized building condition.

The blowers/fans can also be used to blow outdoor air into the building, thereby creating a building over-pressurization condition. A positive pressure difference CPM test suppresses VI pathways; therefore, chemicals detected in indoor air above outdoor air concentrations during this condition are attributed to indoor air sources and facilitates the identification of the presence of indoor air sources.

Data collected during CPM testing, when combined with screening-level VI modeling, can be used to identify which VI chemical migration pathways are significant contributors to indoor air impacts (Guo et al., 2015).

CPM testing guidelines were developed and validated under ESTCP Project ER-201501 (Guo et al., 2020; Johnson et al., 2021). CPM test guidance can be found at https://serdp-estcp.org/content/download/54773/537665/file/ER-201501%20Technical%20Report%20-%20CPM%20Test%20Guidelines.pdf.

Passive samplers can be used to directly measure long-term average indoor air concentrations under natural conditions and during mitigation system operation in houses that warrant longer-term monitoring. They are more practicable and provide more confident assessment for those purposes than an infrequent sequence of short-term grab samples since indoor air vapor concentrations are temporally variable. Long-term average concentrations can also be determined by long-term active sampling (e.g., by slowly pulling air through a thermal desorption (TD) tube); however, passive sampling has the advantage that it doesn't require additional equipment or expertise to deploy.

Use of passive samplers in indoor air under time-varying concentration conditions was demonstrated and validated by comparing against intensive active sampling in ESTCP Project ER-201501 (Johnson et al., 2020 and Guo et al., 2021).

A comprehensive VI conceptual model is always under development and refinement as new site and building data are collected. A VI conceptual model can serve as an effective communication tool in stakeholder discussions and can guide the selection and design for VI mitigation, where needed.

Table 1. VI Diagnosis Toolkit Tools and Investigation Approach

VI Diagnosis Toolkit Component and References [using the numbering in the References List]	Purpose	Inclusive Tools	Investigational Approach	Comment
External VI source strength screening [7, 11, 12, 14, 15]	Identify buildings and neighborhood sub-areas most likely to be impacted by VI and needing building-specific testing	Groundwater concentrations	Historical data or sampling to collect data	---
		Soil gas concentrations		---
		Vapor Concentrations in the sewer and other buried connected utilities	Collect weeklong, time integrated vapor samples from subsurface utility networks.	Results identify buildings that are potentially affected by pipe-flow VI pathways.
		Video surveys of utility pipe network to identify lateral connections to buildings	Video surveys in utility corridors to identify lateral connections leading to structures.	The results identify those structures that have a direct connection to utility corridors, such as land-drains and their laterals that connect sub-slab areas of homes to land drain main piping. Those without connections are not at risk from pipe-flow VI.
		Mathematical Modeling and Risk-Based Concentration Screening Table Values	Calculate maximum chemical entry rate based on chemical concentrations in groundwater and/or soil gas, source depth and soil properties.	Provides more specific criteria for the use of concentration data when identifying the potential for impact.
		VI inclusion Zone Determination	---	Determine those areas which are at risk for VI. The structures in those areas would be candidates for building specific testing.
Indoor air source screening [1, 9]	Identify and remove indoor air sources prior to indoor air testing under natural or controlled pressurization conditions.	Indoor Source Identification	Physical screening, CPM testing and/or use of portable analytical tools	---

Table 1. VI Diagnosis Toolkit Tools and Investigation Approach (Continued)

VI Diagnosis Toolkit Component and References [using the numbering in the References List]	Purpose	Inclusive Tools	Investigational Approach	Comment
CPM testing [3, 4, 6, 7, 8, 10]	Measure the maximum indoor air impact under natural conditions caused by VI; identify the VI pathway most responsible for VI impacts to indoor air	CPM Testing	Negative and positive pressure testing with indoor and ambient outdoor sampling	Negative pressure CPM testing is a fast building-specific testing approach. The results reliably reflect the worst-case VI exposure and are not affected by time of CPM testing. Positive pressure CPM testing suppress VI entry from subsurface, and indoor air concentrations only reflect the impact of indoor air chemical sources.
Passive samplers [5, 7]	Indoor air concentrations for risk assessment, long-term confirmation monitoring, and validation of mitigation system performance.	Passive sampler	Multi-week deployments	Preferred method of sampling
		Active sampler		---
		Grab samples		---
		Risk-Based Concentration Screening Table Values		Used to determine mitigation action levels
Comprehensive VI conceptual model	Used as framework to interpret data collected from the components above.	Mitigation System Selection and Design	---	Sub-Slab depressurization is a presumptive remedy only if the Soil VI pathway is the only significant route to indoor air

4.0 USE OF THE VI DIAGNOSIS TOOLKIT

As stated previously, VI Diagnosis Toolkit tools can be used selectively or in total in a sequence to assess VOC VI impacts at one or more buildings overlying regional-scale chlorinated solvent-impacted dissolved groundwater plumes. It is up to the practitioner and regulatory agencies to decide the relevance of each tool to specific situations.

When applied at the neighborhood or regional scale and when used in total, VI Diagnosis Toolkit components can be applied in a logical progression as outlined below.

Step 1) Identification of buildings that warrant building-specific testing:

a) Most VI pathway assessments will start after enough groundwater data have been collected to create a map showing the depth and extent of the dissolved groundwater plume(s).

b) If neighborhood-scale subsurface piping is present (e.g., sewers, land drains), vapor sampling should be conducted in manholes located above the dissolved plume and outside of the dissolved plume boundaries. Given what is currently known about temporal variability of manhole vapor concentrations (Guo et al., 2020), seasonal sampling may be necessary to adequately characterize vapor concentrations in the subsurface piping network. Video surveys of the piping networks may provide added insight to lateral connections to buildings and connections throughout the piping network.

c) In many cases, the information from (a) and (b) will be sufficient to identify buildings that do and do not warrant building-specific testing. The measured groundwater and piping network vapor concentrations will be compared against relevant screening levels established by the stakeholders to be protective of indoor air (e.g., https://www.epa.gov/vaporintrusion/vapor-intrusion-screening-level-calculator). These might include depth to groundwater, soil type, building construction, and empirically-determined factors as variables in setting the screening levels.

d) It is not typical, but if soil gas data are collected, they can also be considered as they are already included in regulatory guidance for building-specific assessments.

e) An example of a regional-scale external source strength characterization exercise is included in Johnson et al. (2020).

Step 2) Identification and removal of indoor air sources from buildings to be tested:

a) For each building selected for indoor testing, a visual survey and discussion with the building occupants should be conducted to identify and remove any obvious indoor air sources.

b) If a portable analytical device that is sufficiently sensitive and specific to quantify concentrations of compounds of interest is available, a room-by-room indoor air survey can be conducted.

c) In rooms where concentrations exceed relevant screening levels, the portable instrument can be used to locate and identify sources of the chemicals of concern.

Step 3) For each building from Step (2), decide if VI pathway assessment is time-critical and then select the appropriate tool for that VI pathway assessment:

a) CPM testing should be used when rapid determination of worst-case VI impacts is desired, plus CPM testing has the added benefit that it can be used to diagnose contributing VI pathways and identify if indoor air sources are present. Residential testing will take a day or two per building, while complex industrial buildings might require several days of testing. Guidance for CPM testing is given in Guo et al. (2020).

b) Passive sampling can be used to measure long-term average indoor air concentrations in situations where it is acceptable to conduct each building-specific VI pathway assessment over a 6 to12 month period. An evaluation of use of passive samplers in residential and industrial buildings is provided in Johnson et al. (2020) and Guo et al. (2021).

c) Note that passive sampling results can be confounded by unidentified indoor air sources and the data will not provide insight on VI vapor transport pathways. In cases where indoor air concentrations from passive sampling exceed relevant screening levels, practitioners may opt to next invest in CPM testing to determine if indoor air sources are the cause and to gain information valuable for selecting and designing a vapor mitigation system.

Step 4) For each building from Step (2), use the data from Steps (1), (2), and (3) to refine the VI conceptual model (if necessary), and decide if additional indoor air monitoring and/or mitigation are needed:

a) In cases where the data from Step (3) suggest that the VI pathway is not complete relative to relevant indoor air screening levels, practitioners might decide that no further pathway assessment is warranted at that building.

b) Practitioners might also decide that additional indoor air monitoring for a limited time period is needed in that building before feeling confident in making decision (a).

c) In cases where the data from Step (3) suggest that the VI pathway is complete relative to relevant indoor air screening levels, practitioners might decide that mitigation is needed and then would proceed with mitigation system design, installation, operation, and monitoring.

d) Practitioners might also decide that additional indoor air monitoring for a limited period is needed in that building before feeling confident in proceeding with (c).

e) If the decision is to pursue Step (4b), (4c), or (4d), passive sampling (or long-term active sampling) should be used to collect the additional monitoring data for (4b) or (4d), and it should also be used to collect the performance/validation data for (4c).

f) If the decision is to pursue Step (4c), practitioners will benefit from CPM test data that can help identify if VI is occurring through soil migration vs. migration through subsurface piping as conventional sub-slab depressurization systems may not be effective at sites where vapors are migrating via subsurface piping as discussed in Johnson et al. (2020). Using CPM testing to identify VI transport pathways is discussed in Guo et al. (2020).

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